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Hydrogen market research in Malaysia and Thailand

Final Report

Deloitte Consulting Southeast Asia
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Overview of the Project

MY: comprehensive market research was conducted
TH: supply chain, demand and supply were studied

Background

- Following the carbon neutrality commitments made by a lot of countries and the Glasgow Accord, there is an emerging trend to prioritize achieving carbon neutrality by 2050. ASEAN countries have also set targets for carbon neutrality and are expected to accelerate the adoption of renewable energy, energy efficiency measures, and the establishment of hydrogen and ammonia supply chains as they transition away from fossil fuels.
- With the launch of AZEC in March 2023, efforts towards carbon neutrality between ASEAN and Japan are gaining momentum. Hydrogen plays a crucial role in this initiative, and expectations for Japan's contribution are growing.
- In Thailand, initiatives such as Hydrogen Thailand have been launched, and tangible progress is anticipated in the near future. Malaysia has also seen the initiation of hydrogen-related projects, primarily led by PETRONAS and Japanese companies, generating increased interest in the market.

Goal

- This project is designed to provide the insights related to establishment of hydrogen supply chain in the target countries as suggestions for priorities to be explored in depth. Status of hydrogen mobilization and its project implementation in both public and private sectors

  <u>Malaysia Part:</u>

  - To conduct market research (desktop research) of hydrogen and ammonia trend
  - To conduct interviews
  - To provide the insights related to establishment of hydrogen supply chain in target countries

  <u>Thailand Part:</u>

  - To conduct study on supply chains
  - To study hydrogen’s demand forecast
  - To study hydrogen’s supply potential

Summary

Malaysia

NETR and HERT are planning a hydrogen roadmap, including initiatives to develop regulations, policies, and incentives to foster hydrogen development in Malaysia

Executive Summary

Findings	■ **Outlook and Policy** Relating key policies were launched in 2023, namely Hydrogen Economy and Technology Roadmap (HETR) and National Energy Transition Roadmap (NETR) ■ **Potential Player** Both international and domestic Players were listed and categorized in supply chain. Petronas and Sarawak Energy would lead Hydrogen market in Malaysia ■ **Technical Readiness** Water electrolyzer with conventional electricity (grey H2) is in demonstration in Sarawak, aiming to utilize hydropower to producing green hydrogen in the future ■ **High-level Business Model** Supply chain models were separately developed for P. Malaysia through desk research and interviews ■ **Demand Forecast** 2.1 mtpa is estimated for Malaysia by 2050
Challenges	■ No hydrogen-specific framework, regulations, or defined standards are established in Malaysia ■ Insufficient incentive, HETR's RM 2 billion national energy transition seed fund is not exclusively for hydrogen ■ Low technical maturity and sacaling-up issue for hydrogen projects ■ Petronas, SEDC, and Sarawak Energy strong presence potentially to monopolize the hydrogen value chain ■ Bottom-up approach requires extensive time and resources for data collection for greater accuracy ■ P. MY has limited RE potential, while Sarawak hydro dam construction raising environmental and social concerns
Implications	■ To benchmark advanced countries and study framework and implementation plan, such as US, EU and Japan ■ To establish a G2G joint technology development program between Malaysia and Japan for hydrogen innovation ■ To create country and industry collaboration for knowledge transfer, technical development, and project development ■ To study the demand and supply balance using a top-down approach as the initial step ■ To explore the flexibility of hydrogen (or biogas) import possibilities from Sumatra by investigating the supply potential of neighboring countries, especially Sumatra, Indonesia

Malaysia plans to promote RE by phasing out coal power plants and gradually phasing out fossil fuel subsidies, which will be allocated to hydrogen fuel

Executive Summary-Findings (1/2)

Outlook and Policy

- National Energy Transition Roadmap (NETR)
  - Target 70% RE installed capacity, predominantly driven by solar PV with 59 GW installed by 2050.
  - No new coal power plants will be built, leading to a nearly complete phase-out by 2045.
  - Establish Sarawak green hydrogen hub, with one plant in Kuching for domestic use and two plants in Bintulu for export, all operational by 2027
  - Provide incentives support for electrolyzer R&D projects, large-scale manufacturing of low-carbon hydrogen and electrolyzers, development of hydrogen refueling stations and purchase of FCEV
  - To harness bioenergy potential, target of 1.4 GW biomass and biogas power generation capacity by 2050
- Hydrogen Energy Technology Roadmap (HETR)
  - Accelerate technological advancement of hydrogen ecosystem through "Build-Some, Buy-Some" strategy
  - Gradually phase out fossil fuel subsidies for diesel vehicles and reallocate them to hydrogen fuel for commercial and heavy vehicles to support the transition to greener energy for long-term investment.
  - Funding from agencies to support the hydrogen technologies' innovation, demonstration, pre-commercialization and green financial instruments with attractive rates

Potential Player

- Petronas is centered in the Hydrogen discussion in Malaysia.
  - Petronas as a primary fuel supplier involved nearly all aspect of hydrogen value chain in Malaysia
- In Sarawak, the regional government and relating public entity, namely SEDC and Sarawak Energy are key players
  - SEDC promotes development of hydrogen projects such as H2biscus (Korea) and H2ornbill (Japan) projects while Sarawak Energy is a major green hydrogen producer
- Local companies collaborate with international players on major hydrogen-related projects.
  - Eneos, Sumitomo and SEDC are developing the H2ornbill project to produce green hydrogen from hydroelectric power and ship it to Japan using MCH as a carrier
  - Malakoff and Itochu are conducting a feasibility study on decarbonization using hydrogen/ammonia.
  - IHI Corporation and Gentari is exploring green ammonia production and sales in Malaysia

Hydrogen in Peninsular Malaysia is mainly for domestic use, while Sarawak is expected to start exporting hydrogen to Korea and Japan.

Executive Summary-Findings (2/2)

Technical Readiness

Production

- Water electrolysis represents the most promising hydrogen production method in Malaysia [Demonstration]
- No specific SMR+biogas project has been announced yet, but demonstration project is likely to start in Q1 of 2034 according to HETR [No info available]
- SMR+fossil fuel with CCUS is currently under R&D stage [R&D]

Carry & Storage

- There are no Li-H2 projects in Malaysia, instead Malaysia is more interested in solid-state hydrogen (Sodium borohydride ($NaBH_4$)) [Not Yet]
- Malaysia is exploring to transport hydrogen via pipeline to Singapore [R&D]
- The technology for handling hydrogen of MCH has been developed [Demonstration]
- TNB, Petronas and IHI is evaluating the feasibility of production and sales of green ammonia [R&D]

Supply

- Sarawak has 1 HRS in Kuching, while Peninsular Malaysia will launch first HRS in 2024 [Demonstration]

Utilization

- Peninsular Malaysia will deploy FCEV for demonstration in 2024, Sarawak already have few FCEV [Demonstration]

High-level Business Model (SC)

- Peninsular Malaysia
  - Hydrogen production from solar PV and biogas for domestic use. Consumption on-site and transported in gaseous H_2 (it could be either by compressed H_2 and short-pipeline or combination of them). Industrial use and introduction to power plants are expected earlier than in other industries.
- Sarawak
  - Hydrogen production from hydropower, distributed within Borneo and exported to Japan and Korea, using MCH, NH_3, and Li-H2 as carriers. Domestic use in industrial parks and early adoption in transport sector.

Demand Forecast

- Hydrogen demand is expected to reach 2.1 mtpa by 2050
  - Ammonia (57%), power generation (18%), and ethylene (17%) are the three main sectors of consumption

Malaysia's role in the hydrogen economy is growing, driven by diverse utilization and cost-effectiveness to power a sustainable energy shift

Summary for hydrogen outlook and state-of-the-art

		Present				Outlook			
		Malaysia	Thailand	Indonesia	Japan *ref	Malaysia	Thailand	Indonesia	Japan *ref
Use	Hydrogen Demand	N/A	N/A	■ 1.1M t/year (2020)	■ 2M t/year	■ 12 Mt/year (2050) *potential	■ 6 Mt/year (2050) *potential	■ 49 Mt/year (2050) *potential	■ 20Mt/year (2050)
	Major hydrogen users	■ Industry (Heat) ■ Feedstock	■ Industry (steel*1, chemical)		■ Industry (steel*1, chemical) ■ Transport	■ Feedstock ■ Power ■ Industry (Heat) ■ Transport	■ Transport ■ Power ■ Industry	■ Industry	■ Transport ■ Power ■ Industry
	Hydrogen Used	■ Grey	■ Grey			■ Green/blue	■ Green/blue	■ Green/blue	■ Green/blue
Production	Hydrogen production Source	■ Fossil fuel	■ Fossil fuel			■ Renewable	■ Renewable	■ Renewable ■ Fossil fuel + CCUS	■ Renewable ■ Fossil fuel + CCUS
	Hydrogen Production Cost	■ 1.5 USD/kgH2 (grey) ■ 6 USD/kgH2 (green)	■ 0.7 – 1.6 USD/kgH2 (natural gas) *world average	■ 1.6 USD/kgH2 (natural gas) ■ 6.7-13.4USD/kg H2 (renewable)	■ 8-9 USD/kgH2 (low carbon)	■ 1.25 – 2.11 USD/kgH2 (green) (2050) *potential*2	■ 1-2 USD/kgH2 (green) (2050)		■ <2.5 - <3.5 USD/kgH2(green) (2050)
	Importer/ Exporter	N/A	N/A			■ Exporter in APAC	■ Importer *Meanwhile some Indonesian companies seek to export hydrogen		

*Note: *1 Hydrogen use for bright annealing and *2 PETRONAS is carrying out R&D to produce green hydrogen at 2 USD/kg by 2025 and hence the possibility of reducing the cost to below 2 USD/kg by 2050*

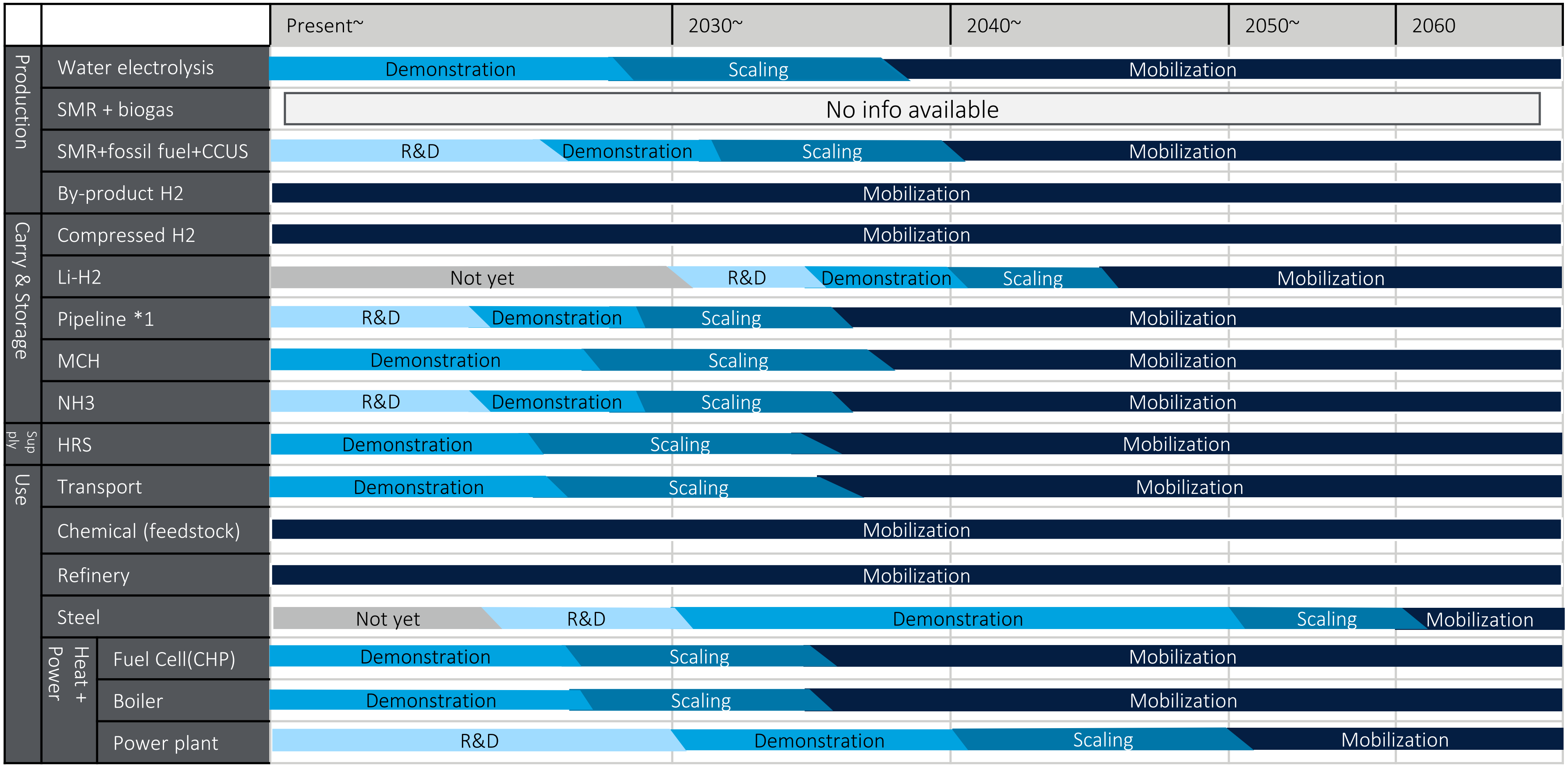
Source: Malaysia Energy Transition Outlook, Petronas' website, DNV report, National Energy Transition Roadmap

Multiple hydrogen production and utilization options could be available in 2030s in scaling status

Technical readiness of hydrogen in Malaysia

Status: Not yet | R&D | Demonstration | Scaling | Mobilization

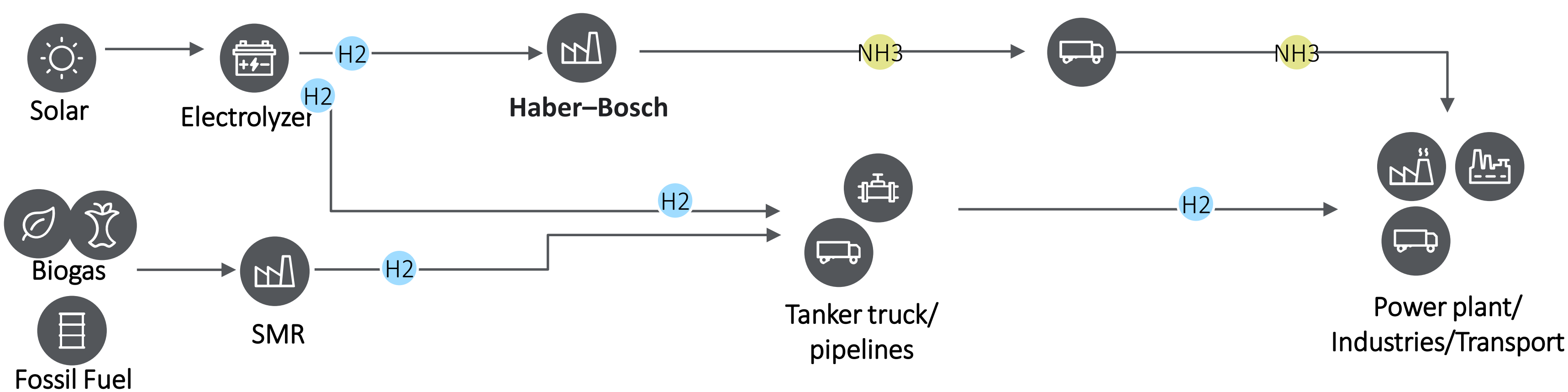
This chart was created by the information on **current technical readiness of each technology** and a **target set by its front runners**. The information was collected by desktop research and the interviews. When a target is not set, the starting point and duration for each status of a technology were projected **based on the Japanese technology development vision** shown by the government . *Note that policies are assumed to be favorable to hydrogen technologies)



Solar PV and biogas are expected for producing clean hydrogen, and providing domestic use in P MY, transportation would be in gaseous H2

Clean Hydrogen Business Model in Peninsula Malaysia in 2030s-40s

Production	Transport + Distribution + Supply	Use
■ MY government is aiming to produce clean hydrogen by **natural gas & biogas with CCUS and solar PV** ■ Start from natural gas with CCUS for establishing supply chain, but biogas + CCUS and solar PV will increase in 2030s	■ Due to the location of Hydrogen Hub in Sarawak on Borneo island, **hydrogen transport from Borneo is not expected**. ■ Distribution within P. MY is expected as well as import. So, **on-site or near location of production is expected** and then, carry mode would **likely to be compressed hydrogen or local pipeline network**	■ The Gov't **highlights the role of hydrogen in industry** for GHG emission reduction over the other sectors such as transport. ■ Industrial use and introduction to power plant are expected in early stage

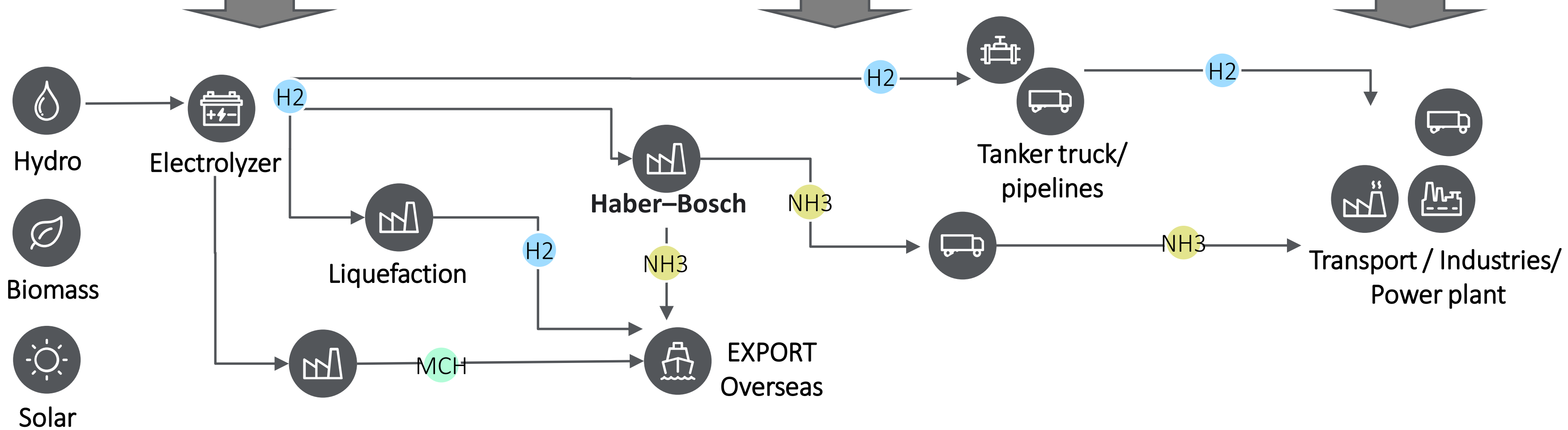


Concept	■ Reduce emission from Energy and Industry sector by taking advantage of renewables in Peninsula Malaysia such solar PV, which cannot be fully utilized through power grids
Area	■ On-site or near-site area of industrial area is preferable

Sarawak is expected to develop hydrogen industry from export to Korean and Japan as well as introduction to industrial parks

Clean Hydrogen Business Model in Sarawak in 2030s-40s

Production	Transport + Distribution + Supply	Use
■ **Hydro** energy potential are relatively high in Sarawak and Sabah ■ Sarawak state government is active to develop **hydropower, which can supply Electrolyzer** to produce hydrogen ■ **Biomass** can be another option, considering hydro's long development time	■ Due to the far distance between Borneo island and Peninsula Malaysia, Hydrogen produced in Sarawak and Sabah would be distributed within Borneo island, or ■ Hydrogen will **be exported** mainly to Japan and Korea ■ MCH, NH3, and Li-H2 can be carriers for export	■ Hydrogen development in Sarawak and Sabah is expected to start from **export** ■ Introduction of hydrogen tech to Industrial parks in Sarawak and Sabah, including Samalaju Industrial Park (under development) is a focus for domestic use ■ As demonstration going on, early adaptation in transport sector is expected



Concept

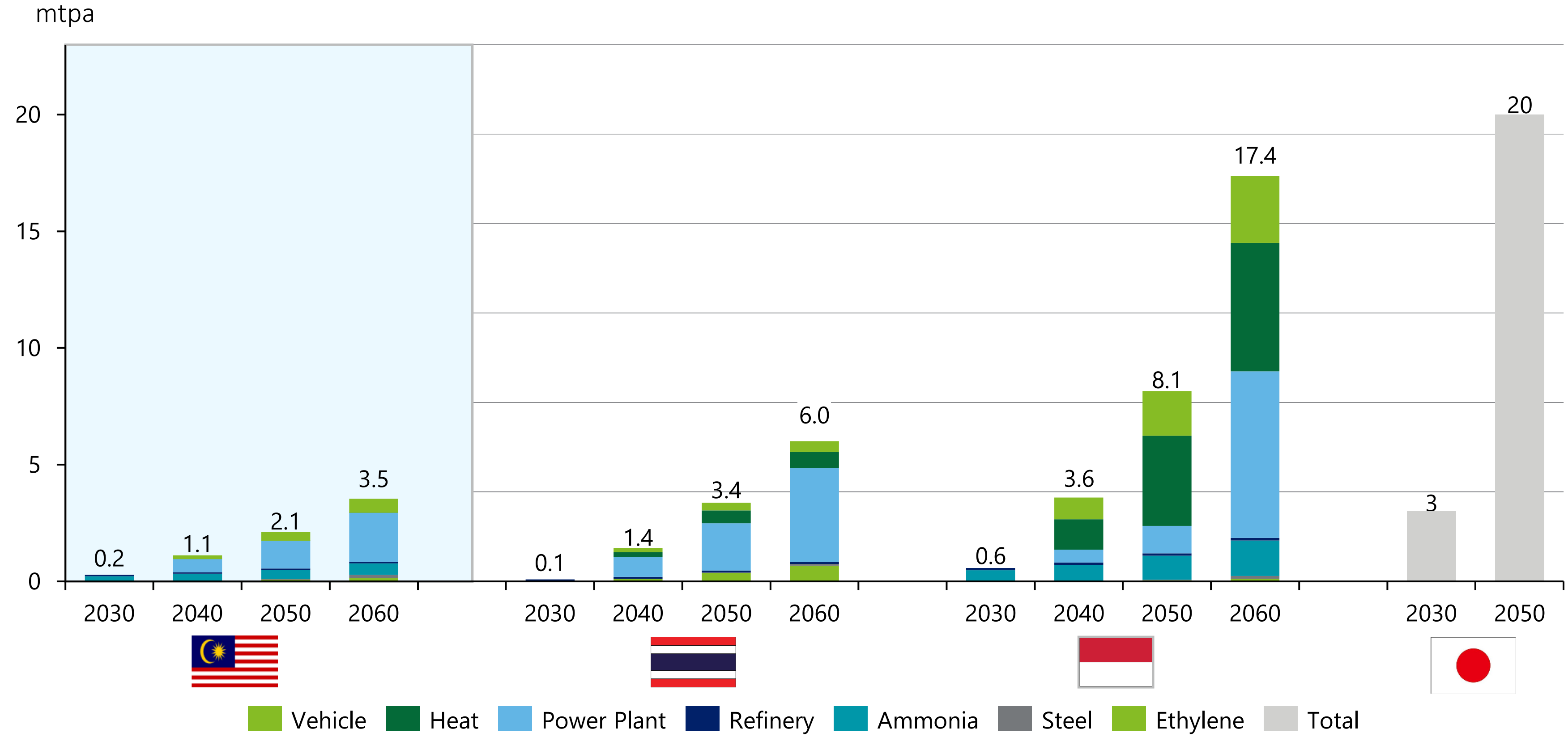
- Reduce emission from Energy and Industry sector by taking advantage of renewables in Malaysia such hydro power whose potential is abundant

Area

- Kuching with near industrial areas, and Bintulu in Sarawak, where is demand center and abundant hydro and solar PV potential for production, and sufficient available land

For the optimistic case, Malaysia will reach 2.1 mtpa and 3.5 mtpa in 2050 and 2060 respectively, and the expected driver of the demand is the power sector

Potential Hydrogen Demand



Note that all fossil fuel in industrial final consumption is assumed to be replaced with hydrogen. In reality, some of the fuel consumption would be electrified, making hydrogen demand smaller:
(as shown by white arrow)

Source: Deloitte analysis

There are multiple challenges to overwhelm for the successful market introduction of hydrogen in each area

Challenges

Policy	■ **Incentives :** NETR to launch RM2 billion seed fund for National Energy Transition Facility, not exclusively for hydrogen, potentially resulting in less allocation for hydrogen ■ **Policy framework**: There is a lack of policy support, defined standards, and regulations governing hydrogen. For example, the Gas Supply Act 1993 and the Renewable Energy Act 2011 may share responsibility for governing hydrogen
Technical Readiness	■ **Low maturity** ➢ Project development of hydrogen-related technologies in Malaysia is mainly dependent on foreign companies and the government, which tends to lag behind others in technology development ■ **Scale-up issues** ➢ The lack of predictability of the balance between future demand and supply makes it difficult to make progress when scaling up after demonstration stage ➢ High initial costs hinder scale-up, which results in vicious cycle of slow or none progress
Potential Player	■ **Competition to win collaborations with locals** ➢ **Restriction on foreign capital in the power sector** forces competition to win collaborations with leading local companies, and the collaboration importantly connect to domestic hydrogen procurement as well ➢ **Petronas in Peninsular Malaysia**, along with **SEDC and Sarawak Energy in Sarawak**, are crucial local partners. Their robust presence in the Malaysian hydrogen value chain positions them to potentially lead the hydrogen supply market
Demand Forecast	■ **Top-down approach** with policy and relating public data source has some limitation in the accuracy. Bottom-up market sizing provides more accurate data, but can be challenging to implement due to extensive time and resources required to collect and analyze data from each of the potential players
High-level Business (SC) Model	■ **Renewable energy source** ➢ Peninsular Malaysia – P. MY's main source will be solar, but the potential of RE is relatively lower than neighboring countries ➢ Sarawak – Sarawak's main RE is hydro, but building large hydro dam entails environmental and social concerns ■ **Lack of flexibility in green hydrogen within the nation** ➢ Due to the distance, it is **unlikely for Sarawak to export green hydrogen to Peninsular Malaysia**

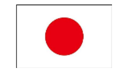
Malaysia launched NETR and a strategy dedicated for hydrogen (HETR) in 2023 and green H2 production target of up to 2.5 mtpa by 2050

Comparison among countries in Policy

Policy	Strategy dedicated for Hydrogen	➢ Malaysia launched the **National Hydrogen Economy and Technology Roadmap (HETR) in October 2023,** aimed at positioning Malaysia as a leading Hydrogen Economy Country by 2050	N/A ➢ However, DPR[*2] & MEMR[*3] **developed proposal** of RUU-EB-ET[*4] Draft Plan to support **Green Hydrogen implementations.** ➢ The government has also **appointed several ministry and SOEs** to **develop hydrogen to be used in the energy sector** as well as its production to be utilize in **electricity & electric vehicle**	➢ Hydrogen Basic Strategy was publicized in 2017 and updated in June 2023, which includes Hydrogen Industry Strategy and Hydrogen Safety Strategy. ➢ Green Growth Strategy (2021) also specified hydrogen as one of pillars
	Quantitative target	<u>NETR</u> sets three goals: ➢ **Replace grey hydrogen with blue hydrogen** as a feedstock by 2050 ➢ **Generate up to 2.5 mtpa of green hydrogen** from renewable sources like hydroelectric and solar by 2050 ➢ Establish one low-carbon hydrogen hub by 2030 and add two more by 2050, **totaling 3 hubs.** <u>HETR</u> ➢ **Export hydrogen of upto 0.5 – 1.0 mtpa** to target countries by **2030** ➢ (not target but demand forecast in 2050) BAU: 3.15 mtpa , emission driven scenario: 10.33 mtpa	N/A ➢ However, according to the most recent AEDP 2018, hydrogen is included as part of the “Alternative Fuels” category with a set target goal of 10 kilotons of oil equivalent (KTOE) in total by 2036	Hydrogen Basic Strategy sets numerical goals as; ➢ **Introducing Hydrogen up to 3 mtpa in 2030, 1.2 mtpa in 2040, and 20 mtpa in 2050.** ➢ CIF cost of H2 : JPY 30 /Nm3 in 2030 and JPY 20 /Nm3 in 2050 (which is less or equal to Gas FPP) ➢ 15 GW of Electrolyzer by Japanese manufacturer to be installed domestically and internationally ➢ Establishment of 3 large-scale and 5 mid-scale consumption center within 10 years

Malaysia launched NETR and a strategy dedicated for hydrogen (HETR) in 2023 and has started to plan more details including incentives

Comparison among countries in Policy

				
Policy	Incentives	➢ NETR to launch **RM2 billion seed fund for all National Energy Transition Facility, not exclusively for hydrogen** ➢ In NETR, **initiatives to establish financial incentive are mentioned**; • To fund elecrolyzer R&D for MY Universities and private sector • To establish financial incentives for Large-scale manufacturing of low-carbon hydrogen and electorlyzer • To provide incentives for development of HRS and purchase of FCEV	N/A However, there is possibility that Income tax incentives can be adopted because the allowance is applicable Geothermal and coal gasification	Japan's government provide **several subsidies to promote hydrogen introduction.** For example, ➢ METI provides subsidy for; demonstration project, technical development for global supply chain establishment, R&D of advanced fuel cell, and installation and O&M of HRS ➢ Ministry of Environment also provides several subsidies for ; demonstration project, purchase of FCEV, and study on decarbonized community model ➢ Green Innovation Fund, implemented mainly by NEDO also attracts private sector to promote hydrogen projects

Malaysia and Indonesia rely on foreign companies to proceed hydrogen related projects while municipalities play important roles in Japan

Comparison among countries in Technical Readiness, Players and Demand Forecast

	Malaysia	Indonesia	Japan
Technical Readiness	➢ MCH, HRS, Transport and Boiler are advanced (in demonstration) compared to Indonesia, and **almost all of them are undergoing led by foreign companies collaboration with local SOEs**	➢ Hydrogen Production by water electrizer is in demonstration stage while other advanced technologies of hydrogen is in R&D. and **almost all initiatives are conducted mainly by foreign companies**	➢ There are **many R&D, pilot, and demonstration projects by Japanese companies, which progresses technical readiness level** ➢ Japan is one of the leading countries for H2 promotion; as an example, NH3 co-firing demonstration at Hekinan CFPP, a USC CFPP, is planned in 1Q of 2024 (1,000 MW, unit 4)
Players	➢ **Petronas & its subsidiaries, and SEDC & Sarawak Energy** are key players in the market. ➢ In Sarawak, Korean and Japanese players are active for hydrogen production project while Chinese players are active in transportation sector ➢ **State government of Sarawak is also active** for promoting hydrogen projects (as well as CCS)	➢ **PERTAMINA & its subsidiaries, and SEDC & Sarawak Energy** are key players in the market. ➢ **Oil majors, namely ExxonMobil and Chevron is active** in CCS and as a result, they would be key players for SMR+CCS	➢ **Japanese companies cover total supply chain: from up- to downstream**, and there are so many players to work in Japan and overseas ➢ **Municipalities are remarkably active to establish hydrogen SC** for achieving CN toward 2050. They play an important role to connect private. They also active in promoting demonstration projects and attracting companies.
Demand Forecast	2030: 0.2 mtpa 2040: 1.1 mtpa 2050: 2.1 mtpa 2060: 3.5 mtpa **(Power > Vehicle > NH3(feedstock)**	2030: 0.6 mtpa 2040: 3.6 mtpa 2050: 8.1 mtpa 2060: 17.4 mtpa **(Power > Heat > vehicle)**	2030: 3.0 mtpa 2040: 12 mtpa 2050: 20 mtpa

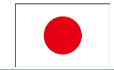
Malaysia is a unique situation; different in import/export balance for Peninsular Malaysia and Sarawak, and then need to consider separately

Comparison among countries in High-level Business Model

High-level Business Model (SC)

- Supply chain of Peninsular Malaysia and Borneo island should be considered separately due to difference in access to renewable energy;
  - Sarawak: **Abundant Hydro potential** can supply Electrolyzer to produce hydrogen, which can be excess the demand in Sarawak. Considering the distance between P. MY and Borneo, **hydrogen can be exported** overseas as NH3, MCH and other modes as per consumers' needs
  - Peninsular Malaysia; surplus of solar PV generation and Fossil fuel/biogas with CCS can be expected. Therefore, **hydrogen can be utilized mainly for use within P. Malaysia**

- For domestic production, **Geothermal and surplus of Solar PV can be main source** for green hydrogen. Due to abundant production of fossil fuel and CCS potential sites in the nation, **fossil fuel + CCS is another option** for Indonesia.
- Considering the huge volume of demand in the future, **Indonesia will be an importer of hydrogen**, and the transportation mode will be mainly NH3 because
  - Ship transportation is required for inter-island transport
  - There are many 'young' CFPP which can be utilized for a while, so that NH3 will be co-fired at CFPPs



- Japan will be **an importer of hydrogen** due to the limitation of potential of renewable energy and fossil fuel reserve and potential CCS sites within the nation.
- Due to the well-developed industry status, the existing there is needs for a variety of hydrogen mode.
- Some of **supply chain models have been studied and demonstrated so far**. And due to establishment of new supply chain, multiple companies have collaborated for estimate demand & supply balance and testify financial feasibility. In some industrial area, companies have created hydrogen association to study co-utility and common a SC model.

To promote hydrogen in Malaysia, financial incentives, commitment by the gov't, partnership and capacity building are consideration points

Implications for Moving forward (1/2)

	Items for Consideration
Policy	■ Incentives ➢ i) **Dedicated Funding for hydrogen** technology innovation, demonstration, and pre-commercialization and ii) setting more generous **incentives for early adopters** are preferable ■ Policy ➢ **Strong leadership and commitment by the government** is required for structuring new policy framework and comprehensive regulation of hydrogen (as MOSTI is introducing for transport and storage)
Technical Readiness	■ **Insufficient technical expertise** and **high CAPEX for green hydrogen production** ➢ **Facilitate partnerships between foreign hydrogen technology providers and local manufacturers** are expected ➢ As HETR mentioned, to pursue 'some buy, some build', so covering total supply chain is not required condition but preferable ➢ **Capacity building** for human capital is also required due to new technical theme

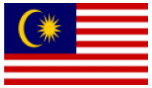
Municipalities' inclusion, association formulation in national and industrial level, and flexibility of hydrogen procurement are consideration points

Implications for Moving forward (2/2)

	Items for Major Consideration
Potential Player	■ **Inclusive Market Creation** ➢ Partnership or collaboration to key players their expertise, technology, and network is a key driver for H2 penetration in the nation ■ **Municipalities inclusion** ➢ In Japan, municipalities play important roles for pursuing carbon neutral and promoting hydrogen projects (i.e. Kawasaki-city
Demand & Supply Forecast	■ **Demand: Bottom-up approach by formulating communication platform** ➢ Bottom-up approach is expected more accuracy for forecast. To collect more actual demand data, it is beneficial to formulate communication platform among stakeholders (i.e. **hydrogen association in i) national level and ii) industrial area** ■ **Supply Forecast**: ➢ Supply estimation is required to understand business feasibility for each project
High-level Business (SC) Model	■ **Flexibility of hydrogen procurement across the boarders** ➢ Exploring **import possibility from Sumatra, and other countries**, considering the geological locations of main energy consumption centers and ports ■ **Renewable energy source** ➢ Peninsular Malaysia – Studying biogas possibility and effective installation of Battery storage ➢ Sarawak – exploring other renewable energy options such as biogas and floating solar

Malaysia side would be expected to conduct benchmarking, R&D promotion, crating association, conduct more SC demonstration and trade consideration

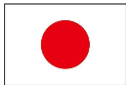
Expected Next Actions



Public and Private Sectors	Politics	➢ To **benchmark** H2 related **policy and regulatory framework** in advanced countries ➢ To encourage municipalities to pursue Carbon neutrality more to generate their own momentum to promote hydrogen introduction
	Technical Readiness	➢ To study **R&D promotion direction study;** • Benchmarking advanced countries • Considering joint development program through G2G collaboration between Malaysia and Japan to develop domestic capability
	Players	➢ To create **Collaboration In national and industrial area levels (association) by participation from both public and private**, aiming; • Information sharing • Creating leading projects • Promoting joint technical development study for whole SC
	Demand forecast	• To study demand and supply balance by **top-down approach** as an initial step • To **study bottom-up approach by collecting detailed information from** the existing industrial areas through the **association** mentioned in the above
	SC	• To **promote SC demonstration projects** in collaboration with Foreign companies (preferably Japan/Korea for Sarawak and Australia for P. Malaysia, because of distance and demand and supply balance) • To start discussion about **intra-APAC trade in hydrogen/ammonia** • To study **supply potential** of neighboring countries, especially for **Sumatra**, Indonesia (including biogas)

For Japan side, public sector would be expected to assist Malaysia side's effort for technical assistance while private sector to promote PJ in collaboration

Expected Next Actions



Public Sector	Politics	• To assist Malaysian government to **design Incentives** • To establish more **agile fund utilization** scheme- i) more simplified process for application and implementation, and ii) relaxing condition for foreign companies with some special conditions • To assist Japanese companies to establish network with local key players- i.e. **assisting establishment of association**, business matching • **To encourage Japanese municipalities** to join the support MY's municipalities to pursue CN and promote hydrogen projects
	Technical Readiness	• **To assist technical development and capacity building** for hydrogen related technology by promoting joint R&D and training sessions
Private Sector	Technical Readiness Players Demand forecast SC	• To **promote demonstration project in collaboration with local private sectors** to establish win-win relationship • To cooperate with both Japanese and Malaysian companies i) to estimate detailed demand and supply forecast through establish association, creating data sharing platform , ii) to promote demonstration project • **To consider utilizing Japan's public fund** for boosting project implementation with Malaysian companies

Thailand

As Thailand is in early stage of hydrogen development, collaboration between entities is needed to work on supply and demand creation

Summary of Potential Demand and Supply Study in Thailand (1/2)

Supply Chain	■ Supply chain models: Direct use of hydrogen in the form of ammonia and byproducts is expected in EEC and pipeline development can be considered within industrial estate, where heavy chemical industries are located. Meanwhile, in Bangkok and Chiang Mai, where non-heavy industries are located, hydrogen will be liquefied and transported by truck. ■ Hydrogen carrier: No particular type of hydrogen carrier has been announced or expected to be promoted. Leading oil and gas companies are open for all types as the usage might depends on each condition/scenario. However, the primary choice would be Ammonia. ■ Current situation: Many leading oil and gas companies are actively investing and collaborating with foreign companies to co-study on hydrogen	
Demand and Supply	**Demand Side**	**Supply Side**
	■ National demand is projected to be 3.4 mtpa in 2050 which is highly contributed from power sector followed by heat and transportation sector ■ Leading oil and gas companies especially in EEC area are expected to be primary and main customer group of hydrogen usage ■ Draft of National energy plan 2023 is expected to establish a target of utilizing hydrogen for electricity generation, aiming to reach a 20% utilization rate by the year 2037	■ Domestic Supply: Expect to supply 1.39 mtpa of hydrogen in 2050 from the combination of electrolysis, SMR-biogas, byproduct, lignite ■ International Supply: Expect to import 1.98 mtpa (equivalent to 5 % of trading volume from Asia, Middle East, Oceania). The potential import country can narrow down to ID, MY, OM, AU as they have existing LNG trading relationship with Thailand.

It is recommended for Thailand to work on i) policy and regulatory framework, ii) supply chain creation, and ii) public acceptance to move forward

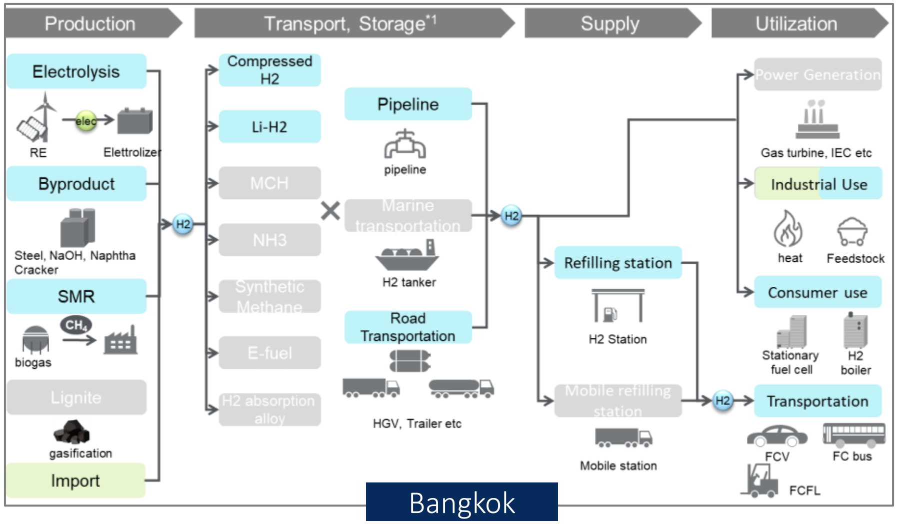
Summary of Potential Demand and Supply Study in Thailand (2/2)

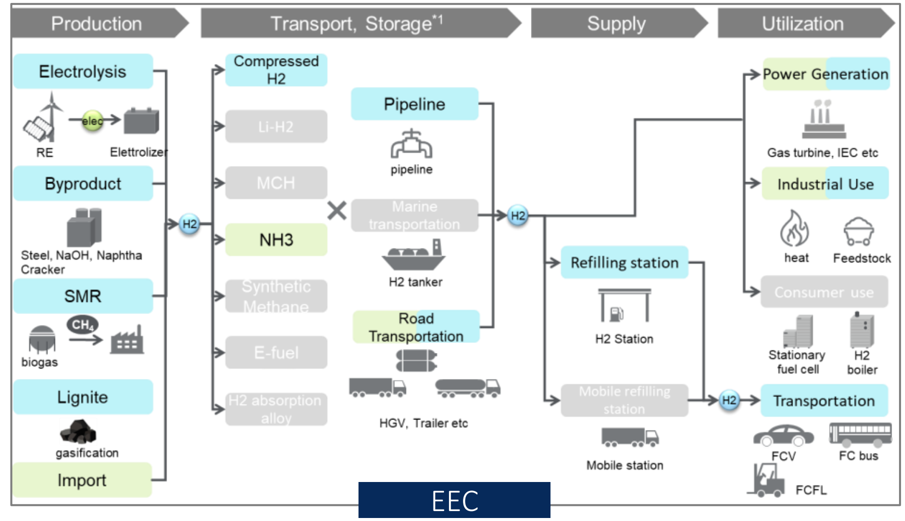
Challenges	■ Policy and Regulatory Framework: 1. No current detailed on hydrogen regulations & legal framework 2. Financial incentive to promote the pilot project & adoption for oil and gas companies 3. Technology advancement : learning from leading market on hydrogen deployment practice ■ Supply Chain Creation Require high investment and industry expert to establish hydrogen infrastructure related e.g. production, transportation, storage. Moreover, many companies might select other decarbonization options because of the production cost issue e.g. Cement sector– biomass, Power sector – opt to CCUS with natural gas to reduce CO2 emission rather than hydrogen-based production ■ Public acceptance: Safety concern need to be addressed to increase the hydrogen adoption which is important for building market demand
Implication	■ Policy and Regulatory Framework: To study Policy and regulation framework and implementation plan; - Benchmarking advanced countries (i.e. EU, SG etc), and Studying examples in other industry of Thailand ■ Supply Chain Creation To create Collaboration in national and industrial area levels (i.e. association), aiming i) Information sharing, ii) Creating leading projects, iii) Proceeding joint technical development study etc. ■ Public acceptance: To consider information Dissemination framework

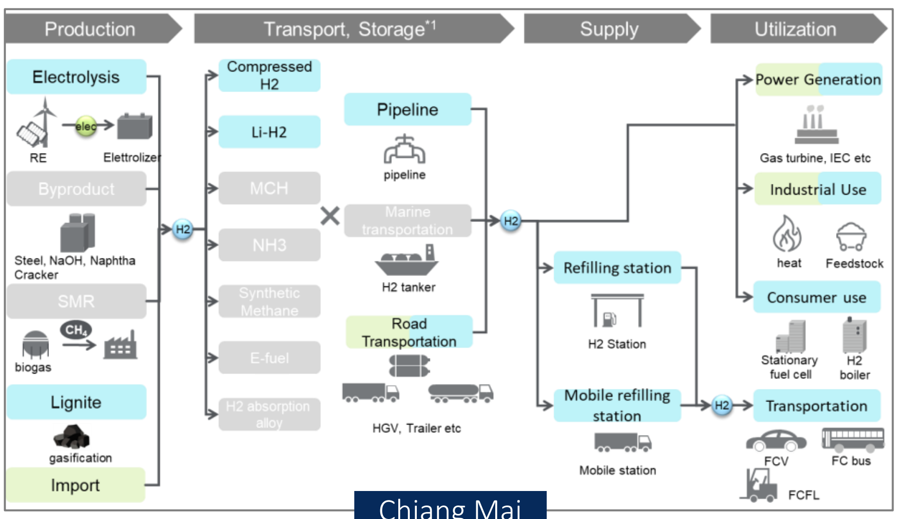
Conceptual supply chain model of Bangkok, Eastern Economic Corridor (EEC), and Chiang Mai are identified in below

Hydrogen Supply Chain Model (Conceptual)

Legend
Blue : H2
Green : NH3



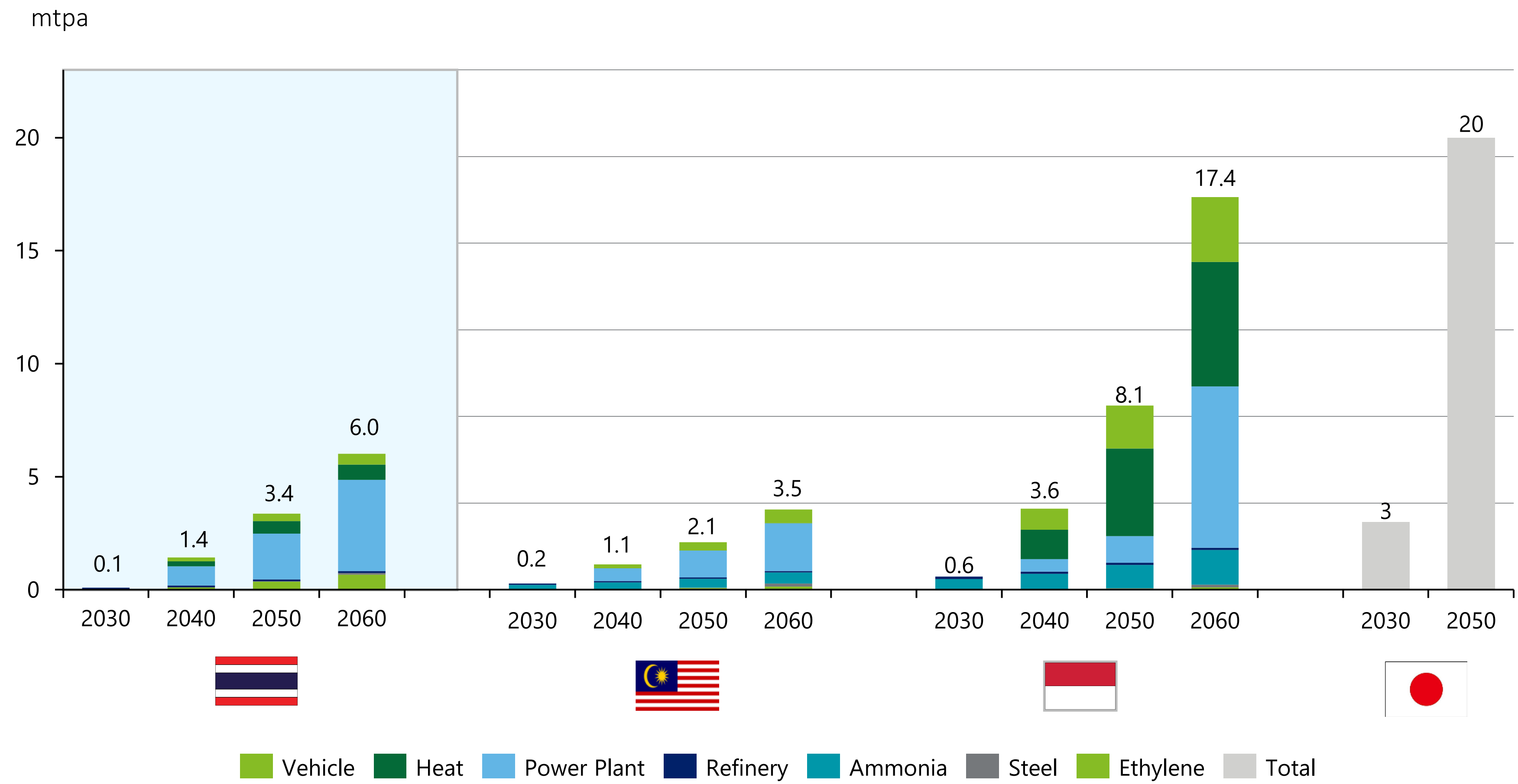




- Bangkok: based on Metropolitan model
- EEC: based on Port industrial area model
- Chiang Mai: based on Satellite city model

Thailand will reach 3.4 mtpa and 6.0 mtpa in 2050 and 2060 respectively in demand forecast, and the expected driver of the demand is the power sector

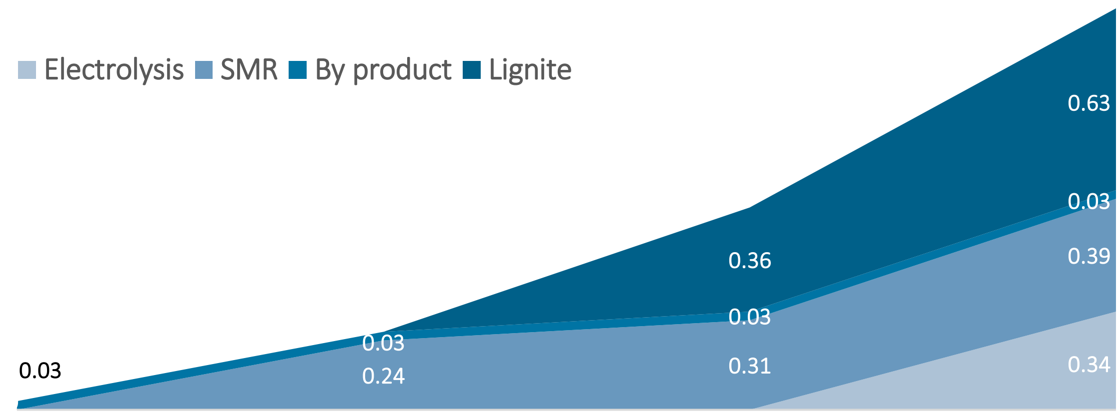
Potential Hydrogen Demand



Source: Deloitte analysis

Domestic hydrogen supply potential is projected as 1.39 mtpa in 2050 in consideration to Electrolysis, SMR-Biogas, Byproduct and Lignite

Domestic Hydrogen Production Estimation



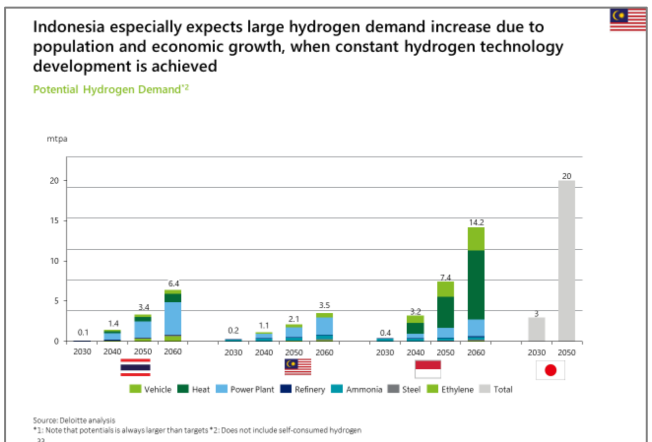
Unit: mtpa

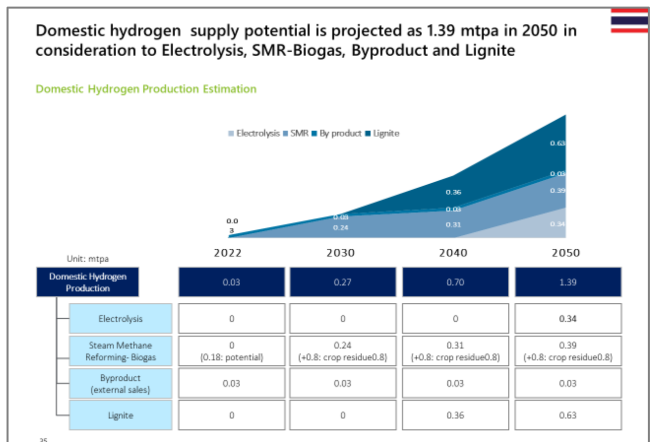
	2022	2030	2040	2050
Domestic Hydrogen Production	0.03	0.27	0.70	1.39
Electrolysis	0	0	0	**0.34**
Steam Methane Reforming- Biogas	0.03 (0.18: potential)	0.24	0.31	0.39
Byproduct (external sales)	0.03	0.03	0.03	0.03
Lignite	0	0	0.36	0.63

In 2050, Thailand shall procure 1.98 mtpa from international market to fulfill the difference between domestic supply and demand

Amount of International Procurement (estimation) 2050 (1/2)

Demand @ 2050		Domestic Supply @ 2050		Supply to be procured from international market
3.37 mtpa	−	1.39 mtpa (+ 0.8 mtpa)	=	1.98 mtpa (1.18 mtpa)

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Byproduct (external sales)	0.03	0.03	0.03	0.03
Lignite	0	0	0.36	0.63

35

In Asian and Oceania region, 37 projects have been announced in 12 countries, which makes sum of 38.35 mtpa of H2 and 34.61 mtpa of NH3 in the future

International Supply –Total amount planned in Potential Trading Counterparts

12 Countries	38 Projects	H2 38.35 mtpa	NH3 34.61 mtpa

Unit: tpa

Country	Project number	H2 Production	NH3 Production
Australia	16	6,373,840	29,290,000
Brunei	1	100	n/a
India	6	17,545,000	1,240,000
Indonesia	3	40,037	1,000,000
Kazakhstan	1	2,000,000	n/a
Malaysia	2	107,000	1,230,000

Unit: tpa

Country	Project number	H2 Production	NH3 Production
New zeland	2	180	500,000
Oman	1	500,000	n/a
Pakistan	1	55,000	n/a
Saudi Arabia	1	219,000	1,200,000
UAE	2	180	n/a
Vietnam	2	11,514,000	150,000

Thailand would need to procure 1.98 mtpa which is equivalent to 5% (3%) of possible international trading amount in Asia, Middle East and Oceania region

Amount of International Procurement (estimation) 2050 (2/2)

Supply to be procured from international market

1.98 mtpa
(1.18 mtpa)

Scenario A

In Asian and Oceania region, 37 projects have been announced in 12 countries, which makes sum of 38.35 mtpa of H2 and 34.61 mtpa of NH3 in the future

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Saudi Arabia	1	219,000	1,200,000
UAE	2	180	n/a
Vietnam	2	11,514,000	150,000

38

Percentage of sum of target countriesto fulfil TH demand

5% (3%)

Scenario B

Total 4 countries production is 7.02 mtpa which surpass current's need of 1.98 (1.18) mtpa

28% (17%)

There are multiple challenges to overcome for the successful market introduction of hydrogen, falling into three categories

Challenges

Area	Point of view	Challenges
Overall Supply Chain	Policy	Policy and Regulatory framework is yet organized
	Economy	Incentives for technology adaptor is insufficient
	Society	Hydrogen and relating technology and their benefit are not well-understood
	Technology	Detailed Supply chain is not clear for each area (information limitation)
Demand	Economy	High price of hydrogen is obstacle to secure bankability of the project
		Consideration of target regions/supply chains in global market is still unclear
	Technology	Technology have not been well-developed yet
Supply	Economy	Development/investment for production sites
		Development/investment for production sites has been insufficient
	Technology	Some of Technologies have not been well-developed yet

Category of challenges
Policy and Regulatory Framework
Supply Chain Creation
Public Acceptance

Toward hydrogen project launching, next actions shall be considered in line with three challenge categories

Implication

Further Steps toward Implementation → Hydrogen Project Launch

Type	Items for Consideration	Next Action	Hydrogen Project Launch
Policy and Regulatory Framework	■ Clear direction and commitment by the government is essential to guide private sector ➢ Comprehensive policy and regulatory framework, and supporting implementation plans ■ Incentives in both CAPEX and OPEX for early adaptors is a key drover to create a new hydrogen and ammonia-structured society ➢ Not only for industry sector but also consumer sector	To study Policy and regulation framework and implementation plan; - Benchmarking advanced countries (i.e. EU, SG etc) - Studying examples in other industry of Thailand etc	No silver bullet; Connection and mutual collaboration among key players in public and private sectors, are a key for H2 transformation • Scheme review • Alliance study • Profitability simulation • Planning of implementation plan etc.
Supply Chain Creation	■ Coordination between Demand and Supply generate momentum of moving forward ➢ Detailed potential demand study and common understandings among stakeholders ➢ Allocating risk and introduction cost with multiple players ■ Technical development ➢ Joint-study about specific technology ➢ Focusing on specific technology areas/themes to invest to improve development efficiency	To create Collaboration In national and industrial area levels, aiming; - Information sharing - Creating leading projects - Promoting joint technical development study - Conducting joint study of carrier etc.	
Public Acceptance	■ Fostering public acceptance of hydrogen is essential ➢ Information to be disseminated and how-to	To consider information Dissemination framework	

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1. Energy trend

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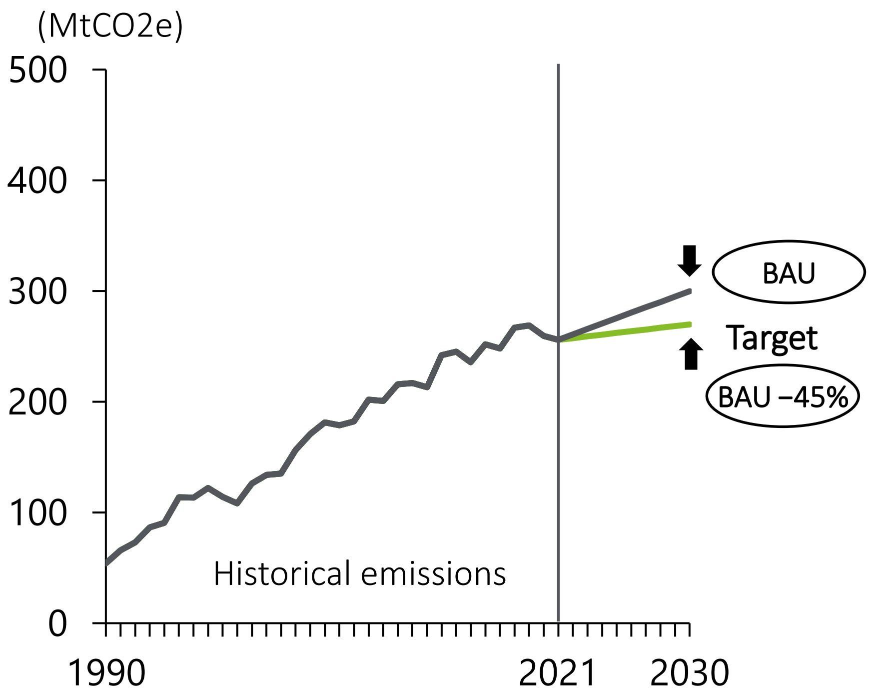
Malaysia updated its NDC by raising its unconditional target to 45% reduction in GHG emission intensity by 2030

Malaysia's emission reduction target and countermeasures



- The reduction in CO_2 emissions could reach 45% by 2030, subject to adequate and enhanced access to finance, technology and capacity building programs
- Malaysia announced a target for net zero emissions by as early as 2050, as echoed in its latest National Energy Policy and is preparing a Long-Term Emission Development Strategy (LT-LEDS)

Challenge and limitation

- Energy system and policy planning
- Regulatory and legal framework
- Technology and innovation
- Renewable energy financing

Adaptation Component

- Malaysia has developed the National Energy Policy (NEP) which includes 4 strategic thrusts:
  - Optimise energy resources to stimulate sustainable economic growth
  - Stimulate growth, market opportunities and cost advantage for the economy and people
  - Enhance energy sector contribution towards environmental sustainability
  - Ensure energy security towards fiscal sustainability

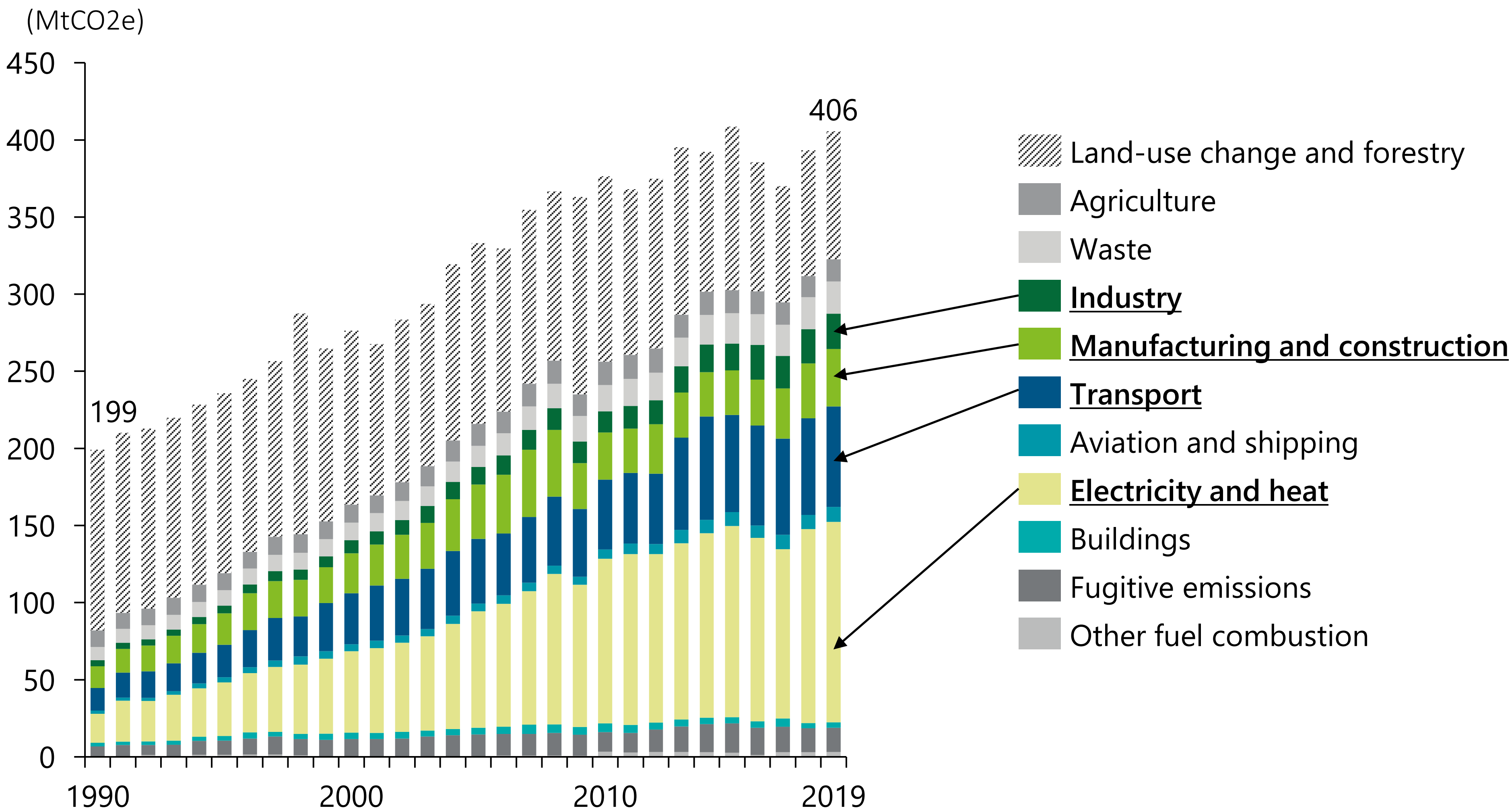
Support needs

1. Governance structure
2. Human capital and capabilities
3. Policy and regulations
4. Technology and infrastructure
5. Financing and investment

 Source: Malaysia Energy Transition Outlook, National Energy Policy, Our World in Data

Emissions from electricity and heat, transport and industry have been increasing in Malaysia

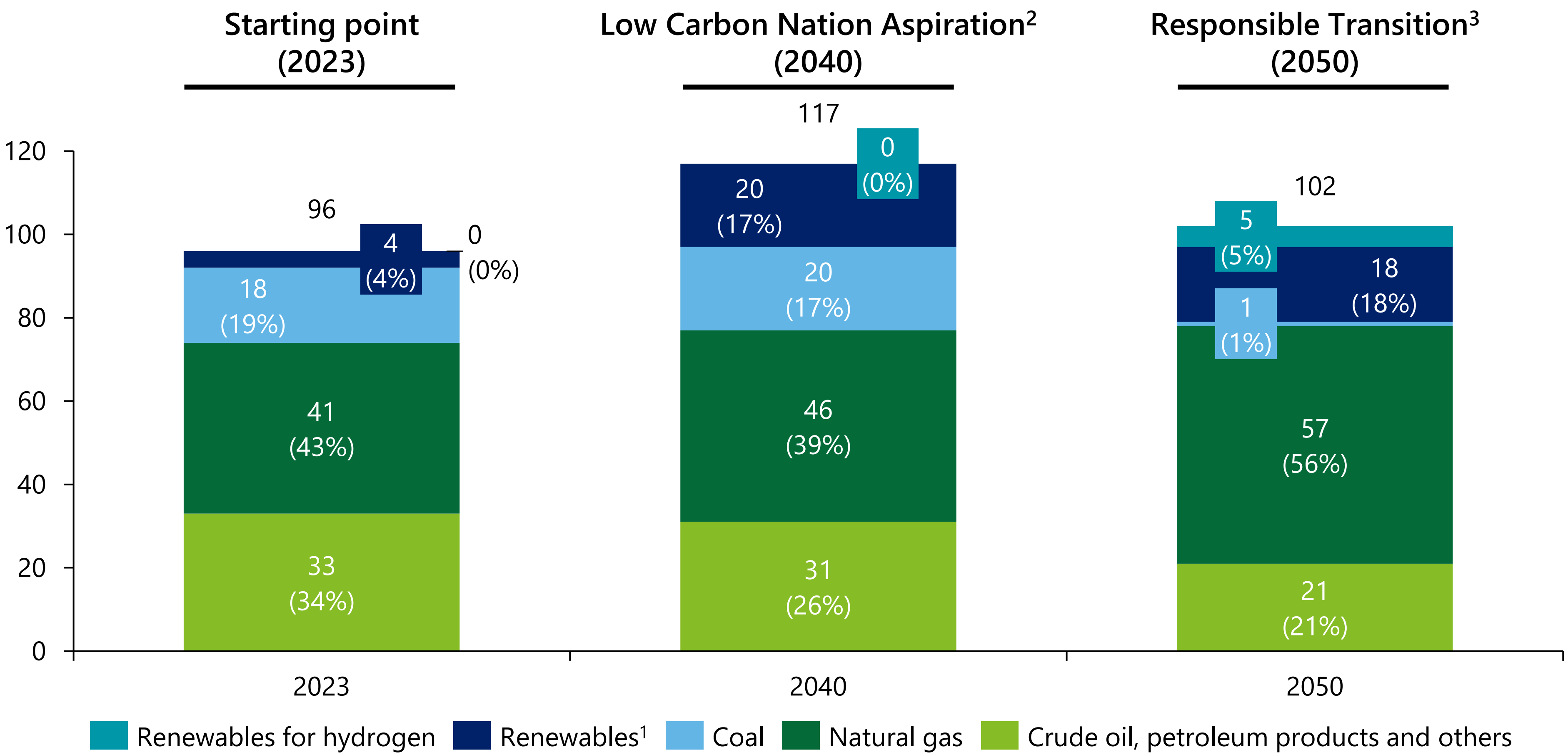
GHG emission by sector of Malaysia



 Source: Our World in Data

By 2050, coal will be nearly phased out, RE will increase from 4% in 2023 to 23% in 2050, and natural gas will constitute 56% of TPES

Total Primary Energy Supply (Mtoe), by energy source

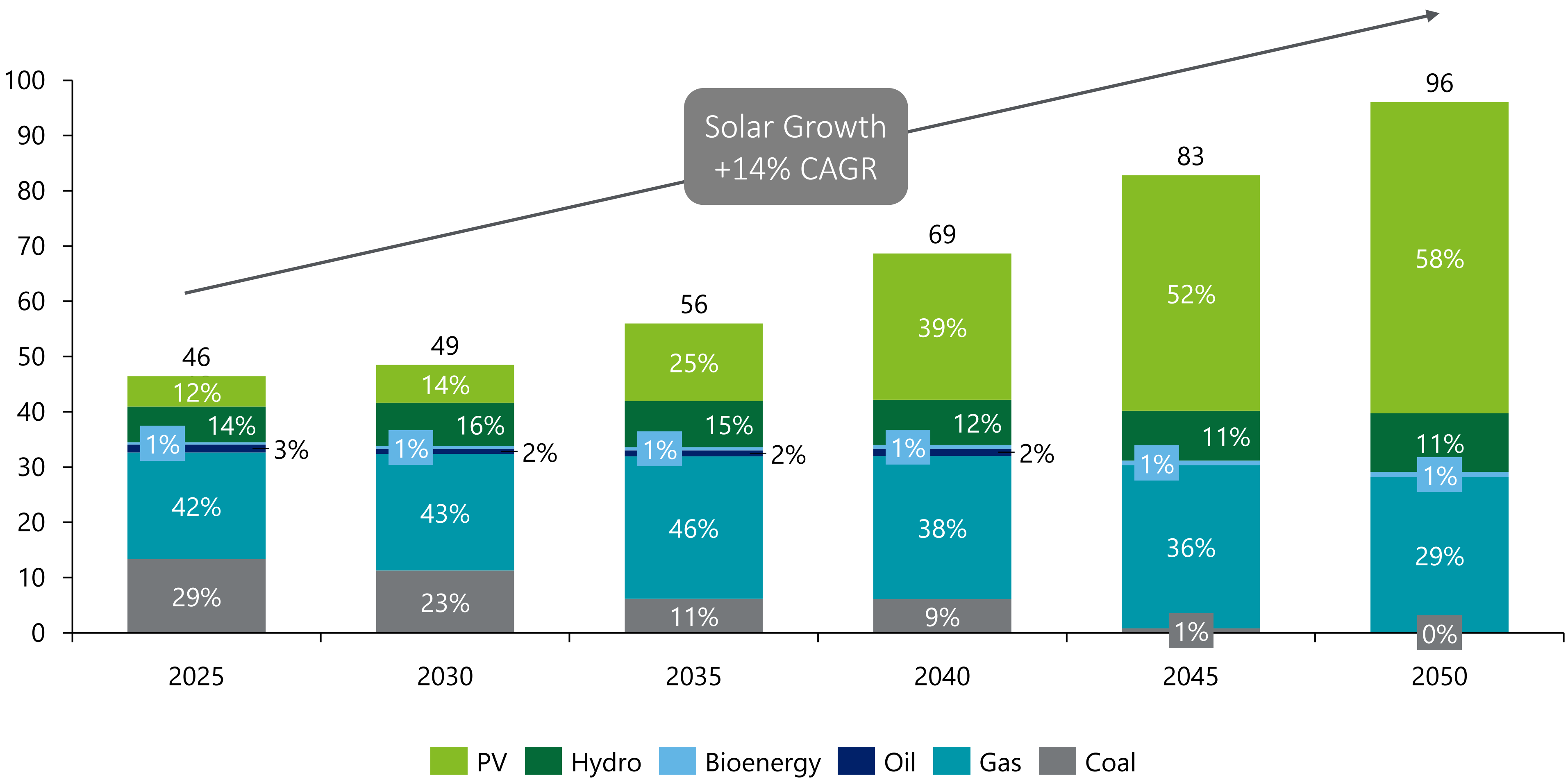


Note: (1) Renewables include bioenergy, solar, hydropower and hydrogen (2) An initiative from the National Energy Policy 2022-2040 that seeks to transition the country towards a sustainable and low carbon economy by 2040 (3) An initiative developed by the National Energy Transition Roadmap to shift Malaysia's energy systems from fossil fuel-based to greener and low-carbon systems by 2050

Source: National Energy Transition Roadmap

In May 2023, the Malaysian government targeted 70% RE in the power mix and no new coal power plant by 2050 to promote a low-carbon economy

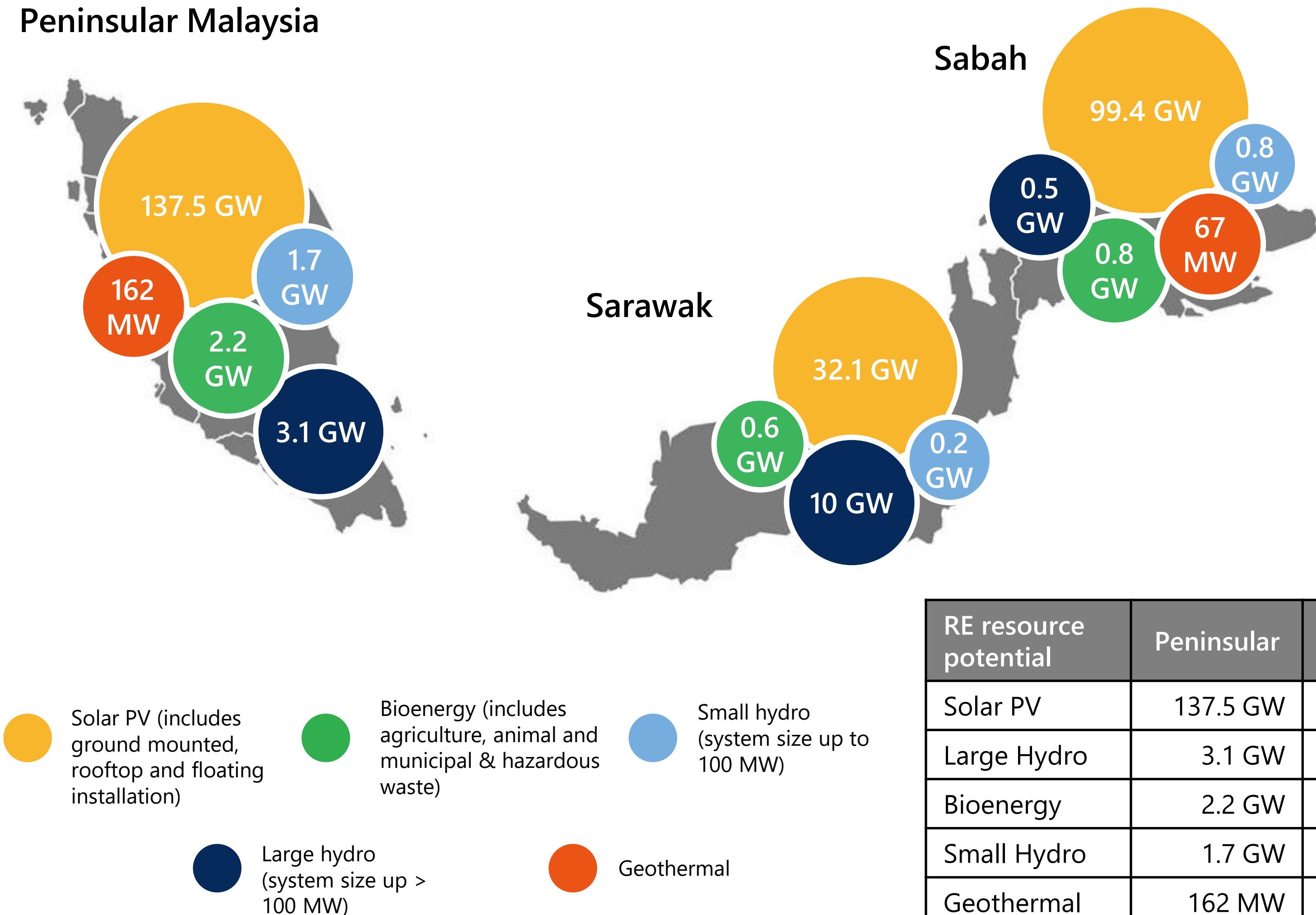
Projected power system installed capacity mix (GW)



Source: National Energy Transition Roadmap

Solar PV has the highest renewable energy resource potential in Malaysia, followed by large hydro, which plays a significant role in Sarawak

Overview of RE resource potential in Malaysia



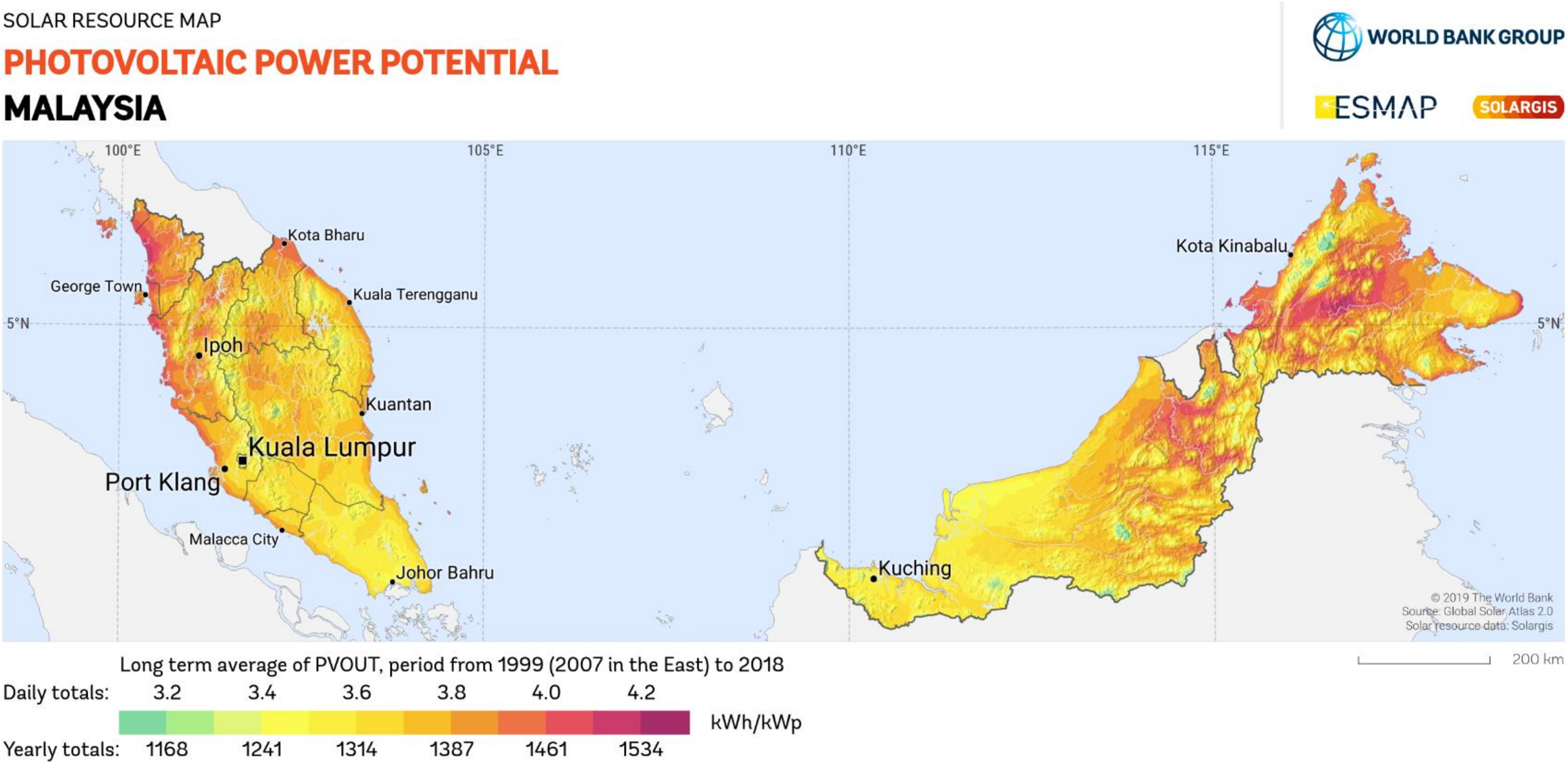
RE resource potential	Peninsular	Sabah	Sarawak	Total
Solar PV	137.5 GW	99.4 GW	32.1 GW	269 GW
Large Hydro	3.1 GW	0.5 GW	10 GW	13.6 GW
Bioenergy	2.2 GW	0.8 GW	0.6 GW	3.6 GW
Small Hydro	1.7 GW	0.6 GW	0.2 GW	2.5 GW
Geothermal	162 MW	67 MW	-	0.2 GW

Source: Sustainable Energy Development Authority (SEDA) Malaysia, National Energy Policy 2022 - 2040

Reference

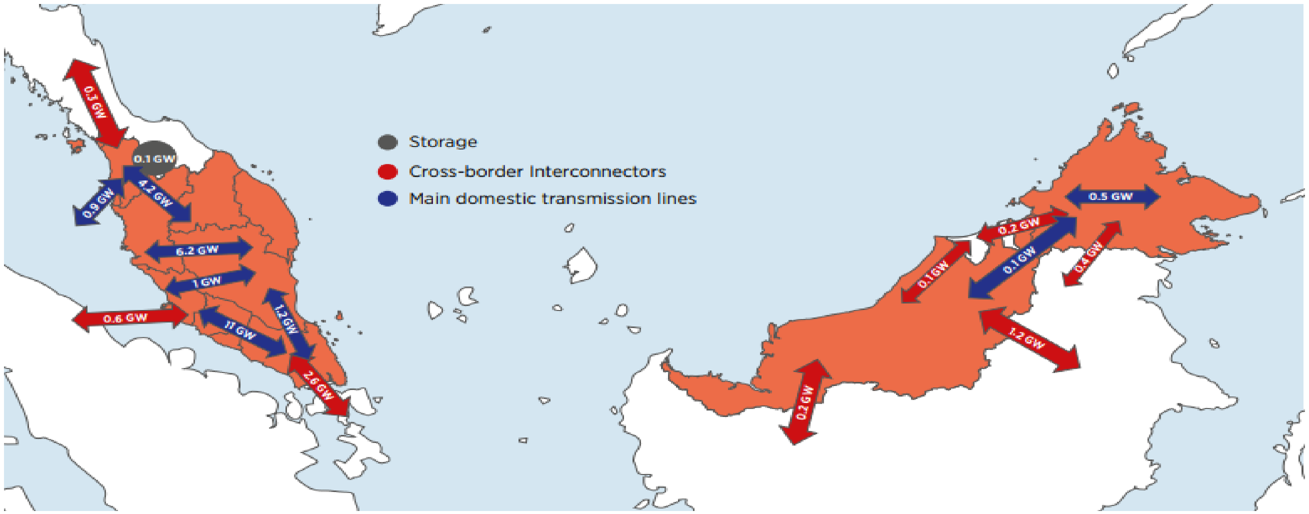
Solar irradiation in the northeastern part of P. Malaysia and the northern part of Borneo are relatively higher than the rest of MY

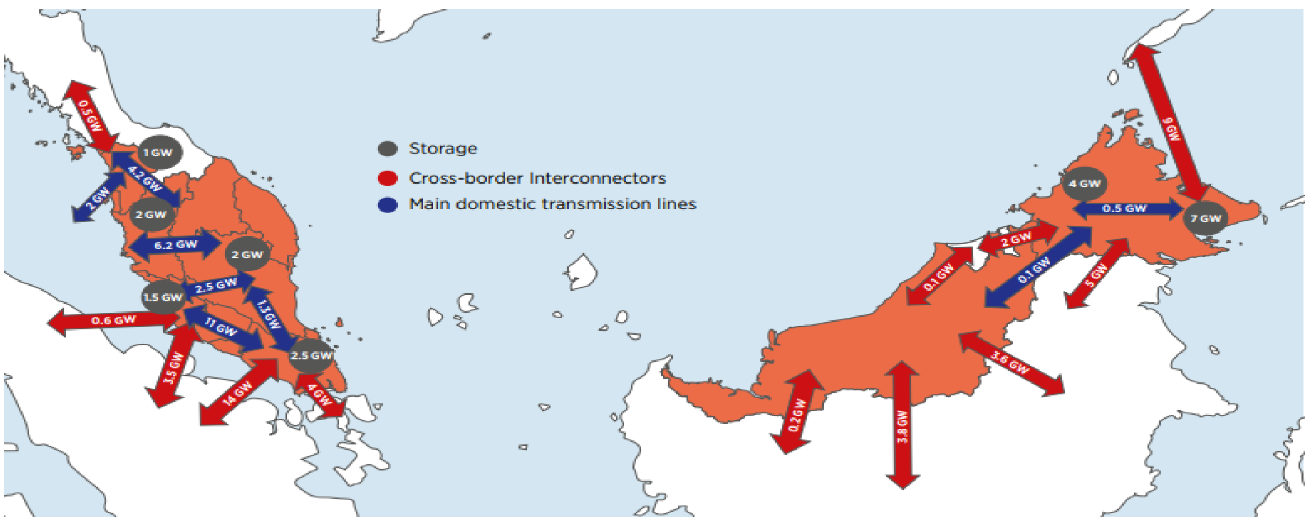
Malaysia Solar Potential Map



From a national perspective, imports of electricity will have a part to play in the future

Transmission lines and storage under the 1.5-S





2030

- Central and Southern Peninsular Malaysia rely on increasing import levels, which kicks off with a relatively small connection with North Sumatra (Indonesia) by 2030.
- In Eastern Malaysia, Sabah is a net importer with Brunei by 2030

2050

- Exchange capacity is enhanced though high-capacity connections with central Sumatra by 2050, resulting in over 150 TWh in net imports from the region.
- In Eastern Malaysia, the situation reverses in the long term with West Sabah predominantly selling power to Brunei in 2050

Note: 1.5-S=1.5 ℃ scenario

Source: Malaysia Energy Transition Outlook

There are currently three hydropower plants operational in Sarawak with a combined capacity of 3,452 MW, alongside three ongoing HEP

List of hydropower plants in Sarawak

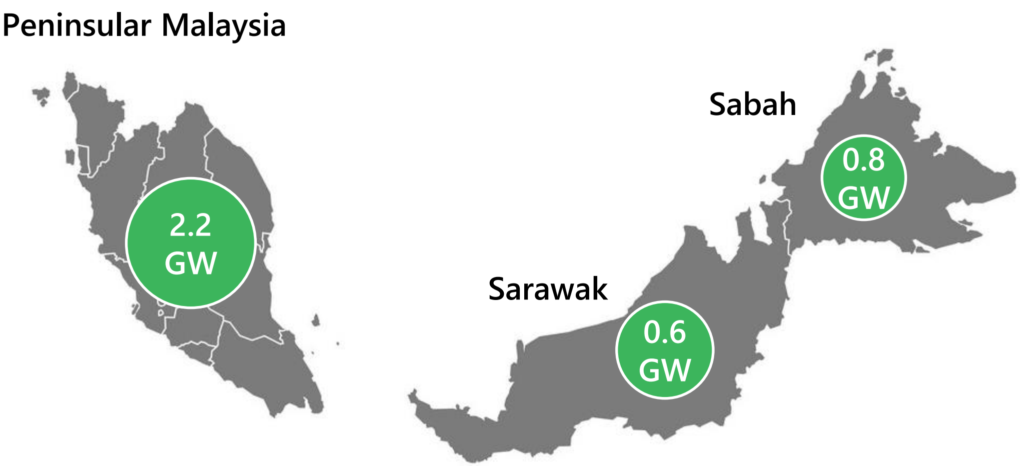
No	Name	Capacity (MW)	Surface Area of Reservoir	Commissioned date / Status	Company	Remark
1	Batang Ai HEP	108	90 km^2	1985	SEB	-
2	Bakun HEP	2,400	695 km^2	2011	SEB	-
3	Murun HEP	944	270 km^2	2014	SEB	-
4	Baleh HEP	1,285	588 km^2	2028	SEB	-
5	Trusan HEP	275	-	Feasibility study in 2023	SEB	Brunei has shown interest in investing in the HEP, and Sarawak Energy is open to collaborating on the project.
6	Baram HEP	1,200	389 km^2	Shelved	SEB	The HEP had come under heavy criticism from anti-dam campaigners, who had opposed its construction
7	Mentarang Induk HEP (MIHEP)	1,375	226 km^2	HoA signed in 2022, commission by 2029	PT KHN*	The Mentarang Induk HEP will supply power to local industries in North Kalimantan
Total		**7,587**	**2,258 km^2**			

Note: HEP- Hydro-Electric Power
PT KHN is a foreign investment holding company owned by PT Adaro Energy Indonesia Tbk (50%), Sarawak Energy Berhad (25%) and PT Kayan Patria Pratama (25%). PT Adaro is a public listed company and also one of the largest thermal coal miners in Indonesia.
Kayan Patria Pratama (PT KPP) is a private company operations across various industries (coal mining, plantation, energy, forestry and shipping) in East and North Kalimantan.

 Source: SEB websites, several news

Biogas has significant potential in Malaysia, and there is strong demand for biogas projects, supported by the FiT and the National Energy Policy

Summary of bioenergy potential and future plan in Malaysia



A total of 3.6 GW resource potential for bioenergy, including:

- Biomass (2.3 GW)
- Biogas (736 MW)
- Municipal solid waste (516 MW)

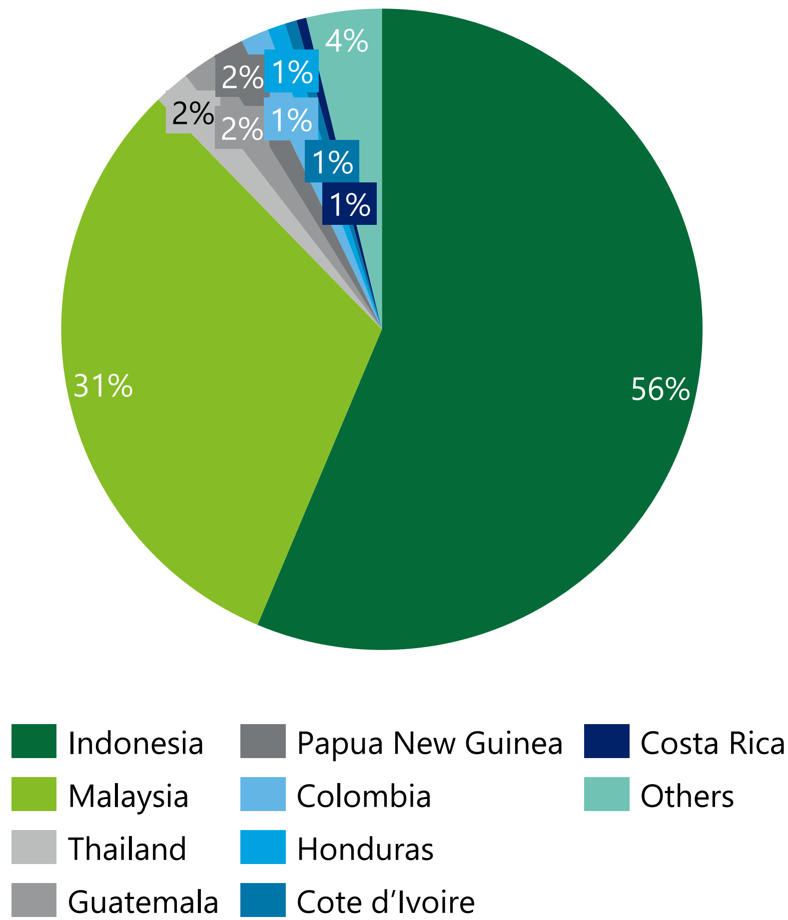
Total Biogas Project (2021)	As of November 2021, **60 biogas project have been commissioning with a combined capacity of 119.74 MW** with another 95.58 MW in construction
FiT E-bidding (2021)	In 2021, the e-bidding **allocated 31.805 MW of biogas quota**, a total of 24 application were received with a **total capacity of 36.472 MW**
Policy	The RE Act 2011 established the Feed-in Tariff (FiT) mechanism to accelerate RE growth in Malaysia. Prior to FiT, the biogas industry grew slowly, mainly for compliance with Malaysia Palm Oil Board (MPOB) regulations at palm oil mill owners' expense
Future Plan NEP (2022-2040)	1) Optimize the role of bioenergy for power generation including explore opportunities where bioenergy can support cost-effective rural electrification through micro grid 2) Invest to build local capabilities and technology to unlock high potential of biofuel (e.g., biogas, biomethane) in industry, supported by early-stage funding and grants to encourage early-mover adoption

 Source: Sustainable Energy Development Authority (SEDA) Malaysia, National Energy Policy 2022 - 2040

Indonesia and Malaysia are the world's leading palm oil exporters, accounting for 88% of global palm oil exports

Top 10 palm oil world export country (2022)

Rank	Country	Export (1,000 MT)	Percent of World Export
1	Indonesia	28,400	56.4%
2	Malaysia	15,800	31.4%
3	Thailand	900	1.8%
4	Guatemala	860	1.7%
5	Papua New Guinea	800	1.6%
6	Colombia	700	1.4%
7	Honduras	430	0.9%
8	Cote d'Ivoire	300	0.6%
9	Costa Rica	240	0.5%
10	Others	1,934	3.8%
Total		**50,364**	**100%**



 Source: U.S. Department of Agriculture, Foreign Agricultural Service

Biogas is a promising renewable energy source for Malaysia, but government support is needed to address current challenges and accelerate its growth

Overview of palm oil production, challenges and opportunities in Malaysia

Overview of Palm Oil in Malaysia

Oil Palm Planted Area in Malaysia

- Total oil palm planted area at 5.67 million hectares in 2022.
- Sarawak is the largest oil palm planted state in Malaysia, with 1.62 million hectares (28.6% of Malaysia's total oil palm planted area).
- Sabah is the second-largest oil palm planted state, with 1.51 million hectares (26.6%).
- Peninsular Malaysia has 2.54 million hectares of oil palm planted area (44.8%).

Palm oil Production

- Produce an average of **53 million tons of palm oil** yearly

POME and EFB Production

- Generate 13 million tons of empty fruit bunches (EFB) yearly
- Generate 68 million m3 of palm oil mill effluent (POME) yearly

Potential of POME

- Most palm oil mills in Malaysia use POME to generate biogas. If all the POME were digested anaerobically, it could generate over 500MW of electricity for the mills.

Challenges

- Palm oil mills in **remote areas face challenges connecting biogas plants to the grid**, limiting their ability to use the FiT mechanism or requiring expensive infrastructure upgrades
- In 2017, the total **FIT quota** offered to the prospective biogas applicants **was insufficient to meet the existing demand** due to the constraints in the Renewable Energy Fund
- Malaysia's **biomethane industry is in its infancy stages**, with most technology imported from Germany
- **Removing H2S from biogas is a challenge**, requiring additional investment
- **Fossil fuel subsidies** make biomethane less attractive

Opportunity

- The **government is developing a long-term solution to the challenge of connecting palm oil mill biogas plants to the grid**, while businesses are looking for short-term solutions such as using the biogas onsite, selling it as domestic fuel, or investing in microgrids.
- **The government is now transitioning to an e-bidding system for FIT biogas quota** which will make the market more competitive and attract more project to be implemented

 Source: Several News Articles

In 2021, there are 8 FiT commercial biogas projects, seven of which are fueled by POME biogas, and the another one is fueled by landfill gas

Total FiT commissioned biogas plant (2021)

No	Company	Installed Capacity (MW)	FiT Commercial Date	Location	RE Type
1	Cenergi Sri Ganda Sdn Bhd	2.404	18/2/2021	Teluk Intan, Perak	POME
2	Bion Sdn Bhd	2.338	8/5/2021	Kg. Gajah, Perak	POME
3	GLT Climate Sdn Bhd	1.200	11/7/2021	Kuala Kangsar, Perak	POME
4	Cenergi West Sdn Bhd	1.560	15/8/2021	Pulau Carey, Klang, Selangor	POME
5	Jana Landfill Sdn Bhd	3.600	7/10/2021	Jeram, Selangor	Landfill
6	Cenergi Sua Betong Sdn Bhd	1.560	29/10/2021	Port Dickson, Negeri Sembilan	POME
7	GLT Morib Power Sdn Bhd	1.502	29/12/2021	Tenjung Sepat, Kuala Langat, Selangor	POME
8	BAC Biogas (Kg. Gajah) Sdn Bhd	1.501	24/12/2021	Kg. Gajah, Perak	POME
Total		**15.67**			

Note: Most of the commissioned biogas plants use covered lagoon for methane capture

 Source: Sustainable Energy Development Authority (SEDA) Malaysia

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7. Demand Forecast

Malaysia would require 1 Mtoe for lower scenario and 4 Mtoe for higher demand sicarios respectively in 2040 according to ERIA's forecast

Hydrogen Demand in Thailand, Indonesia and Malaysia

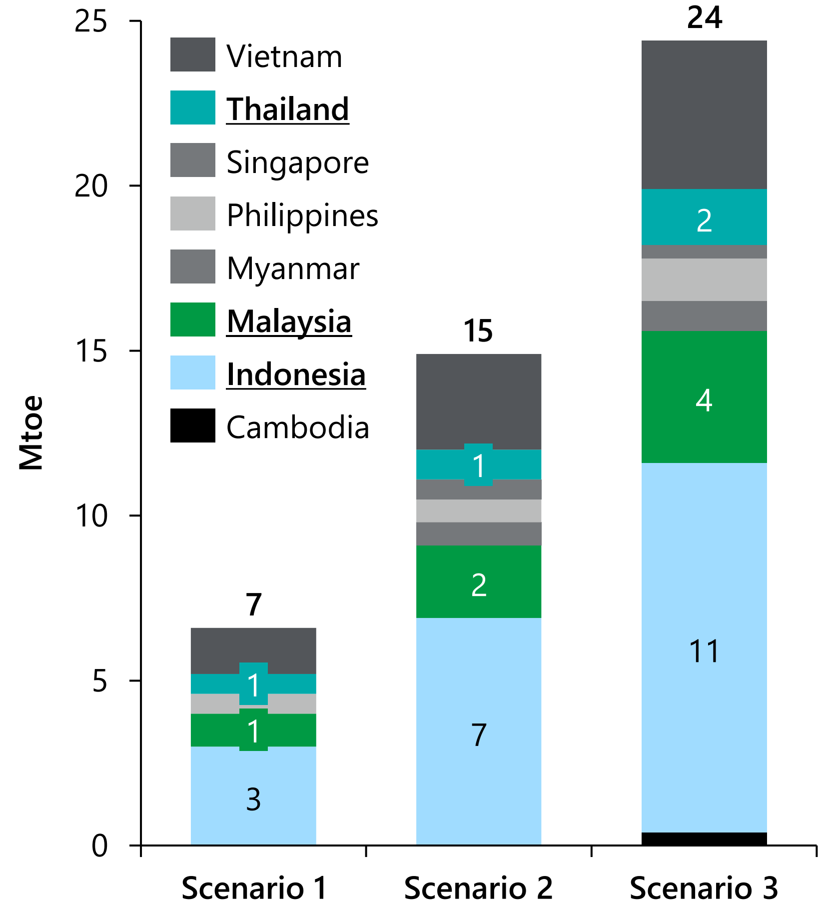
Hydrogen Demand Scenario

- ERIA*1 has forecasted scenario-based calculations on the potential demand for hydrogen by 2040, using the following scenarios for power generation:

	% of hydrogen	% of natural gas
Scenario 1	10%	90%
Scenario 2	20%	80%
Scenario 3	30%	70%

Key Takeaway

- Overall, by 2040, the potential ASEAN hydrogen demand is 7 Mtoe (Scenario 1), 15 Mtoe (Scenario 2) and 24 Mtoe (Scenario 3)
- Malaysia has a comparatively large demand potential with 1 Mtoe (Scenario 1), 2 Mtoe (Scenario 2), and 4 Mtoe (Scenario 3)
- Indonesia is leading with 3 Mtoe (Scenario 1), 7 Mtoe (Scenario 2) & 11 Mtoe (Scenario 3) while Thailand is only managed to gain demand of 1 Mtoe (Scenario 1), 1 Mtoe (Scenario 2) & 2 Mtoe (Scenario 3)



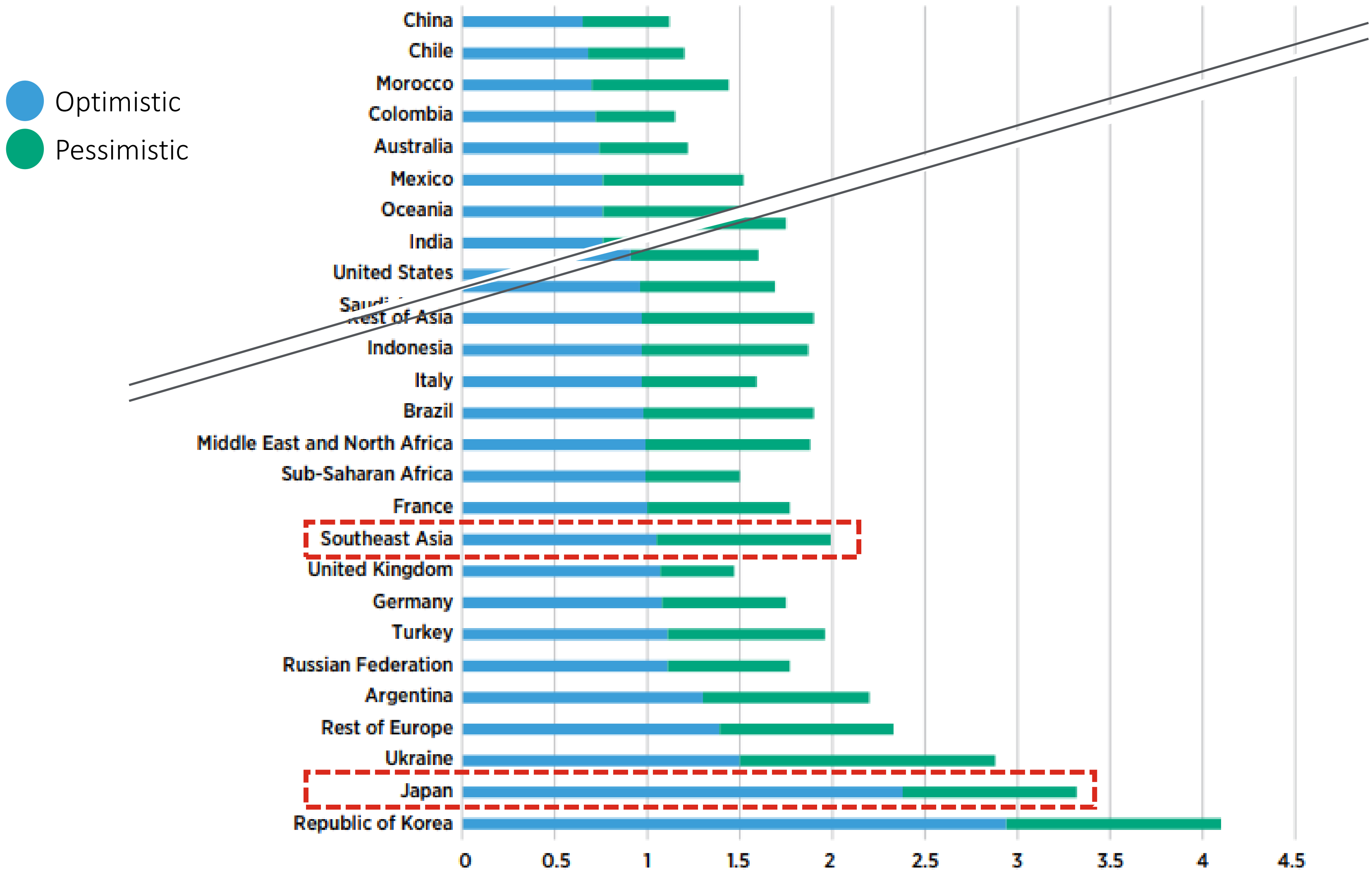
Hydrogen demand forecast by ERIA in ASEAN region in 2040

Source: Demand and Supply Potential of Hydrogen Energy in East Asia ERIA, JICA Indonesia Decarbonization Survey (2022)

*1: Economic Research Institute for ASEAN (ERIA)

According to IRENA, hydrogen production cost in Southeast Asia will be 1~2 USD/kg in 2050

Levelized cost of hydrogen in 2050

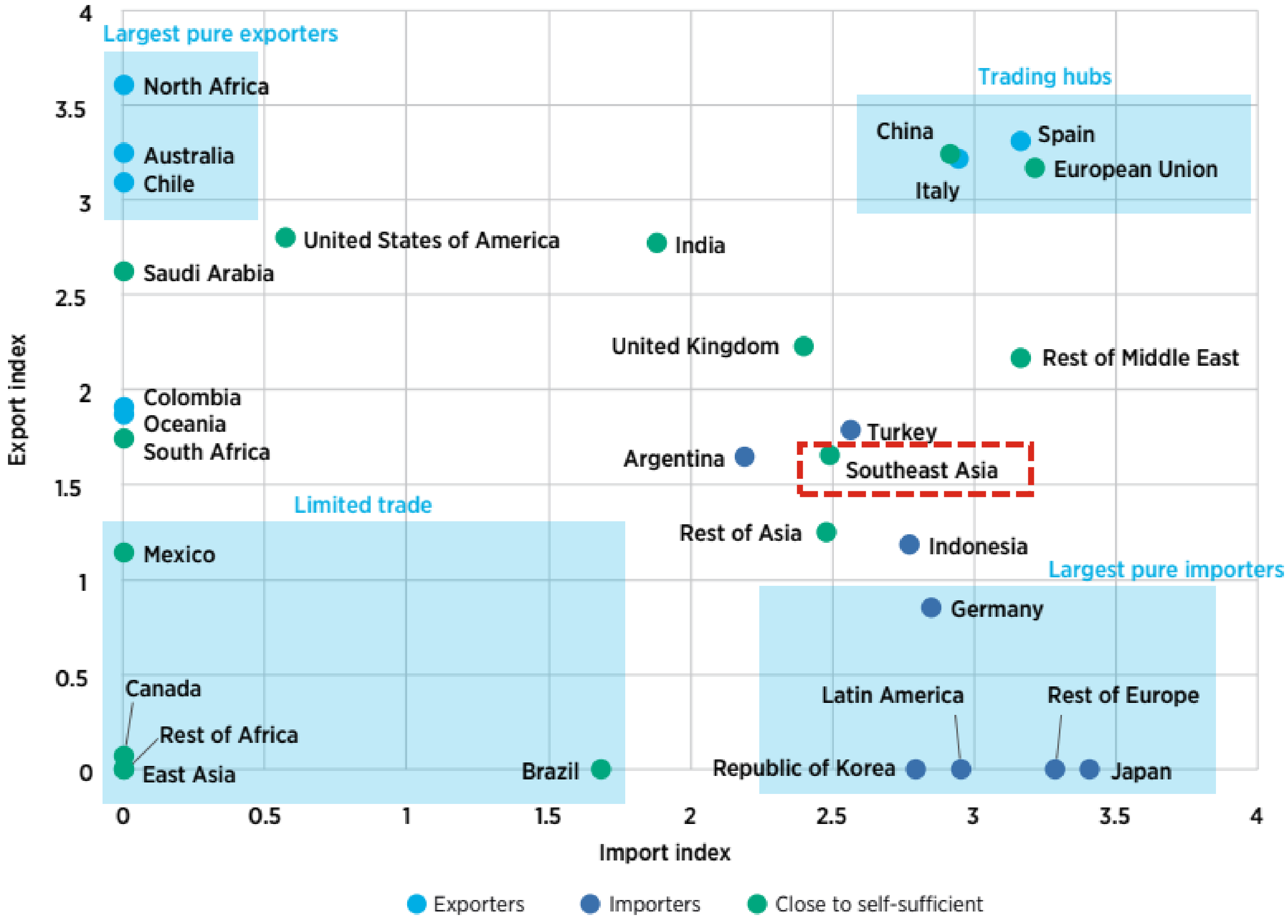


 Source: Global hydrogen trade to meet the 1.5 ℃ climate goal: Part III – Green hydrogen cost and potential,, International Renewable Energy Agency (2022)

The Southeast Asian countries, including Malaysia, in general fall in-between close-to-self-sufficient and importers

Volumes of hydrogen export and import for regions in 2050 (optimistic)

FIGURE 3.17. Volumes of hydrogen export and import for regions around the world in 2050 with *optimistic* technology assumptions



"The largest net importers are Germany, Indonesia, Italy, Japan, __Southeast Asia__ and the rest of Asia. " (IRENA, 2022)

 Source: Global hydrogen trade to meet the 1.5 ℃ climate goal: Part I – Trade outlook for 2050 and way forward, International Renewable Energy Agency (2022)

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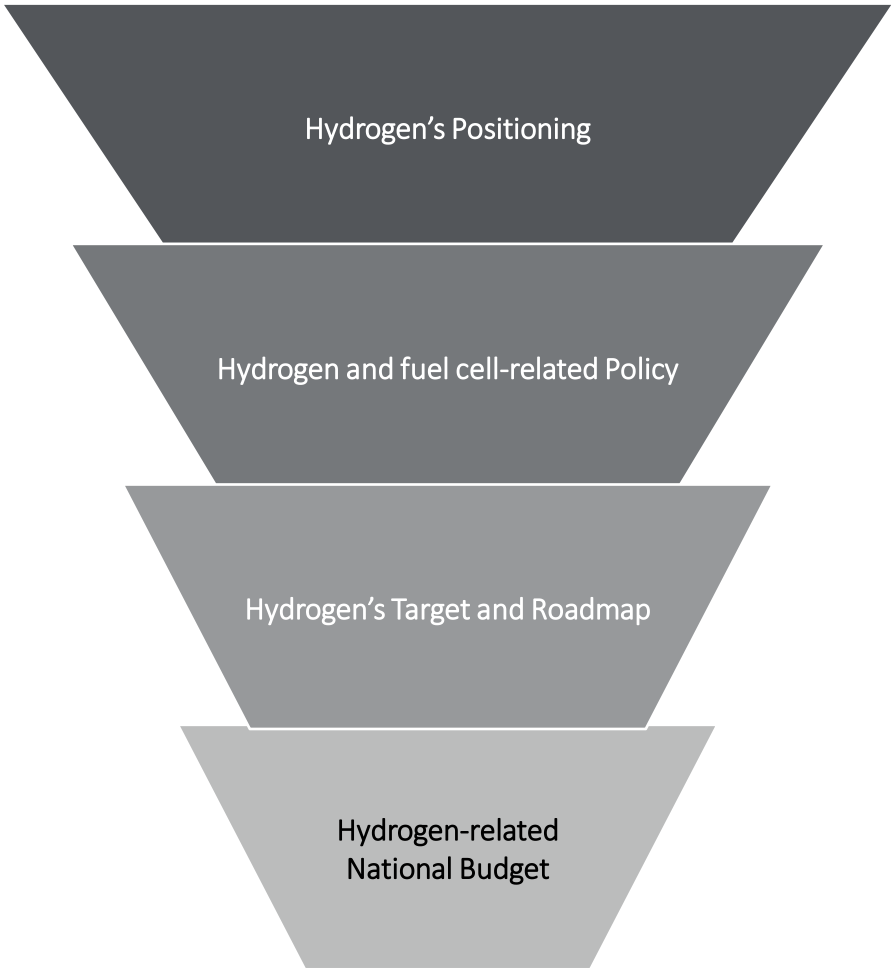
Hydrogen policy will be surveyed from the concept to implementation, namely from positioning to budget for Malaysia

Research process on hydrogen-related policy



Positioning	• To understand hydrogen's positioning in environmental policy by studying Nationally Determined Contribution (NDC), a mid-term target based on the Paris Agreement and Long-term strategy. • To survey emission reduction target
Policy	• To investigate the policy frameworks (strategies and plans) related to hydrogen and fuel cell • To identify and scrutinize related entities that implement policies
Target	• To understand level of focus on hydrogen and fuel cell policies quantitatively by survey of hydrogen and fuel cell adoption target
Budget	• To understand the degree to which Malaysia are promoting these measures and the types of projects that are being focused on by investigating the budgets for R&D and demonstration projects

A new hydrogen economy is expected to contribute between RM49bil and RM61bil to Malaysia's gross domestic product by 2030

Summary

Overview	■ Malaysia’s intended Nationally Determined Contribution (NDC) is to **reduce its greenhouse gas (GHG) emissions intensity of GDP by 45% by 2030** relative to the emissions intensity of GDP in 2005. ■ The National Energy Transition Roadmap (NETR) articulates Malaysia’s commitment **to achieve net-zero GHG emissions by 2050.** NETR has developed the Responsible Transition (RT) Pathway 2050 to **shift Malaysia’s energy systems from fossil fuel-based to greener and low-carbon systems**.
Hydrogen Strategy (strategy and plans dedicated for hydrogen and fuel cell)	■ Malaysia’s National Nanotechnology Centre, under the Ministry of Science, Technology and Innovation, has initiated the **National Hydrogen Economy and Technology Roadmap (HETR),** aimed at positioning Malaysia as a leading Hydrogen Economy Country by 2050. This initiative is based on five main factors: 1. Increasing revenue and productivity in exports, mobility, power generation, industrial heating and non-energy 2. Promoting green growth aspirations in transportation sector 3. Cementing Malaysia’s position as the key hydrogen player in Asia Pacific 4. Creating job opportunities from the hydrogen economy 5. Enhancing national intellectual capabilities and capacities in hydrogen technologies.
Hydrogen quantitative target	■ NETR sets three goals: 1. **Replace grey hydrogen with blue hydrogen** as a feedstock by 2050 2. **Generate up to 2.5 Mtpa of green hydrogen** from renewable sources like hydroelectric and solar by 2050 3. Establish one low-carbon hydrogen hub by 2030 and add two more by 2050, **totaling three hubs.**
Hydrogen project and support	■ Malaysia is harnessing hydrogen's potential, **notably in Sarawak with projects like H2ornbill and H2biscus, in partnership with Japanese and South Korean entities.** These align with Sarawak’s Hydrogen Economy Roadmap, aiming for state development by 2030. The upcoming HETR will boost Malaysia's hydrogen goals.

 Source: UNFCCC, MIDA, NETR and Monitor Deloitte Analysis

NETR highlights several critical insights regarding Malaysia's evolving power mix as the country advances on this journey

Key observations for the dynamics of Malaysia's power mix

1

Renewable vs. Fossil Fuels
Renewables will constitute the majority share (70%) of installed capacity by 2050. However, the contribution of RE to the total generation mix will be comparatively lower than fossil fuels, particularly natural gas. This reflects the inherent low-capacity factor associated with solar, compared against the high-capacity factor of gas.

2

Coal Phase-Out
The share of coal-fired power generation is expected to ramp down over time, driven by natural retirement timelines of existing coal-fired power plants. No new coal-fired power generation will be developed, leading to almost complete phase out by 2045.

3

Natural Gas as Transition Fuel
Natural Gas is expected to act as a lower-carbon transition fuel away from baseload coal, and will be the dominant source of fuel for baseload power.

4

Solar-Driven RE Target
The ambition to achieve 70% RE share of installed capacity by 2050 is expected to be achieved, predominantly driven by solar PV installation. Significant solar capacity growth is required in the next three decades, with 59 GW of installed capacity by 2050.

 Source: National Energy Transition Roadmap (2023)

Hydrogen provides Malaysia an economic and sustainable energy path, with Sarawak projects positioning the nation at the forefront of energy transition

Key targets and challenges of hydrogen adoption

Key Targets

NETR proposes the following targets:

- **Blue Hydrogen:** To completely phase out the use of grey hydrogen as a feedstock by 2050
- **Green Hydrogen:** To produce up to 2.5 Mtpa of green hydrogen by 2050 from RE such as hydroelectric power and solar
- **Low-carbon Hydrogen Hubs:** To establish one low-carbon hydrogen hub by 2030, and an additional two hubs by 2050, bringing the total to three hubs

Key Challenges

Despite its potential, hydrogen adoption is not without challenges:

- **Technical and Commercial Barriers:** Limited electrolyzer supply, technical gaps, and high costs hinder green hydrogen production
- **Electrolyser Cost Implications:** Electrolyzers, vital for RE-sourced hydrogen in Malaysia, account for a third of its production cost; efficiency improvements could offer a competitive advantage
- **Production and Regulatory Hurdles:** Malaysia's hydrogen sector lacks clear policy and regulations, with governance ambiguities between existing energy acts

 Source: National Energy Transition Roadmap

Hydrogen infrastructure, fuel cell applications, and emerging fuel cell technologies should be addressed in the Malaysia Plans

Malaysia's hydrogen roadmap in 2020

2021 - 2025
12th Malaysia Plan (Short Term)

To utilise advances in R&D on hydrogen infrastructure

To publish guidelines, regulations, and policies

To raise public awareness

To ensure safety measures are in place

To establish satisfactory local standards and policy structure

To utilise advances in R&D on fuel cell applications

To enact policies, standards, and guidelines

2026 - 2035
13th and 14th Malaysia Plans (Medium Term)

To secure financial support from relevant stakeholders

To set up a local supply chain and related facilities

To enhance capacity building in human resources

To reduce cost by mass production

To have suitable alternatives for convenient fuel cell applications

To raise the profile of fuel cells

To have sufficient funding for the local fuel cell industry

To have a pool of champions for the fuel cell industry

To set up monitoring bodies

To nurture fuel cell technology and infrastructure in target market segments

To educate the public on the potentials and benefits of fuel cells

2036 - 2050
15th, 16th, 17th & 18th Malaysia Plans (Long Term)

To establish National Priority for hydrogen fuel infrastructure

To gain proven high track records in the industry

To nurture high-quality green hydrogen producer

To secure active involvement by stakeholders

To become a strong regional market leader

To have industrial projects for fuel cell applications

To have a sustainable fuel cell powered-city model

To have new indigenous resources to replace expensive components

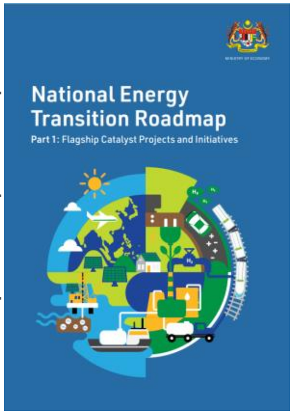
Legend:
- Hydrogen Infrastructure
- Fuel Cell Applications
- Emerging Fuel Cell Technologies

Source: Position Paper on Hydrogen Economy, Monitor Deloitte Analysis

Part 1 of the NETR identified 6 levers comprising 10 flagship catalyst projects reducing GHG by at least 10 Mt per year

National Energy Transition Roadmap Part 1

Policy	National Energy Transition Roadmap Part 1 Flagship Catalyst Projects and Initiatives
Date	July 2023
Entity	Ministry of Economy
Main Purpose	Part 1 of the National Energy Transition Roadmap (NETR) was launched by the Ministry of Economy on 27 July 2023, outlining ten flagship catalyst projects and initiatives based on six energy transition levers – (1) energy efficiency (EE); (2) renewable energy (RE); (3) hydrogen; (4) bioenergy; (5) green mobility; and (6) carbon capture, utilisation and storage (CCUS)



Summary

- NETR doubles down on **reducing GHG intensity against GDP by 45% by 2030** compared to 2005 baseline
- **By 2050, low-carbon sources will account for more than 90% of energy**, and fossil fuels will account for less than 10%
- As such, **the transition from a fossil fuel dependent economy to a high-value green economy must be done meticulously**, to amplify positive impacts and reduce any ramifications to near zero, especially to the *Rakyat*

Summary

- **Sarawak Hydrogen Hub to be championed by Sarawak Economic Development Corporation**. These integrated projects to produce green hydrogen which comprises of a **green hydrogen production plant in Kuching by 2025 for domestic use**, and **two plants in Bintulu by 2027, mainly for export purposes**

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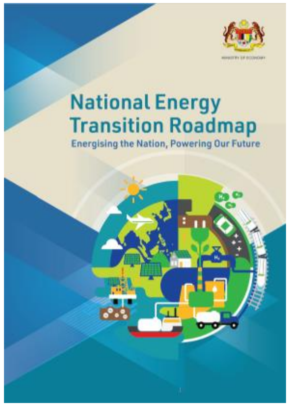
 Source: National Energy Transition Roadmap Part 1

Part 2 of the NETR outlines Malaysia's energy transition strategy and highlight main catalysts, such as technological advancements and policy reforms

National Energy Transition Roadmap Part 2

Policy	National Energy Transition Roadmap Part 2 Energising the Nation, Powering Our Future
Date	August 2023
Entity	Ministry of Economy
Main Purpose	Part 2 of the NETR was announced on 29 August 2023, which was essentially an introduction of the NETR in full and an introduction of, among others, the six levers and five enablers needed for the country's energy transition



Summary

- **Key challenges are always centered around the Energy Trilemma – (1) Security**: a nation's capacity to meet current and future energy demand reliably; **(2) Equity**: ability to provide universal access to reliable, affordable, and abundant energy; **(3) Sustainability**: avoiding potential environmental harm and climate change impacts
- **NETR outlines 50 initiatives under the six energy transition levers and five enablers**, in addition to the 10 flagship projects and initiatives announced in July 2023. The energy transition financing will be undertaken through a combination of grants, loans, rebates, incentives, and other investments to support the whole-of-nation approach

Summary

- NETR's Responsible Transition (RT) Pathway 2050 aims to transition Malaysia from fossil fuels to sustainable energy. Energy demand will grow 0.2% annually, reaching 102 Mtoe by 2050. Fossil fuel reliance will decrease from 96% in 2023 to 77% in 2050. By 2050, natural gas will contribute 56% to the TPES, while renewables will increase from 4% in 2023 to 23%

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- Section 1: Introduction
- Section 2: Case for Malaysia's Energy Transition
- Section 3: National Energy Transition Roadmap (NETR)
- Section 4: Energy Transition Ambition and Macro Position
- Section 5: Energy Transition Levers and Key Initiatives
- Section 6: NETR Flagship Catalyst Projects and Initiatives
- Section 7: Cross-Cutting Enablers

 Source: National Energy Transition Roadmap Part 2

NETR aims to rapidly steer Malaysia towards net-zero emissions, enhancing GDP, job creation, and revenue in green industries

Summary of NETR Benefits

People

- Addition of 310,000 jobs in future-proof sectors across the country
- Balanced economic outcomes with 70% of income gains to benefit medium- and low-income households
- Better quality of life and health outcomes with lower emissions
- Greater empowerment to reduce carbon footprint
- Up-skilling support for just transition

Business

- RM120-180 billion investment opportunities in co-funded government facility for energy transition
- Investment opportunities for green growth across energy transition value chain, up to RM1.2-1.3 trillion
- Lower carbon footprint with cleaner energy mix and energy efficiency to future-proof trade and investment position

Government

- 10-15% uplift in GDP value with spurring of new growth areas
- 32% reduction in energy sector emissions, supporting climate change commitments
- Enhanced energy self-sufficiency
- Enhanced diversification of fiscal income with new growth
- Carbon footprint reduction to future-proof industries and generate Green FDI

 Source: National Energy Transition Roadmap

National Energy Transition Roadmap (1 of 4)

Policy Overview – Malaysia

Guiding Principles

- The first principle highlights the importance of **aligning the energy sector with the country's aspirations and commitments to sustainable development**
- The second principle emphasizes **a just, inclusive, and cost-effective energy transition**, ensuring benefits for all segments of society, especially the low-income and vulnerable populations
- The third principle stresses the need for **effective governance and a whole-of-nation approach**
- The fourth principle highlights the significance of **creating high-value employment for people and generating high-impact economic opportunities for SMEs**

Flagship Catalyst Projects and Initiatives

Energy Transition Levers	Flagship	Modalities	Champion (Responsible Entity)
3 Hydrogen (*See P65 for detailed initiatives*)	Green Hydrogen	**Sarawak Hydrogen Hub** Implementation of three integrated projects to produce green hydrogen will propel Sarawak as a regional green hydrogen hub. These projects involve the development of a green hydrogen production plant in Kuching by 2025 for domestic use, and two plants in Bintulu by 2027, mainly for export purposes. Sarawak State Government through SEDC Energy is collaborating with strategic partners to develop the state into a green hydrogen hub	SEDC Energy
	Hydrogen for Power	**Co-Firing of Hydrogen and Ammonia** Green hydrogen and ammonia co-firing in collaboration with PETRONAS to decarbonize TNB generation plants	TNB
1 Energy Efficiency (EE)	Efficient Switch	**Energy Efficiency and Conservation Act (EECA)** The Energy Efficiency and Conservation Bill to regulate energy-intensive users, buildings and products will be tabled in Parliament in the fourth quarter of 2023.	NRECC
		Energy Audit for Rail Sector Railway operators to perform energy audit exercise under the Energy Audit Conditional Grant (EACG 2.0) aimed at establishing the current energy consumption baseline, identifying potential energy savings in their premises and lowering utility costs	MOT

 Source: National Energy Transition Roadmap

National Energy Transition Roadmap (2 of 4)

Policy Overview – Malaysia

Flagship Catalyst Projects and Initiatives	Energy Transition Levers	Flagship	Modalities	Champion (Responsible Entity)
	2 Renewable Energy (RE)	Renewable Energy Zone (RE Zone)	**Integrated RE Zone** A large-scale, integrated sustainable development spanning the entire energy supply chain, from generation and energy storage to efficient demand management and consumption, will be created. A pilot RE Zone will be established encompassing an industrial park, zero-carbon city, residential development and data centre	Khazanah Nasional Berhad
			Solar Park Centralised large-scale solar (LSS) parks co-developed by TNB, in partnership with SMEs, cooperatives, and state economic development corporations. These parks will consist of 100 MW deployment per site across 5 sites in several states	TNB
			Hybrid Hydro-Floating Solar PV (HHFS) Development of 2500 MW HHFS potential at TNB hydro dam reservoirs will increase RE generation close to 24-hour availability. The hydro plant acts as energy storage by conserving the water in the reservoir during peak hours and discharging it during non-peak, while providing quick response to the duck curve	TNB
			Residential Solar The construction of 4.5 MW solar capacity across 450 homes in City of Elmina and Bandar Bukit Raja. Up to 10 kW solar capacity per house through rooftop leasing with offtake within the township by high-demand users from the commercial or industrial sector	Sime Darby Property
		Energy Storage	**Energy Storage System (ESS)** Development of utility-scale ESS to enable higher penetration of variable RE in Malaysia	NRECC
		Energy Secure	**Sabah Energy Security Initiative** An integrated initiative is underway to secure the long-term energy supply and support the socioeconomic development of the state. This includes: the development of large-scale solar (LSS) and small hydropower plants; the formulation of policy and regulatory framework on biowaste to ensure a consistent supply of feedstock; and the feasibility of geothermal for power generation	Energy Commission of Sabah (ECoS)

 Source: National Energy Transition Roadmap

National Energy Transition Roadmap (3 of 4)

Policy Overview – Malaysia

	Energy Transition Levers	Flagship	Modalities	Champion (Responsible Entity)
Flagship Catalyst Projects and Initiatives	4 Bioenergy	Biomass Demand Creation	**Biomass Clustering** Development of potential biomass clusters with a centralised plant using aggregated feedstock from multiple neighbouring mills. Biomass clustering is expected to improve economies of scale as well as securing larger and more reliable feedstock	NRECC SEDA
			Biomass Co-firing Co-firing initiative at the existing 2100MW Tanjung Bin Power Plant by burning biomass along with coal. Biomass sources include Empty Fruit Bunch (EFB) pellets, wood chips, wood pellets, bamboo pellets, coconut husk and rice husk. A pilot phase of co-firing will commence in 2024 with a view to scale up to a minimum of 15% biomass co-firing capacity by 2027	Malakoff
	5 Green Mobility	Future Mobility	**Mobile Hydrogen Refueling Station** Introduction of the first mobile hydrogen refueling station for transportation in Peninsular Malaysia, in collaboration with NanoMalaysia Berhad, PETRONAS, United Motor Works (UMW) and the MGTC	MOSTI
			EV Charging Stations Installation of 10,000 EV charging stations by 2025 along highways and at selected commercial buildings in collaboration with strategic partners, among others, TNB, Plus Malaysia Berhad (PLUS), Permodalan Nasional Berhad (PNB), Gentari and Sunway Group	MITI
			Public Transport Electrification This project involves electrification of first and last mile public transport and upgrading infrastructure and electrical lines at bus deports for charging, with maintenance, repair and overhaul (MRO) opportunities for local SMEs	MOT Prasarana
			Solar Photovoltaic (PV) Installation for Rail Operations The Rail Sector Energy Management and Renewable Energy (EMRE) Action Plan entails the installation of Solar Photovoltaic (PV) systems for non-traction electricity usage in rail operations such as stations and depots	MOT

 Source: National Energy Transition Roadmap

National Energy Transition Roadmap (4 of 4)

Policy Overview – Malaysia

Flagship Catalyst Projects and Initiatives	Energy Transition Levers	Flagship	Modalities	Champion (Responsible Entity)
	5 Green Mobility	Future Fuel	**Biofuels Hub** A bio-refinery will be developed in Pengerang, Johor, to serve as a catalyst for creating hubs to produce a range of bio-based products, including sustainable aviation fuel (SAF), hydrotreated vegetable oil (HVO), advanced sustainable fuel (ASF) and biochemicals	PETRONAS
	6 Carbon Capture, Utilisation and Storage (CCUS)	CCS for Industry	**Regulatory Framework** Development of policy and regulatory framework to facilitate the implementation of CCUS projects, including transboundary carbon movement	Ministry of Economy
			Kasawari and Lang Lebah CCS Implementation of carbon capture and storage (CCS) catalyst projects for Kasawari and Lang Lebah high-CO_2 gas fields, which are expected to be in operation by 2026 and 2028 respectively. CCS technology will be used to capture CO_2 from the gas production field and store it in the depleted fields	PETRONAS

 Source: National Energy Transition Roadmap

In Phase 2 of the NETR, the Malaysian government outlines 4 initiatives under the hydrogen energy transition lever

Key initiatives under hydrogen energy transition lever 3

Energy Transition Lever: Hydrogen		
Code	Initiatives	Champions
HY-1	**Establish low-carbon hydrogen standards and regulations** o Adopt low-carbon hydrogen standard to ensure consistent definition of low-carbon hydrogen with global trading partners o Establish domestic guarantee of origin certification to meet the standards of importing countries o Introduce hydrogen-specific regulations relating to transportation and storage o Streamline permitting process for hydrogen projects for expedited approval	MOSTI
HY-2	**Develop domestic green electrolyser manufacturing capabilities** o Fund electrolyser research and development (R&D) projects in local universities targeting efforts that reduce manufacturing costs o Provide financial incentives for electrolyser R&D activities by the private sector	MOSTI
HY-3	**Reduce Levelised Cost of Hydrogen (LCOH) for low-carbon hydrogen** o Establish hydrogen hubs to optimize economics of low-carbon hydrogen (see slide 52) o Establish financial incentives for large-scale manufacturing of low-carbon hydrogen and electrolyser o Facilitate partnerships between foreign electrolyser technology providers and local manufacturers for knowledge transfer	MOSTI MITI
HY-3	**Stimulate demand for low-carbon hydrogen** o Explore bilateral agreements with key importing countries to develop low-carbon hydrogen value chain, catalyse project development and secure long-term green hydrogen offtakes o Provide incentives for development of hydrogen refuelling stations and purchase of hydrogen fuel cell vehicles o Explore hydrogen co-firing with coal as a technology to reduce GHG emissions in the short term	MOSTI MITI

 Source: National Energy Transition Roadmap

Malaysia's energy transition hinges on five key enablers and twelve initiatives, addressing core challenges outlined in the NETR

Cross-cutting enablers and initiatives

Financing and Investments	1	Establish National Energy Transition Facility
	2	Mobilise and attract private capital flow for energy transition sectors
	3	Roll out carbon pricing mechanism
Policy and Regulation	4	Launch National Gas Roadmap
	5	Rationalise energy subsidies
Human Capital and Just Transition	6	Establish green skills taxonomy and ensure strategic workforce planning
	7	Develop and roll out targeted green skilling programmes
	8	Develop and implement community support programmes
	9	Enhance energy literacy and energy efficiency awareness among students, SMEs and energy consumers
Technology and Infrastructure	10	Develop a National Energy Knowledge Hub for public services
	11	Accelerate development of domestic industries for green manufacturing and adoption of green technologies
Governance and Implementation	12	Establish National Committee on Energy Transition under the National Energy Council (MTN)

 Source: National Energy Transition Roadmap

Malaysia is in the process of developing a hydrogen economy roadmap, identifying incentives to boost investment in hydrogen production (Part 1)

Potential incentives across key enablers

Enabler: Financing and Investment

Code	Incentives	Champions
EN1	**Launch a National Energy Transition Facility (NETF)** ○ Launch initial seed fund amounting to RM2 billion ○ Explore the catalytic blended finance platform, aimed at expediting the mobilisation and deployment of capital to enhance the accessibility of funds, streamline investment processes, and ensure a seamless flow of financial resources towards energy transition projects	Ministry of Economy
EN2	**Mobilise and attract private capital for energy transition sectors** ○ Attract private capital from the green foreign direct investments (FDI), international and domestic capital markets, venture capital (VC), and private equity (PE) ○ Accelerate adoption of innovative sustainable finance instruments e.g. sustainability-linked/green/SDG financing, bonds and sukuk, blended finance structures ○ Develop capacity building programme to upskill FIs and fund managers in collaborations with Joint Committee on Climate Change (JC3) and financial industry training institutes ○ Scale-up sustainable finance literacy, awareness programmes and technical capacity building targeting SMEs by JC3 including through pilot programmes such as Greening the Value Chain ○ Expedite VC investments in high-risk, early-stage energy ventures in suitable areas	MITI BNM SC
EN3	**Roll out carbon pricing mechanism** ○ Implement a phased and meticulously calibrated carbon pricing mechanism that sends clear market signals on decarbonization while simultaneously creating an additional capital pool for investments in energy transition ○ Roll out communication strategy to seek buy-in from the businesses and rakyat	MOF NRECC

 Source: National Energy Transition Roadmap

Malaysia is in the process of developing a hydrogen economy roadmap, identifying incentives to boost investment in hydrogen production (Part 2)

Potential incentives across key enablers

Enabler: Policy and Regulation

Code	Incentives	Champions
EN4	**Rationalise energy subsidies** ○ Develop a targeted subsidy mechanism based on needs ○ Ensure transparency and effective communication on subsidy removal ○ Leverage Pangkalan Data Utama (PADU) to facilitate targeted subsidies	MOF Ministry of Economy KPDN NRECC

Enabler: Human Capital and Just Transition

Code	Incentives	Champions
EN5	**Establish green skills taxonomy and ensure strategic workforce planning** ○ Develop green skills taxonomy that defines the essential skills needed for a just transition towards a sustainable workforce ○ Facilitate a strategic alignment between workforce demand and supply based on the green skills taxonomy and competency standards of present and future industry requirements ○ Establish a task force to develop strategic plans for the future of the energy sector's workforce	Sector-specific agencies

Enabler: Technology and Infrastructure

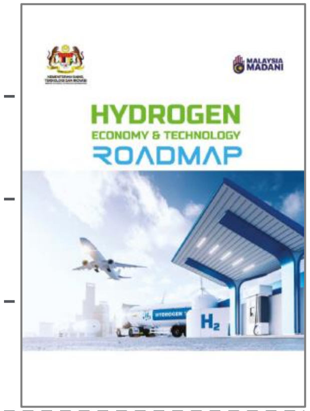
Code	Incentives	Champions
EN6	**Accelerate development of domestic industries for green manufacturing and adoption of green technologies** ○ Develop programmes tailored to support SME involvement in the green value chain in the form of technical expertise and financial support	MITI

 Source: National Energy Transition Roadmap

HETR outlines 3 goals: hydrogen export, diversification of sustainable energy, and the inclusion of the mobility sector in the hydrogen ecosystem

Hydrogen Energy Technology Roadmap

Policy	Hydrogen Energy Technology Roadmap
Date	October 2023
Entity	Ministry of Science, Technology and Innovation (MOSTI)
Main Purpose	HETR was announced on 5 October 2023, with objective to realize the vision for Malaysia to be a leading nation in Hydrogen Economy by 2050, outlining 3 goals with 5 strategic thrusts, 9 strategies and 29 action plans



Summary

- **HETR three goals – (1) Hydrogen export**: To focus on the export of hydrogen to the APAC regions with a cumulative revenue of RM648 billion; **(2) Sustainable energy mix**: To achieve diversification of energy type and increase cleaner energy shares in Malaysia, creating a hydrogen demand of 68.2 TWh/year; **(3) Develop mobility sector**: To include mobility sector in the ecosystem to create hydrogen demand of 30.5 TWh/year
- **HETR outlines 5 strategic thrust under 9 strategies and 29 action plan**, involving various ministries, agencies, research institutions and stakeholder to create hydrogen economy to **untap a potential revenue of RM89 billion by 2050**

Summary

- **HETR focuses on developing a robust and competitive hydrogen ecosystem across the value chain in Malaysia via accelerate technological advancement through ‘Build-Some and Buy-Some’ strategy**. Hydrogen production volume is projected at 16 MTPA by 2050 under emission driven scenario and to achieve **15% GHG reduction in long term (2041-2050)**.

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 Source: Hydrogen Energy Technology Roadmap

Institutionalizing and strengthening the national hydrogen governance and ecosystem for a sustainable future in Malaysia

Hydrogen Energy Technology Roadmap (1/12)

Strategies, Action plan and Targets	Strategies	Action Plan	Targets	Champion (Responsible Entity)
	1.1 Institutionalizing and strengthening the National Hydrogen Governance and Ecosystem	1.1.1 Establish National Hydrogen Economy and Technology Steering Committee to provide direction, facilitate & monitor the national hydrogen initiatives and oversee the hydrogen export operation to be reported to National Science Council (NSC). (Supporting NEP Action Plan B8 and Action Plan E1)	One (1) National Hydrogen Economy and Technology Steering Committee (HET) represented by all main hydrogen players.	MOSTI
			Recognition of Hydrogen Economy and Technology Roadmap (HETR) as supplementary document to support the implementation of the National Energy Policy 2022-2040 (NEP) (Dasar Tenaga Negara 2022-2040).	MOSTI
			Incentivization or permit for local manufacturers to be part of the hydrogen export supply chain.	MITI
			Standard operational procedure across the hydrogen supply value chain according to different energy and raw material sources.	
		1.1.2 Develop and establish collaborative platforms to form government-to-government relations with countries in hydrogen-related areas for demand-driven R&D and market-driven delivery. (Supporting NEP Action Plan E2)	Develop mechanisms on hydrogen economy partnerships with importing countries (e.g.: Australia) that show great potential for cost-effective green hydrogen production that can contribute to the long-term security of green hydrogen supply.	MITI
			Develop a framework and mechanism for export of hydrogen to the targeted countries (Singapore, South Korea, and Japan).	
			Build a strategic partnership network with hydrogen-producing countries to produce Malaysian graduates who are skilled in the hydrogen field to improve knowledge of hydrogen technology in the TVET program while also producing graduates who meet the latest industry and technology requirements.	

 Source: Hydrogen Energy Technology Roadmap

Creating a conducive environment for the hydrogen export through B2B partnerships and establishing collaborative platform for local players

Hydrogen Energy Technology Roadmap (2/12)

Strategies, Action plan and Targets	Strategies	Action Plan	Targets	Champion (Responsible Entity)
	1.1 Institutionalizing and strengthening the National Hydrogen Governance and Ecosystem	1.1.3 Form a business-to-business (B2B) partnership through collaboration between Malaysia and targeted countries for export and import of hydrogen, collaboration, technology, and knowledge exchange. (Supporting NEP Action Plan A3, B5 and B8)	Malaysia–Japan, South Korea Malaysia–Singapore, China Malaysia–Importing countries (e.g., Australia, Chile). Capture the market share of imported hydrogen by exporting hydrogen produced domestically in Malaysia (of up to 0.5–1 MTPA by 2030) to targeted countries while the local hydrogen economy is being developed	MITI
		1.1.4 A centralised database & impact tracking system which include monitoring & evaluation components (M&E) on TRL and status of technology development across the hydrogen value chain in Malaysia.	A centralized database & impact tracking system which include monitoring & evaluation components (M&E) on TRL and status of technology development across the hydrogen value chain in Malaysia. Study on the feasibility and identify technologies under pilot study for demonstration projects/scale-up. Develop a framework for each technology across the hydrogen value chain from development to deployment phase.	MOSTI
	1.2 Strengthen regulatory framework, existing policies/act, and legislation.	1.2.1 Establish collaborative platform for a B2B and B2C partnership among local players. (Supporting NEP Action Plan B8)	One (1) collaborative platform that brings together local players to push forward hydrogen economy initiative.	MOSTI

 Source: Hydrogen Energy Technology Roadmap

Assessing regulatory measures and mechanisms to facilitate hydrogen production and consumption

Hydrogen Energy Technology Roadmap (3/12)

Strategies, Action plan and Targets	Strategies	Action Plan	Targets	Champion (Responsible Entity)
	1.2 Strengthen regulatory framework, existing policies/act, and legislation.	1.2.2 Review and identify regulatory measures for the Hydrogen Economy. (Supporting NEP Action Plan B8)	Proposed amendments on regulations to address the usage, licensing, tariff, safety, and standards in the existing Malaysian Gas Supply Act.	Energy Commission
			Development of guidelines for verifiable certification systems and guarantees of origin schemes that allow end-users to know the origin, quality (purity), and life cycle GHG emissions of hydrogen.	Standards Malaysia
			Study and develop guidelines as well as monitor the safety aspects implementation along the hydrogen economy value chain.	DOSH/JKKP
		1.2.3 Enhancement of mechanism to facilitate hydrogen production and consumption in the power sector. (Supporting NEP Action Plan B5 and B6)	Study on potential renewable energy sources that have not been tapped for hydrogen production as an energy storage medium.	NRECC/ Energy Commission
			Study on the allocation of a special tariff for electricity generation from hydrogen using the Green Electricity Tariff (GET) programme for hydrogen production using the allocated hydropower capacity business model.	
			Study and analyze the business model for the implementation of on-site off-grid power generation in reference to the Electricity Supply Act 1990 for hydrogen production based on the industry business model and investment to the allocated green energy funds by considering deregulation of off-grid power generation in the private sector.	
			Roll out feasible and cost-effective technologies related to hydrogen for energy storage solutions.	

 Source: Hydrogen Energy Technology Roadmap

Facilitating hydrogen production and consumption in the power sector and incentivize to phase-out fossil fuel subsidies to promote adoption of hydrogen

Hydrogen Energy Technology Roadmap (4/12)

Strategies, Action plan and Targets	Strategies	Action Plan	Targets	Champion (Responsible Entity)
	1.2 Strengthen regulatory framework, existing policies/act, and legislation.	1.2.3 Enhancement of mechanism to facilitate hydrogen production and consumption in the power sector. (Supporting NEP Action Plan B5 and B6)	Study on the blending of up to 20% hydrogen in Combined Cycle Gas Turbine Power Plant (consideration for the initial 1% blending of hydrogen in retrofitted or retired CCGT power plant).	NRECC/ Energy Commission
			Detailed technical economic feasibility studies to set parameters for hydrogen blending with natural gas in existing pipelines according to the pipeline conditions (e.g., internal pipe wall protection, ancillaries' equipment stability).	Energy Commission
		1.2.4 Adopt and harmonize hydrogen taxonomy, technical code, and safety standards. (Supporting NEP Action Plan B8)	Study and adopt the relevant standards that are applicable across the hydrogen economy value chain to facilitate future flow or trade of hydrogen.	Standards Malaysia
	2.1 Acceleration of hydrogen economy adoption by the local industry sector	2.1.1 Subsidize and incentivize economic sectors that will generate and adopt hydrogen to promote the creation of domestic and export hydrogen economy. (Supporting NEP Action Plan D1)	Phase-out fossil fuel subsidies for diesel vehicles by stages and reallocate to subsidize hydrogen fuel for Commercial and Heavy Vehicles by stages to support the transition from fossil fuels to greener energy for long-term investment.	NRECC

 Source: Hydrogen Energy Technology Roadmap

Supporting hydrogen project, R&D and commercialization through dedicated funding

Hydrogen Energy Technology Roadmap (5/12)

Strategies, Action plan and Targets	Strategies	Action Plan	Targets	Champion (Responsible Entity)
	2.1 Acceleration of hydrogen economy adoption by the local industry sector	2.1.2 Dedicated funding and allocation from focused area budget/grants as a stimulus to support hydrogen initiatives. (Supporting NEP Action Plan E2)	Strengthen international networking to facilitate the provision of international funding and green hydrogen investment projects to spearhead green economy based on hydrogen.	NRECC
			Allocate and review incentives and source funding from agencies (including GITA/GITE and e-dana) to support the hydrogen technologies' innovation, demonstration, and early commercialization projects. Examples of incentives are: i. Purchase subsidy, Exemption of Sales Tax, Excise Duty, Import Duty, and Road tax for FCEV; ii. Green Investment Tax Allowance and Green Income Tax Exemption for Projects and Purchase of Hydrogen Technologies as Assets. iii. Pioneer status and import duty exemption for investment on relevant manufacturing activities.	MoF
		2.1.3 National Hydrogen Fund for hydrogen-related projects and technology at R&D and Commercialization phase from dedicated funding and allocation under focused area budget. (Supporting NEP Action Plan B8)	Green financial instruments with attractive rates to develop the local hydrogen ecosystem and projects, nurturing the sustainability of the green hydrogen economy. Allocation of the fund for the development of strategic hydrogen assets until 2030 (e.g., early phases of hydrogen production and its conversion projects, shared infrastructure, key end-use projects). Feasibility studies on technology, socio-economy, and GHG emissions implication (including lifecycle costing and lifecycle analysis) for hydrogen production, delivery, and end-use sectors for domestic industry development and export market.	MOSTI

 Source: Hydrogen Energy Technology Roadmap

Advancing hydrogen supply chain, development of blue hydrogen with CCUS facility and unlocking hydrogen mobility in Malaysia

Hydrogen Energy Technology Roadmap (6/12)

	Strategies	Action Plan	Targets	Champion (Responsible Entity)
Strategies, Action plan and Targets	2.1 Acceleration of hydrogen economy adoption by the local industry sector.	2.1.4 Develop a portfolio on the stream of feedstock availability and steady supply for hydrogen production. (Supporting NEP Action Plan A6)	Study on the existing renewable sources landscape and perform feasibility studies on the amount of raw feedstock for hydrogen production both at demand and supply sides. Agreement with focused industry sectors for raw material sourcing for hydrogen demonstration projects. Study and analyze the staggered or incentivize pricing for biomass feedstock.	MIPC
		2.1.5 Study on economy feasibility to develop the production of blue hydrogen from natural gas complete with CCS / CCUS facilities to reduce total CO2 emission of the industrial clusters. (Supporting NEP Action Plan A3)	Natural Gas-Steam Methane Reforming-Carbon Capture, Usage and Storage demonstration project (NG-SMR-CCUS) Develop clean industrial clusters that use low-carbon sources including hydrogen, complete with CCS / CCUS facilities to reduce total CO2 emission of the industrial clusters.	Ministry of Economic
		2.1.6 Unlock opportunities from energy-related mobility trends in the heavy vehicles segment and public transport. (Supporting NEP Action Plan B1 and B2)	Track latest developments on various future powertrains for heavy vehicles (e.g., hydrogen, electric, LNG) and determine focus fuel of the future as technology matures. Encourage pilots into various future ministries & agencies. powertrains (e.g., hydrogen trucks / light duty commercial vehicles) in the Peninsular, Sarawak, and Sabah.	MoT

 Source: Hydrogen Energy Technology Roadmap

Accelerating the transition to a low-carbon economy through circular economy and low carbon hydrogen initiatives

Hydrogen Energy Technology Roadmap (7/12)

	Strategies	Action Plan	Targets	Champion (Responsible Entity)
Strategies, Action plan and Targets	2.1 Acceleration of hydrogen economy adoption by the local industry sector.	2.1.7 Comply and capture value pools from international marine bunkering fuel regulations (International Maritime Organization - IMO) (Supporting NEP Action Plan B3)	Determine optimal positioning on fuels of the future (including hydrogen in the form of green ammonia etc.) in view of near-term Sulphur cap and longer-term carbon cap requirements.	MOT
		2.1.8 Keep track on aviation development which affect energy demand. (Supporting NEP Action Plan B4)	Study on the trend and track on the limit of carbon dioxide emission from airline based on Carbon Reduction Scheme for Aviation Industry (CORSIA). Initiate studies to culminate into commercial projects to capture the emerging clean fuels for aviation. Decarbonization of aerospace sector by developing a sustainable ecosystem that involve hydrogen technology through industrial program.	MOT
	2.2 Accelerating transition to the Circular Economy	2.2.1 Feasibility study for Hydrogen Economy adoption by industries through Circular Economy approach. (Supporting NEP Action Plan A6)	Economic study for Circular Economy projects that has proof-of-concept for each targeted industry sector. Hydrogen Economy to be part of the circular bioeconomy for industries that produce biowaste.	MOSTI
	2.3 Low Carbon Hydrogen contributing to GHG mitigation strategies	2.3.1 Implementation of Low Carbon Hydrogen projects that contribute to the Long-Term Low Emissions Development Strategies (LT-LEDS). (Supporting NEP Action Plan C1, Action Plan C3 and Low Carbon Nation Aspiration)	Assessment of low carbon hydrogen initiatives as a potential mitigation action. Assessment of methodology on Low Carbon Hydrogen to be adopted under the international carbon market mechanism.	NRECC

 Source: Hydrogen Energy Technology Roadmap

Advancing hydrogen innovation and economy through build-some, buy-some strategy and development of localized hydrogen infrastructure

Hydrogen Energy Technology Roadmap (8/12)

Strategies, Action plan and Targets	Strategies	Action Plan	Targets	Champion (Responsible Entity)
	3.1 Advancing Research Development Innovation Commercialization and Economy through Build-Some and Buy-Some strategy	3.1.1 Increase RE competitiveness for hydrogen production from renewable sector. (Supporting NEP Action Plan A9, B5)	Demonstration project for hydrogen production through on-site off-grid RE power generation for hydrogen projects.	MOSTI
			Industrial scale project (by local and international players) to be deployed and start commission at potential location that supports export and domestic consumption.	MITI
		3.1.2 Development of localized hydrogen infrastructure for domestic consumption and export purpose. (Supporting NEP Action Plan B8)	Study the low-carbon and hydrogen industrial concept in Malaysia, with targeted industries and segments along the hydrogen economy value chain to be promoted as main domestic hydrogen sector.	MITI
			Participation of local services providers (e.g., services providers of logistics, engineering, construction, O&M) in the development of local projects by international and local hydrogen players.	
			Deployment of hydrogen fuel-cell trucks as the mode to transport hydrogen by truck for decentralized hydrogen production.	
			Decentralized hydrogen production in the early deployment stages of the Hydrogen Economy.	
			Large-scale centralized hydrogen production plants.	

 Source: Hydrogen Energy Technology Roadmap

Hydrogen economy development through technology penetration and integrated low-carbon hydrogen hubs from production to end-use sector

Hydrogen Energy Technology Roadmap (9/12)

Strategies, Action plan and Targets	Strategies	Action Plan	Targets	Champion (Responsible Entity)
	3.1 Advancing Research Development Innovation Commercialization and Economy through Build-Some and Buy-Some strategy	3.1.3 Technology penetration into the market through the Build-Some and Buy-Some approach. (Supporting NEP Action Plan E2)	Analyze the economic viability for technology that has proof-of-concept.	MOSTI
			Develop infrastructure for projects that are at pilot scale with proven proof-of-concept for hydrogen storage and delivery.	
			Public-Private partnership to speed up the technological development of hydrogen fuel cell technologies in strategizing the transition from conventional internal combustion engine (ICE) to fuel cell electric vehicles (FCEVs) technology.	
			Industry to provide facilitation (testing facility) and government to provide fundamental and matching grant according to the TRL of the research/project.	
			Incentives for hydrogen pre-commercialization scale projects.	
		3.1.4 Develop and establish integrated low carbon and hydrogen industrial cluster, and hubs/complex/city at production and the end-use sector.	Hydrogen export to targeted countries from potential terminal ports in Malaysia. (Supporting NEP Action Plan B8)	MITI
			Remote and off-grid hydrogen fuel cells to serve as hydrogen backup power for telecommunication, rural electrification, and manufacturing industries. (Supporting NEP Action Plan B6)	
			Transportation sector networks which include hydrogen pump stations, related infrastructure, and dedicated hydrogen corridors with strategic depots. (Supporting NEP Action Plan B2)	

 Source: Hydrogen Energy Technology Roadmap

Building a competent and adaptive talent for the hydrogen economy through hydrogen-related education and professional training and certification

Hydrogen Energy Technology Roadmap (10/12)

Strategies, Action plan and Targets	Strategies	Action Plan	Targets	Champion (Responsible Entity)
	3.1 Advancing Research Development Innovation Commercialization and Economy through Build-Some and Buy-Some strategy	3.1.4 Develop and establish integrated low carbon and hydrogen industrial cluster, and hubs/complex/city at production and the end-use sector.	Identify new or existing industrial clusters to be further developed with demonstration and/or commercialized low carbon or hydrogen projects for captive production and demand co-location concept (e.g., 2 in Peninsular Malaysia, 1 in Sarawak/Sabah). (Supporting NEP Action Plan D2)	MITI
	4.1 Building a competent and adaptive talent for the Hydrogen Economy	4.1.1 Leverage hydrogen talent development to cater job losses among the low-skilled workers and increase awareness in hydrogen-related education and career pathway. (Supporting NEP Action Plan E3)	Development of syllabus/module for youth program including the Technical and Vocational Education and Training (TVET) on hydrogen technologies.	KBS
			Include performance specification/skills required under National Occupational Skills Standards (NOSS).	MOHR
			Development of green job guideline to increase awareness among graduates from IHLs including TVET.	
			Professional courses on building the hard-core skills for the unemployed and low-income group.	
			Certification of competent personnel for hydrogen jobs under ISO 17024 – Accredited Personnel Certification.	

 Source: Hydrogen Energy Technology Roadmap

Building hydrogen literate workforce through STEM education, transfer of knowledge and enhance public awareness through B2C approach

Hydrogen Energy Technology Roadmap (11/12)

	Strategies	Action Plan	Targets	Champion (Responsible Entity)
Strategies, Action plan and Targets	4.2 Strengthen knowledge for the continuous enhancement of skills for future needs	4.2.2 Develop and introduce a dedicated continuous development program (CPD) in hydrogen for experts and educators that covers from hydrogen value chain, from production to end-use. (Supporting NEP Action Plan E3)	**150 Experts from IHLs. 150 Experts from RIs. 225 Experts from industry.**	MOHR
		4.2.3 Effective and fun STEM Education integrating hydrogen component. (Supporting NEP Action Plan E3)	Training and continuous professional development for STEM teachers on hydrogen economy that meets the criteria for primary and secondary education.	MOE
		4.2.4 Enforce local content and transfer of capability, technology, and knowledge. (Supporting NEP Action Plan E3)	Strategic alliance and licensing for the technology transfer between the research/academia community and local industries.	MOE
			Prioritise specific segments and value chain to develop the capability of SMEs.	MITI
	5.1 Enculturation and Acculturation of Hydrogen Economy	5.1.1 Create awareness to the consumers through the application of hydrogen as fuel in public transport through business-to-consumer approach. (Supporting NEP Action Plan E3)	Business plan on hydrogen application for mobility through demonstration project. Public transport powered by hydrogen fuel cell to be deployed in the Federal Territory.	MOT

 Source: Hydrogen Energy Technology Roadmap

Fostering hydrogen awareness in society through TVET programs, career pathways, and science communication

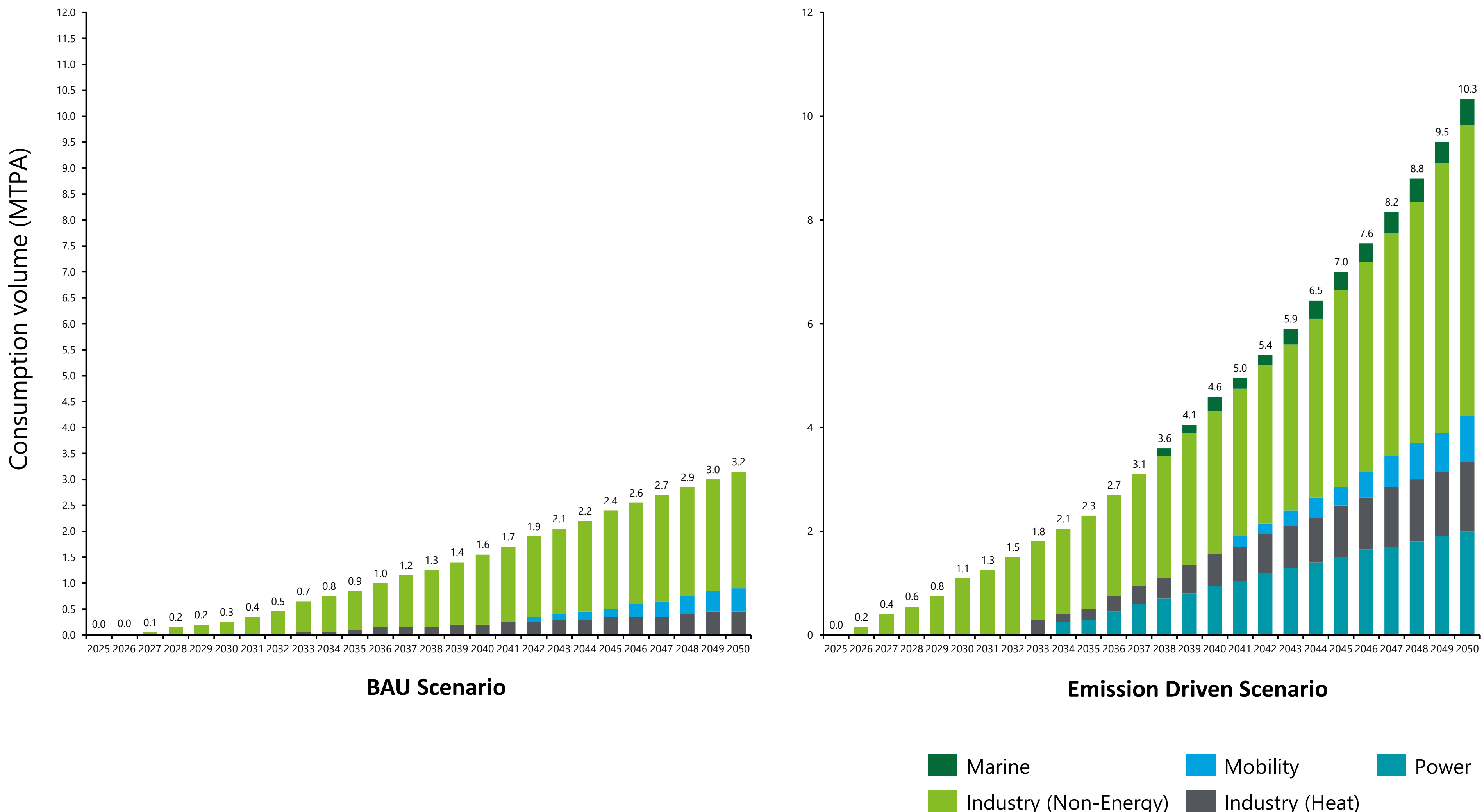
Hydrogen Energy Technology Roadmap (12/12)

Strategies, Action plan and Targets	Strategies	Action Plan	Targets	Champion (Responsible Entity)
	5.1 Enculturation and Acculturation of Hydrogen Economy	5.1.2 Nurture interest and awareness in hydrogen-related education & career pathway through strategic partnership with local and foreign industries. (Supporting NEP Action Plan E3)	Upskill future talent by introducing hydrogen-related courses in Technical and Vocational Education and Training (TVET) programmes. Collaboration between local companies and training institutions to have a National Dual Training System (SLDN) on hydrogen-related job scope. Enculturation and acculturation programmes to inculcate understanding of the hydrogen economy from primary to tertiary level.	MOHE
		5.1.3 Develop understanding through Science Communication on the application of hydrogen. (Supporting NEP Action Plan E3)	Learning through factsheets and other interactive platforms that could have a substantial outreach to the public.	MOSTI

 Source: Hydrogen Energy Technology Roadmap

In HETR, hydrogen consumption of BAU and emission driven scenario are estimated to reach 3.15 and 10.33 MTPA by 2050, respectively

Hydrogen Consumption in End Use Sectors



 Source: Hydrogen Energy Technology Roadmap (2023)

Desktop Research - ①Malaysia

1. Energy trend
2. Outlook for hydrogen
3. Policy
4. **Potential players**
5. Technical readiness roadmap and projects
6. High-level business model (supply chain)
7. Demand Forecast

Malaysia has made headway on several fronts in its foray into a green hydrogen economy

Summary

Current production and use of hydrogen		■ Currently, it is mostly used in **chemical and oil refining sector**
Major hydrogen projects	Production	■ In Sarawak, projects H2ornbill and H2biscus are partnering with Japanese and South Korean firms to produce **100,000 tpa and 220,000 tpa of green hydrogen**, respectively
	Carry, Storage and Supply	■ Sarawak launched Southeast Asia's first integrated hydrogen production plant and refuelling station in **May 2019**
	Use	■ UMW Toyota Motor has provided four units of FCEV (Fuel Cell Electric Vehicles) to SEDC Energy ■ Since February 2020, Sarawak has been testing hydrogen fuel cell buses ■ Presently, in Malaysia, hydrogen is mainly used for industrial purposes, including the chemical and refining, steel making processes ■ As of 2021, thermal capacity represented 55.1% of global power plant installations, with a total of 4,482GW. Malaysia contributed 0.68% to this global thermal capacity.

 Source: To be confirmed, Monitor Deloitte Analysis

Malaysia is positioning Sarawak as the regional hydrogen hub by 2030 through key international partnerships and projects

Key characteristics of a hydrogen hub

Hydrogen Hub

Significant scale

Embarking on double-digit multi-million ringgit investment projects that extend beyond the pilot stages and demonstrations

Broad value chain coverage

Covering multiple steps in the value chain, from hydrogen production to storage, transport, and off-take

Multi-sector supply

Showcasing the versatility of hydrogen by catering to more than one end sector or application in the transport, industry, and power sectors

Defined geographical scope

Establishing hydrogen ecosystems that cover specific geographical areas, from local/regional activities to international outreach

 Source: National Energy Transition Roadmap

Companies in Malaysia are actively engaged to develop a robust and competitive hydrogen ecosystem

Criteria to select companies

1. Desktop study on currently active projects (see ①-5. Technical readiness roadmap and projects), 2. companies listed up in HETR (2023), 3. suggested through interviews to both Malaysian and Japanese interviewees

Local hydrogen player map in Malaysia*1

Produce

Water electrolysis
- PETRONAS
- sarawak energy
- SEDC ENERGY
- TENAGA NASIONAL
- gentari

SMR (biogas) *2
- SEDC ENERGY
- SIRIM
- PETRONAS

SMR (fossil fuel) + CCUS
- TENAGA NASIONAL
- PETRONAS

By-product (chemical, steel caustic soda)
- PETRONAS
- ORIENTAL SHIELD
- ccm

Transport + Carry + Storage

Compressed hydrogen
- UMW

Pipeline
- PETRONAS
- TENAGA NASIONAL

Li-H2 *3
- SEDC ENERGY

Alloy
N/A

MCH *3
- SEDC ENERGY
- PETRONAS

NH3 *3
- SEDC ENERGY
- gentari

Solid-state *4 (NaBH4)
- GALAXY FCT (H_2 in SOLID)

Supply

Hydrogen refueling station

Operator
- gentari
- PETRONAS
- NANOMALAYSIA

Regulator*5
- Suruhanjaya Tenaga Energy Commission
- ENERGY COMMISSION OF SABAH
- Ministry of Utility and Telecommunication SARAWAK

Utilization

Transport
- SEDC ENERGY
- Sime Darby Motors
- UMW

Chemical feedstock
- PETRONAS
- gentari

Refinery
- PETRONAS

Fertilizer
- PETRONAS (PCF)
- AGROMATE
- bm BEHN MEYER Since 1840

Steel (hydrogen reduction)
N/A

Stationary fuel cell
N/A
- SEDC ENERGY

Boiler
N/A

Thermal power plant
- TENAGA NASIONAL
- SEDC ENERGY
- sarawak energy

*1: Note that hydrogen players do not just include players that have core technologies but also those who are engaged with related projects. *2: Proof of concept in Sarawak *3: Hydrogen careers that are likely to be options for hydrogen shipping. *4: Galaxy FCT: Start up mentioned in HETR *5: Potential regulator for hydrogen energy in Malaysia. Note: With reference to the Hydrogen Energy Technology Roadmap players' map

The local hydrogen ecosystem is advancing, with a growing involvement of international companies (JP, KR, AU) in this domain

Criteria to select companies

1. Desktop study on currently active projects (see ①-5. Technical readiness roadmap and projects), 2. companies listed up in HETR (2023), 3. suggested through interviews to both Malaysian and Japanese interviewees

External/global hydrogen player map in Malaysia

Produce

Water electrolysis
- Linde
- Thales New Energy
- Air Liquide
- POSCO Holdings
- HDC
- Samsung
- Samsung Engineering
- ENEOS
- Siemens Energy
- Asahi KASEI
- Lotte Chemical
- Sumitomo Corporation

SMR (biogas)*3
- IHI

SMR (fossil fuel) + CCUS
- CityEnergy
- ENEOS
- Air Products
- Air Liquide
- Linde

By-product (chemical, steel, caustic soda)
- Malay-Sino Chemical Industries Sendirian Berhad (197301002584 (16055-T))

Transport + Carry + Storage

Compressed hydrogen
- Linde
- Air Products

Pipeline
- Linde
- CityEnergy
- Air Products

Li-H2 *2
- Air Products
- Hydrexia
- Air Liquide

Alloy
N/A

MCH *1
- Sumitomo Corporation
- ENEOS

NH3 *1
- Samsung
- Samsung Engineering
- POSCO Holdings
- Lotte Chemical
- IHI
- HDC
- Thales New Energy

Solid-state *4 (NaBH4)
N/A

Supply

Hydrogen refueling station

Operator
- CityEnergy
- Linde
- ENEOS
- Hydrexia
- Air Products

Regulator
N/A

Utilization

Transport
- Toyota
- HDC

Chemical feedstock
N/A

Refinery
N/A

Steel (hydrogen reduction)
N/A

Stationary fuel cell
- Air Liquide
- HDC

Boiler
- Miura

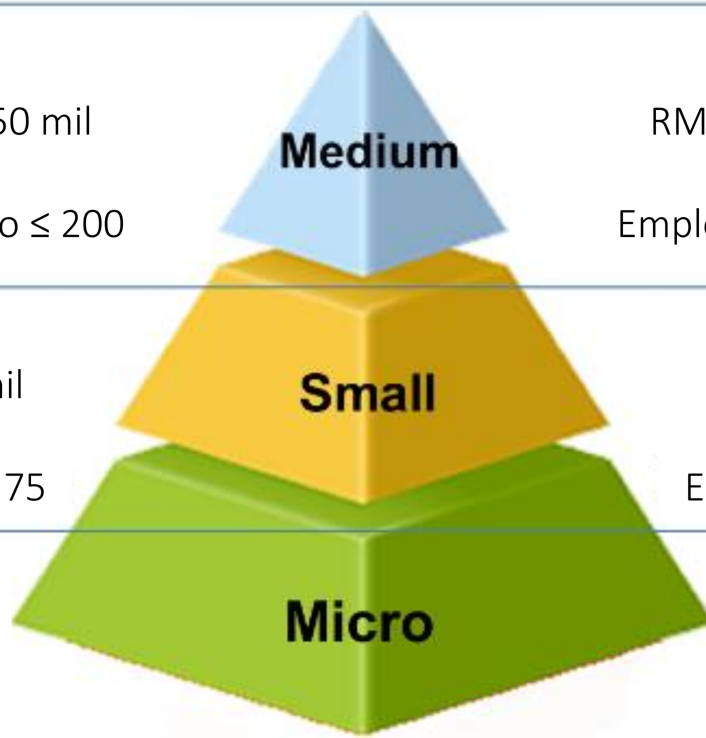
Thermal power plant (including GT)
- JERA
- IHI
- Mitsubishi Heavy Industries
- Kawasaki (Powering your potential)

*1: *2: Hydrogen careers that are likely to be options for hydrogen shipping, *3: potential e-methane producer

Note: With reference to the Hydrogen Energy Technology Roadmap players' map

Reference

SME Definition in Malaysia



Manufacturing	Services and Other Sectors
Sales turnover: RM 15 mil to ≤ RM 50 mil <u>OR</u> Employees: From 75 to ≤ 200	Sales turnover: RM 3 mil to ≤ RM 20 mil <u>OR</u> Employees: From 30 to ≤ 75
Sales turnover: RM 300k to < RM 15 mil <u>OR</u> Employees: From 5 to ≤ 75	Sales turnover: RM 300k to < RM 3 mil <u>OR</u> Employees: From 5 to ≤ 30
Sales turnover: < RM 300k <u>OR</u> Employees: < 5	Sales turnover: < RM 300k <u>OR</u> Employees: < 5

 Source: SME Corporation Malaysia

Desktop Research - ①Malaysia

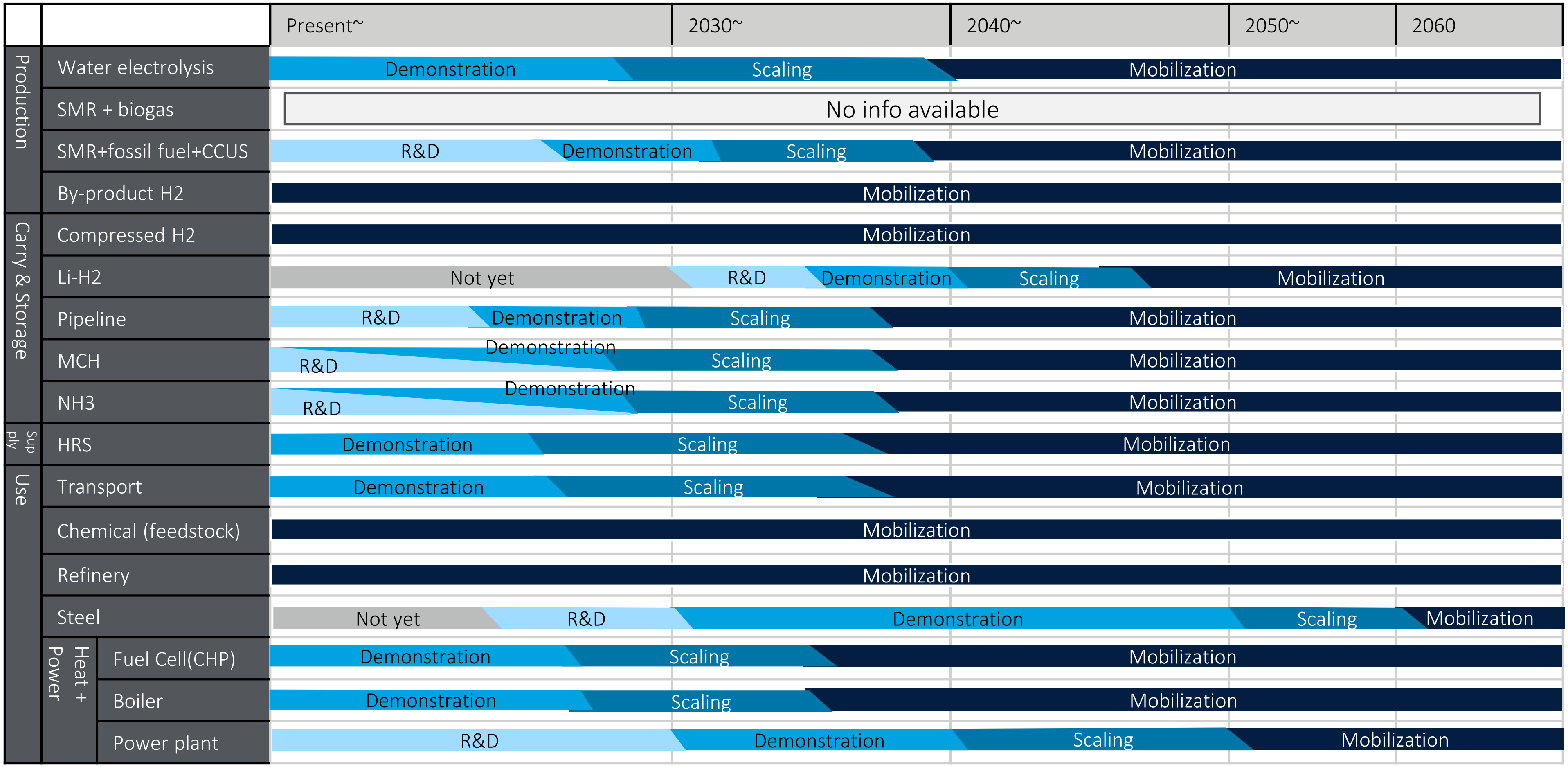
1. Energy trend
2. Outlook for hydrogen
3. Policy
4. Potential players
5. **Technical readiness roadmap and projects**
6. High-level business model (supply chain)
7. Demand Forecast

Multiple hydrogen production and utilization options could be available in 2030s in scaling status

Technical readiness of hydrogen in Malaysia

Status: Not yet | R&D | Demonstration | Scaling | Mobilization

This chart was created by the information on **current technical readiness of each technology** and a **target set by its front runners**. The information was collected by desktop research and the interviews. When a target is not set, the starting point and duration for each status of a technology were projected **based on the Japanese technology development vision** shown by the government. Mobilization status is assumed as commercial mobilization. (see P 93 for more status details)



*Note that policies are assumed to be favorable to hydrogen technologies)

Reference

Technical Readiness & Players in Hydrogen Industry

Definition of technical readiness status

Status	Description
■ Not yet	■ No program and/or initiatives has been introduced yet ■ Non-existent to minor interest to the topic, with no clear, detailed plans
■ R&D (Research and Development)	■ There has been initial research, study, and/or regulatory drafts regarding the topics ■ Clear, detailed plans within the research that include future trial project
■ Demonstration	■ Several trial projects has been conducted to study the topics ■ The trial produced both quantitative & qualitative results as initial implementation regarding the topics
■ Scaling	■ Advanced study to accelerate it into larger scales ■ Clear, detailed plans on how to scale-up results from trial, detailed in quantitative & qualitative metrics
■ Mobilization	■ Technology has been fully implemented and/or operated on daily basis, meaning commercial mobilization.

Water electrolysis and SMR+CCUS are in demonstration and R&D stage respectively, while no information is available about SMR+biogas

Hydrogen Production in Malaysia (1/2)

Status: Not yet | R&D | Demonstration | scaling | mobilization

	Water electrolysis	SMR + biogas	SMR (fossil fuel) + CCUS
Status	Demonstration	Not yet	R&D
Status Detail	**Local companies** signed MoU with multiple international companies to **study the production of green hydrogen for domestic use and export purposes**	No known public information on SMR (biogas) in Malaysia	PETRONAS signed an MOU with TNB to study about green energy technologies, in which **CCUS is one of the topics for collaborative studies**
Challenge	Some challenges, which include: 1) Limited infrastructure readiness 2) Incentives & technology uncertainty 3) Limitations in regulatory support & technical standard	Some challenges, which include: 1) Incentives & technology uncertainty 2) Limitations in regulatory support & technical standard 3) Negative perspective towards waste-to-energy	Some challenges, which include: 1) Limited infrastructure readiness 2) Incentives & technology uncertainty 3) Limitations in regulatory support & technical standard
Potential	The federal government has laid out several strategies to develop a robust and competitive hydrogen ecosystem, **with a forecast amount of US$3.1 billion or two percent by 2030**	No known public information about potential while HETR mentions the future possibility of the technology	Leveraging on the strengths of both TNB and PETRONAS, the study serves as a **unique pioneering project in deploying green technologies that may be utilised in future power plants**
Player	1. PETRONAS 2. Sarawak Energy 3. SEDC Energy 4. TNB 5. Gentari 6. Samsung Engineering 7. Lotte Chemical 8. Posco Holdings 9. ENEOS 10. IHI Corporation 11. H2X Global 12. Thales New Energy	No known public information about potential	1. PETRONAS 2. TNB 3. City Energy 4. ENEOS

Source: Several news article

Byproduct hydrogen in chemical and other industries have already been utilized in their process

Hydrogen Production in Malaysia (2/2)

Status: Not yet | R&D | Demonstration | scaling | mobilization

	Byproduct (chemical and steel)
Status	Mobilization
Status Detail	1. Currently, Malaysia produces 660,000 barrels of liquids and approximately 7.0 billion cubic feet of gas per day. 2. As of 2022, Malaysia produced approximately 10 million tones of crude steel.
Challenge	1. Less incentives for hydrogen utilizations 2. High cost to reduce emissions from steel and oil industries
Potential	Currently, hydrogen is produced as a by-product of oil and steel production. The hydrogen (by-product) is reused in refining oil and gas, the production of fertilizers and in some food processes.
Player	1. PETRONAS 2. WenAn Steel 3. Alliance Steel 4. Oriental Shield 5. Eastern Steel

Source: PETRONAS' website, World Steel Association, South East Asia Iron and Steel Institute, The Edge Malaysia

Compressed Hydrogen is commercially distributed, Li-H2 Pipeline in R&D phase, and pipeline in R&D phase in Malaysia

Hydrogen Carry and Storage in Malaysia (1/3)

Status: Not yet | R&D | Demonstration | scaling | mobilization

	Compressed hydrogen	Li-H2	pipeline
Status	Mobilization	Not yet	R&D
Status Detail	Some hydrogen manufacturers supply hydrogen in compressed hydrogen form.	No known public information on liquid hydrogen in Malaysia	Gentari and City Energy (Singapore's sole piped town gas provider) signed a MoU to **explore importing hydrogen from Malaysia to Singapore** (no detailed information is available yet)
Challenge	Some challenges, which include: *1 1. Expensive method of transport, which increase hydrogen price 2. Limited development plan for hydrogen infrastructure by government	Some challenges, which include: *2 1. High R&D cost 2. Limited expert and knowledge 3. Limited incentive from the government	Some challenges, which include: *2 1. High R&D cost 2. Limited expert and knowledge 3. Limited incentive from the government
Potential	This method has long been used with other gases	No known public information about potential	City Energy is well placed to **establish a hydrogen supply for the future production of Singapore's town gas** (City Energy currently powers more than 880,000 homes and businesses in Singapore)
Player	1. Linde	No known public information about player	1. PETRONAS 2. TNB 3. Gentari 4. City Energy

*Source: *1 Global Hydrogen Review by IEA 2022 (Global Hydrogen Review 2022 (windows.net) , *2 Global Hydrogen Trade to Meet The 1.5 C Climate Goal by IRENA 2022 (Global hydrogen trade to meet the 1.5℃ climate goal: Trade outlook for 2050 and way forward (irena.org)*

Remarkable projects for MCH and NH3 completed FS in 2023 and is under consideration to shift next stage while there is no information about alloy

Hydrogen Carry and Storage in Malaysia (2/3)

Status: Not yet | R&D | Demonstration | scaling | mobilization

	Alloy	MCH	NH3
Status	Not yet	R&D or Demonstration	R&D or Demonstration
Status Detail	No known public information on Alloy	Sarawak and two other Japanese companies have **completed feasibility studies for H2ornbill project and is expected to proceed to the FEED design**	Sarawak and three other Korean companies have **completed feasibility studies for H2biscus project and is expected to proceed to the FEED design**
Challenge	Some challenges, which include: *1 1. High R&D cost 2. Limited expert and knowledge 3. Limited incentive from the government	Some challenges, which include: *1 1. High R&D cost 2. Limited expert and knowledge 3. Limited incentive from the government	Some challenges, which include: *1 1. High R&D cost 2. Limited expert and knowledge 3. Limited incentive from the government
Potential	No known public information about its potential	The developers also target green hydrogen production from hydroelectric power and aim to **ship the output to Japan using methylcyclohexane (MCH) as a carrier**	A large-scale project for **hydrogen production for conversion to ammonia that will be exported to South Korea**
Player	No known public information about player	1. Sarawak Energy 2. SEDC Energy 3. Sumitomo Corporation 4. ENEOS	1. Sarawak Energy 2. SEDC Energy 3. Samsung Engineering 4. LOTTE Chemical 5. POSCO Holdings

*Source: *1 Global Hydrogen Trade to Meet The 1.5 C Climate Goal by IRENA 2022 (Global hydrogen trade to meet the 1.5 ℃ climate goal: Trade outlook for 2050 and way forward (irena.org)*

Synthesis CH4 seem to be not yet available in Malaysia

Hydrogen Carry and Storage in Malaysia (3/3)

Status: Not yet | R&D | Demonstration | scaling | mobilization

	Synthesis CH4
Status	Not yet
Status Detail	No known public information on synthesis CH4
Challenge	Some challenges, which include: *1 1. High R&D cost 2. Limited expert and knowledge 3. Limited incentive from the government
Potential	No known public information about its potential
Player	No known public information about player

*Source: *1 Global Hydrogen Trade to Meet The 1.5 C Climate Goal by IRENA 2022 (Global hydrogen trade to meet the 1.5 ℃ climate goal: Trade outlook for 2050 and way forward (irena.org)*

Hydrogen refueling station is in demonstration status, with Southeast Asia's first integrated hydrogen refueling station launched in Sarawak

Hydrogen Supply in Malaysia

Status: Not yet | R&D | Demonstration | scaling | mobilization

	Hydrogen Refueling Station
Status	Demonstration
Status Detail	1. Sarawak launched its first multi-fuel station, which caters to vehicles powered by electricity or hydrogen. 2. Peninsular Malaysia's first hydrogen fuel station is coming
Challenge	Some challenges, which include: *2 1. Limited hydrogen demand due to hydrogen-powered car is not widely used in Malaysia
Potential	1. Results from the prototype station can be used to improve hydrogen stations in the future 2. It can potentially be scaled if there is enough demand
Player	1. PETRONAS 2. Gentari 3. NanoMalaysia 4. City Energy 5. Hydrexia

*Source: *1 Various News Articles (Thailand to launch its first hydrogen filling station in Pattaya by year end - The Pattaya News) *2 Thailand's Public Company Limited (PTT) Company Articles (PTT Public Company Limited: News : Launching Thailand's first hydrogen fueling prototype station, "PTT - OR - TOYOTA - BIG" joins forces to embark on future energy. (pttplc.com)*

Transportation sector is demonstrating hydrogen utilization in Sarawak and is ready for demonstration in P. Malaysia

Hydrogen Utilization in Malaysia

Status: Not yet | R&D | Demonstration | scaling | mobilization

	Transportation	Chemical (feedstock)	Refinery
Status	Demonstration	Mobilization	Mobilization
Status Detail	1. **UMW Toyota Motor hands over four units of FCEV to SEDC Energy** 2. **Sarawak started pilot testing hydrogen fuel cell buses in February 2020** 3. There is refilling station demonstration is planned in the northern part of P. Malaysia	1. Currently, hydrogen utilization is almost completely for the chemical and refining, steel making process, and other industrial purposes	1. Currently, hydrogen utilization is almost completely for the chemical and refining, steel making process, and other industrial purposes
Challenge	Some challenges, which include: *2 1) Limited expert & knowledge	Some challenges, which include: *1 1) Lack of policies that promote hydrogen development	Some challenges, which include: *1 1) Lack of policies that promote hydrogen development
Potential	Sarawak is in the position to produce hydrogen, which in the future will be required in large quantities. **There will be a lot of demand when everybody starts to convert their vehicles into fuel cell vehicles**	1. BNEF report predicts that by 2050, green hydrogen could be the cheapest production method for steel. 2. Malaysia can use hydrogen as a feedstock for chemical industries.	Malaysia produces 660,000 barrels of liquids and approximately 7.0 billion cubic feet of gas per day. The country's remaining commercial reserves are estimated at over 17 billion barrels of oil equivalent from more than 400 fields, with gas making up three-fourths of the mix
Player	1. SEDC Energy 2. UMW 3. Toyota 4. H2X	1. PETRONAS 2. CCM Chemicals 3. ASEAN Bintulu Fertilizers	1. PETRONAS

*Source: *1 Global Hydrogen Trade by IRENA 2022 (Global hydrogen trade to meet the 1.5℃ climate goal: Trade outlook for 2050 and way forward (irena.org) *2 Various News Articles (Hydrogen for ASEAN Countries' Clean Energy Transition in Road Transport Sector - News and Views : ERIA, The Future Lies In : EV? or FCEV? – Hyundai Motor Group TECH)*

There is no specific information available for these three sectors

Hydrogen Utilization in Malaysia

Status: Not yet | R&D | Demonstration | scaling | mobilization

	Steel	Fuel cell (CHP)	Boiler
Status	Not yet	Not yet	Not yet
Status Detail	No known public information on steel	No public information available	No known public information on boiler
Challenge	Some challenges, which include: *1 1. High R&D cost 2. Limited expert and knowledge 3. Limited incentive from the government	1. High investment cost*2	Some challenges, which include: *1 1. High R&D cost 2. Limited expert and knowledge 3. Limited incentive from the government
Potential	Not known public information about its potential	No public information available	Not known public information about its potential
Player	Not known public information about its player	No public information available	Not known public information about its player

*Source: *1 Global Hydrogen Trade to Meet The 1.5 C Climate Goal by IRENA 2022 (Global hydrogen trade to meet the 1.5 ℃ climate goal: Trade outlook for 2050 and way forward (irena.org) *2 EGAT and Thailand Construction and Engineering News*

Multiple feasibility study has being conducted for power plants in Malaysia, whereas no specific information is available for e-fuel

Hydrogen Utilization in Malaysia

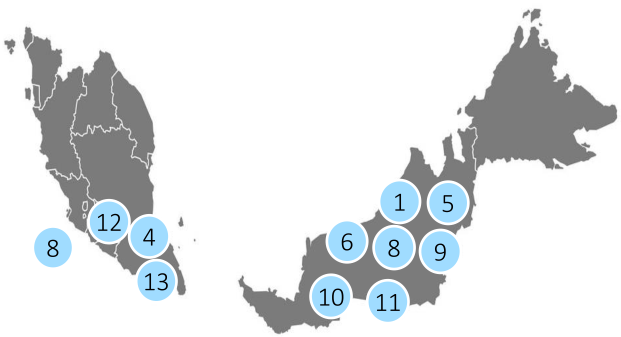
Status: Not yet | R&D | Demonstration | scaling | mobilization

	Power Generation	e-fuel
Status	R&D	Not yet
Status Detail	Thermal capacity accounted for 55.1% of total power plant installations globally in 2021, according to GlobalData, with total recorded thermal capacity of 4,482GW. Of the total global thermal capacity, 0.68% is in Malaysia.	No known public information on e-fuel
Challenge	Some challenges, which include: *1 1. High R&D cost 2. Limited expert and knowledge 3. Limited incentive from the government 4. Procurement of large volume of Hydrogen Consumption	Some challenges, which include: *1 1. High R&D cost 2. Limited expert and knowledge 3. Limited incentive from the government
Potential	1. As part of Malaysia's effort to integrate hydrogen into its energy mix, hydrogen can be used across multiple sectors, including electricity generation. 2. Between 2050 and 2060, fuel cell-based power stations are anticipated to replace ageing thermal power plants.	No known public information about its potential
Player	1. TNB 2. Sarawak Energy Berhad 3. Sabah Electricity Sdn. Bhd. 4. IHI 5. ITOCHU 6. MHI	No known public information about player

*Source: *1 Global Hydrogen Trade to Meet The 1.5 C Climate Goal by IRENA 2022 (Global hydrogen trade to meet the 1.5 ℃ climate goal: Trade outlook for 2050 and way forward (irena.org)*

Malaysia is currently bustling with multiple ongoing projects, and notably, Sarawak is emerging as the leading regional green hydrogen hub

Hydrogen Project Map of Malaysia



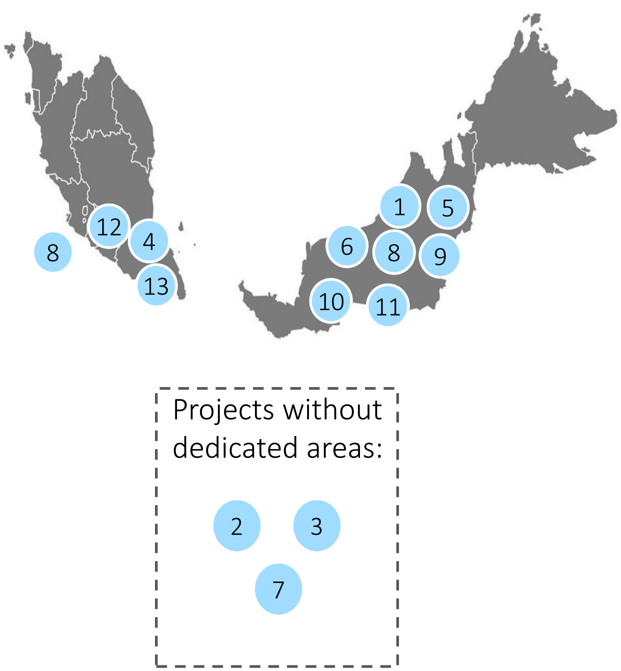
Projects without dedicated areas:

2 3 7

#	Name of project	Country	Supply chain: Production	Supply chain: Carry/transport	Supply chain: Use	Status: Agreement	Status: R&D	Status: FS	Status: Demo	Status: Commercial
1	Collaborative Study for Green Hydrogen Ecosystem and Carbon Capture and Storage (CCS) Technology	MY	●	●	●	▬	▬	▬		
2	Feasibility Study on Green Ammonia Production and Sales	JP	●	●	●	▬	▬	▬		
3	Feasibility Studies on Malaysia-Singapore Hydrogen Supply Chain	SG	●	●		▬	▬	▬		
4	H2biscus Project	KR	●	●		▬	▬	▬		
5	H2ornbill Project	JP	●	●		▬	▬	▬		
6	Technical-Commercial Joint-Study to Develop Malaysia-Japan Hydrogen Supply Chain	JP	●	●		▬	▬	▬		
7	Samalaju Hydrogen Production Plant	AU /FR	●	●		▬				
8	Rembus Hydrogen Production Plant and Refueling Station	MY	●		●	▬	▬	▬	▬	
9	Strategic Collaboration on Deploying Clean Energy Solutions	MY	●		●	▬				
10	Hydrogen Refueling Station and Hydrogen Storage	AU		●	●	▬				

Malaysia is currently bustling with multiple ongoing projects, and notably, Sarawak is emerging as the leading regional green hydrogen hub

Hydrogen Project Map of Malaysia



#	Name of project	Country	Supply chain: Production	Supply chain: Carry/transport	Supply chain: Use	Status: Agreement	Status: R&D	Status: FS	Status: Demo	Status: Commercial
11	Hydrogen Fuel Cell Vehicle Production	AU	●							
12	Mobile Hydrogen Refueling Station	MY			●					
13	Feasibility study for decarbonization by utilizing hydrogen/ammonia	JP	●	●	●					

TNB and PETRONAS have signed a MoU to advance hydrogen economy

Collaboration Study on Green Hydrogen and CCS

1

Name of project	N/A
Period	MoU was signed in August 2022
Place	Malaysia
Partners	■ TNB (Tenaga Nasional Berhad) ■ PETRONAS
Purpose	■ To conduct a collaborative study for the development of green hydrogen ecosystem and carbon capture and storage (CCS) technology leveraging both organisations' technical expertise and resources
Budget	■ N/A
Future plan	■ In a significant step towards decarbonizing the energy sector, Malaysia's Tenaga Nasional Bhd (TNB) and Petronas have signed a Joint Feasibility Study Agreement (JFSA) to explore and develop business ventures in the field of green hydrogen

Images

 Source: Several news article

IHI and Gentari sign MoU to explore green ammonia production and sales in Malaysia

Green Ammonia Production and Sales

2

Name of project	N/A
Period	MoU was signed in December 2022
Place	Johor
Partners	■ IHI Corporation *(Japan)* ■ Gentari
Purpose	■ To evaluate the feasibility of leveraging the abundant solar resources of Malaysia to produce and sell green ammonia derived from renewables ■ The green ammonia produced will be used for power generation and marine fuel supply
Budget	■ N/A
Future plan	■ Through this feasibility exploration, IHI and Gentari aim to demonstrate several ammonia application models in Malaysia and build a fuel ammonia supply chain to address the future increase of clean fuel demand

Images

 Source: Several news article

Gentari has signed a MoU with City Energy to explore Malaysia-Singapore hydrogen supply chain

Feasibility Studies on Hydrogen Supply Chain

3

Name of project	N/A
Period	MoU was signed in April 2023
Place	Malaysia and Singapore
Partners	■ Gentari (subsidiary company of PETRONAS) ■ City Energy (*Singapore)*
Purpose	■ To conduct feasibility studies of a hydrogen supply chain from Malaysia to Singapore ■ To deepen understanding of the EV market and behaviour of EV users in Singapore and Malaysia, while co-deploying publicly accessible EV chargers on each other's EV networks
Budget	■ N/A
Future plan	■ N/A

Images

(From left) Gentari head of H2 marketing Ariff Adry Adnan, chief hydrogen officer Michèle Azalbert, City Energy CEO Perry Ong and president of strategic planning Desmond Tay

 Source: Several news article

Sarawak ties up with 3 South Korean multinationals to develop a green hydrogen derivative

Green Hydrogen Manufacturing Project (1/2)

4

Name of project	H2biscus Project
Period	2022 - 2027
Place	Bintulu Petchem Industrial Park in Sarawak
Partners	■ Samsung Engineering *(South Korea)* ■ SEDC Energy ■ Sarawak Energy Berhad ■ LOTTE Chemical *(South Korea)* ■ POSCO Holdings *(South Korea)*
Purpose	■ H2biscus project is expected to produce 220,000 tonnes of green hydrogen (the bulk of green hydrogen produced will be exported to South Korea, with 7,000 tonnes being for Sarawak's domestic use), 600,000 tonnes per annum of blue ammonia, 630,000 tonnes per year of green ammonia and 460,000 tonnes per year of green methanol; the power source is coming from hydroelectric power plants in Sarawak
Budget	■ Final investment decision is expected to be made in the first quarter of 2024 (1Q24)
Future plan	■ The plant will also create new hydrogen-based industries such as the manufacturing of electrolyzers, fuel cells and the green chemical industry

Images

 Source: Several news article

H2biscus is a G2G hydrogen project to drive sustainable development in Sarawak and achieve carbon neutrality in South Korea

Green Hydrogen Manufacturing Project (2/2)

4

Name of project	H2biscus Project
Period	2022 - 2027
Place	Bintulu Petchem Industrial Park in Sarawak

Entities	Project Interest
Samsung Engineering	H2biscus project will strengthen Samsung Engineering's status as a 'green solution provider' through strategic alliances and technology acquisition in the field
Lotte Chemical	Lotte Chemical aims to turn hydrogen into ammonia and bring it to South Korea for use at hydrogen fueling stations
POSCO	POSCO plans to use hydrogen for "greening" its steel business
Korea	The H2biscus project will contribute to the achievement of the Korean carbon neutrality goal and vitalization of the hydrogen economy
Sarawak	Sarawak set to become Malaysia's green hydrogen production export hub by 2027 with H2biscus project. The project will serve as for renewable energy trading and hydrogen transportation between Korea and Malaysia

Images

Samsung Engineering president Sungan Choi **presented H2biscus project to the president and ministers of Korea** to highlight project will contribute to reducing Korea's carbon emissions and revitalizing the hydrogen economy

Samsung Engineering, POSCO and Lotte Chemical will be taking an active role in developing the entire cycle of the project, which includes direct investment, construction, transportation and utilization

 Source: Several news article

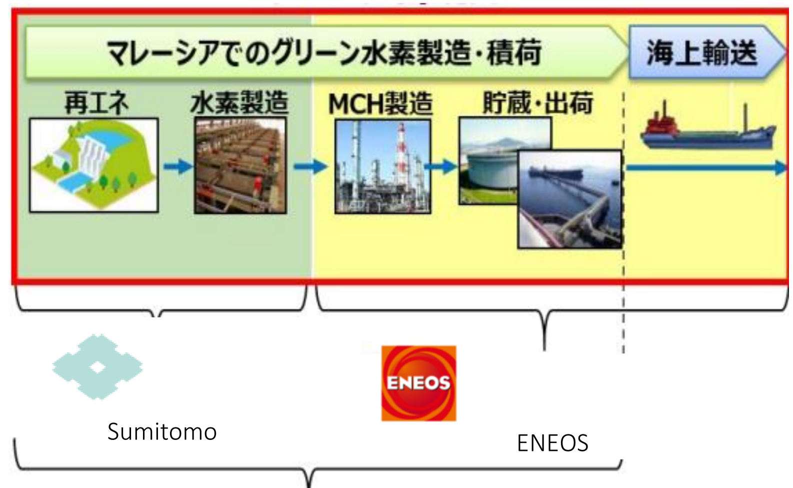
Sarawak is collaborating with 2 Japanese companies to venture into large-scale production of green hydrogen

Green Hydrogen Manufacturing Project

5

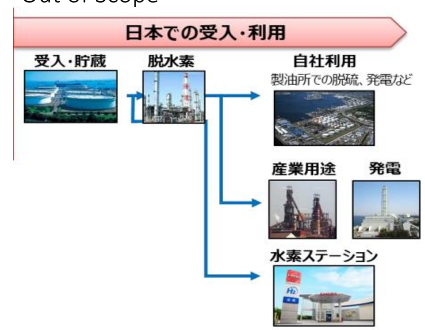
Name of project	H2ornbill Project
Period	Project completion is expected to be in 2027
Place	Bintulu Petchem Industrial Park in Sarawak
Partners	■ SEDC Energy ■ Sumitomo Corp *(Japan)* ■ ENEOS *(Japan)*
Purpose	■ The project aims to develop i) dehydrogenation technology for MCH(Methylcyclohexane) carrier, and ii) build green hydrogen supply chain by MCH carrier (considering export). ■ The production target of the projects are; 3,000 tpa by 2023, 10,000 tpa by 2025, and 100,000 tpa by 2030.
Budget	■ Final investment decision is expected to be made in the second quarter of 2025 (2Q25)
Future plan	■ Other than producing green hydrogen, the plant will also create new hydrogen-based industries such as the manufacturing of electrolyzers, fuel cells and the green chemical industry

Images



Supported by SEDC for site selection, EIA, Building Partnership with local stake holders etc

Out of Scope



 Source: Several news article

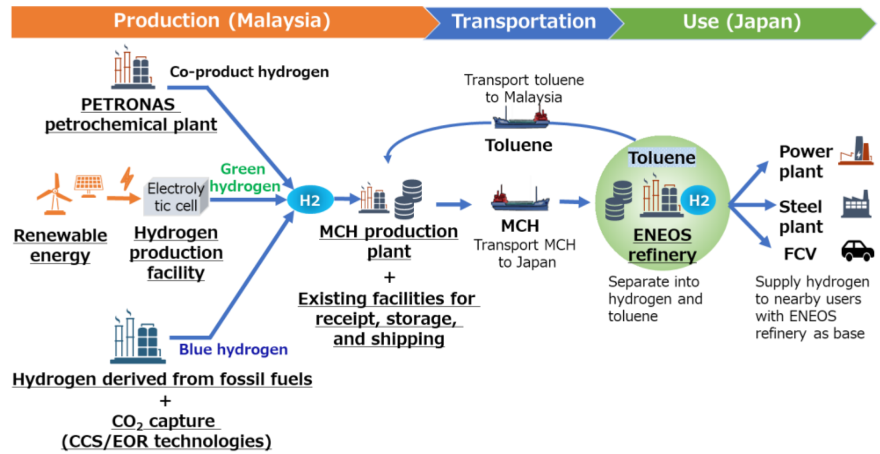
PETRONAS and ENEOS expand energy partnership to include hydrogen business

Technical-Commercial Joint-Study

6

Name of project	N/A
Period	MoU was signed in September 2021
Place	Malaysia
Partners	■ PETRONAS ■ ENEOS
Purpose	■ To jointly develop a competitive, clean hydrogen supply chain between Malaysia and Japan, and to explore other hydrogen opportunities, which include hydrogen production and its transportation in methylcyclohexane (MCH) form
Budget	■ N/A
Future plan	■ To sign a Joint Feasibility Study Agreement (JFSA) to advance the studies for a commercial hydrogen production and conversion project in Kerteh, Terengganu

Images



Overview of potential collaboration

 Source: Several news article

Joint venture formed to develop 1.3 GW hydrogen export facility in Malaysia

Hydrogen Export Facility

7

Name of project	Samalaju Hydrogen Production Plant
Period	MoU was signed in November 2021
Place	Sarawak
Partners	■ SEDC Energy ■ H2X Global *(Australia)* ■ Thales New Energy *(France)*
Purpose	■ To produce gigawatt-scale green ammonia and hydrogen with an eye for export by 2024/25; capable of producing as much as 170,000 tonnes per year of liquid hydrogen or 970,000 tonnes per year of ammonia ■ The facility will generate green hydrogen using electrolysis powered by hydroelectricity and will be constructed in the newly constructed Samalaju Industrial Park and Port
Budget	■ N/A
Future plan	■ Given the scale of the project the parties will also look to develop local electrolyser build capabilities in Sarawak

Images

 Source: Several news article

Sarawak launches Southeast Asia's first integrated hydrogen production plant and refueling station, which unveils hydrogen buses

Hydrogen Production Plant and Refueling Station

8

Name of project	Rembus Hydrogen Production Plant
Period	The project is expected to be completed in 2025 (May 2019～)
Place	Sarawak
Partners	■ SEDC Energy
Purpose	■ To support the Kuching Urban Transportation System (KUTS) which promote the use of hydrogen fuel cell buses ■ To produce up to 130kg of hydrogen per day and can support and fully refueling up to 5 fuel cell buses and 10 fuel cell cars per day
Budget	■ N/A
Future plan	■ N/A

Images

Yang Amat Berhormat Datuk Patinggi Abang Haji Abdul Rahman Zohari Tun Bin Datuk Abang Haji Openg, Chief Minister of Sarawak (3rd from right) and other dignitaries posing with one of Sarawak Energy's hydrogen-powered Hyundai NEXOs

 Source: Several news article

Gentari partners with Sarawak Energy and SEDC Energy for hydrogen production and EV charging network in Sarawak

Collaboration on Deploying Clean Energy

9

Name of project	N/A
Period	Signing ceremony on strategic collaboration agreements occurred in June 2023
Place	Sarawak
Partners	■ Gentari ■ Sarawak Energy Berhad ■ SEDC Energy
Purpose	■ To explore potential opportunities for collaboration in developing and deploying clean energy solutions in Sarawak ■ To focus on green hydrogen production through optimizing Sarawak's renewable resources ■ To diversify Sarawak's energy mix
Budget	■ N/A
Future plan	■ To foster a greener and more energy resilient future for the state, besides positioning Sarawak as a regional leader in clean energy, with a focus on the green hydrogen sector

Images

 Source: Several news article

Hydrexia and SEDC Energy sign MoU on hydrogen cooperation in Malaysia including capacity building programs

Hydrogen Refueling Station and Hydrogen Storage

10

Name of project	N/A
Period	MoU was signed in April 2023
Place	Sarawak
Partners	■ SEDC Energy ■ Hydrexia *(Australia)*
Purpose	■ SEDC Energy recognises the potential benefits of Hydrexia's technology and intends to collaborate with Hydrexia in hydrogen production, distribution, storage, and transportation infrastructure. The cooperation mainly includes: (1) Hydrexia's Participation in SEDCE Projects (2) Metal Hydride Hydrogen Storage Technology (MHX) Application (3) Adoption of Hydrogen Refueling Station Information Management System—H_2Meta
Budget	■ N/A
Future plan	■ Hydrexia will also provide training and technical support to SEDC Energy staff at the commencement of any partnership hydrogen project, including knowledge transfer on the operation and maintenance of HRS and their monitoring systems

Images

 Source: Several news article

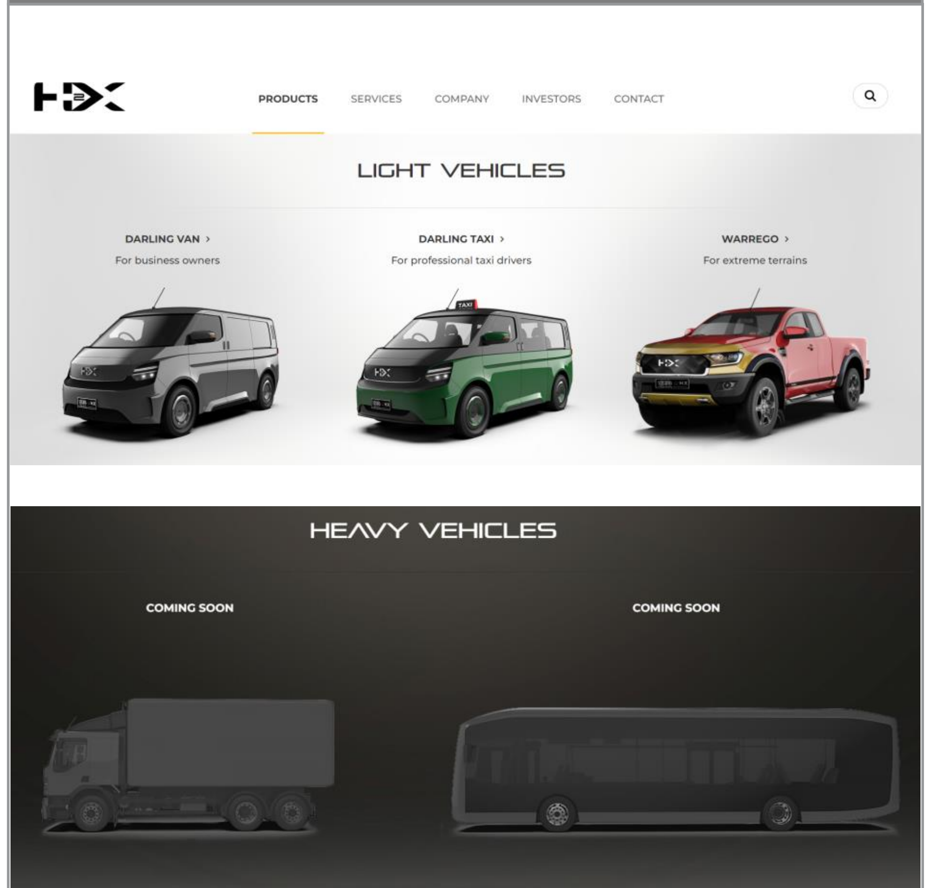
H2X executes groundbreaking deal to start hydrogen fuel cell vehicle (HFCV) production in Sarawak

Hydrogen Fuel Cell Vehicle Production

11

Name of project	N/A
Period	MoU was signed in November 2021
Place	Sarawak
Partners	■ SEDC Energy ■ H2X Global *(Australia)*
Purpose	■ To manufacture hydrogen fuel cell vehicles in Sarawak; the joint venture will immediately begin with the assembly of relevant vehicles – from its trademark Warrego Pick up to City Buses and H2x Hydrogen Powered Generators, taking advantage of the hydrogen distribution network already set-up within Sarawak State
Budget	■ N/A
Future plan	■ It is likely that Sarawak will not only produce vehicles for its own use but will become a major supplier to other States and countries in the region ■ Production of heavy vehicles is coming soon; HFCV is more suitable for high-load journey due to more power

Images



 Source: Several news article

Peninsular Malaysia's first hydrogen fuel station is coming; UMW, Petronas, and more sign MoU

Hydrogen Fuel Station

12

Name of project	Mobile Hydrogen Refueling Station Project
Period	MoU was signed in July 2023
Place	Malaysia
Partners	■ UMW ■ NanoMalaysia Berhad ■ PETRONAS ■ Malaysian Green Technology and Climate Change Corporation (MGTC)
Purpose	■ To revolutionize clean mobility and drive the adoption of fuel-cell electric vehicles (FCEVs), ushering in a new era of sustainable transportation in the region
Budget	■ N/A
Future plan	■ The introduction of the Mobile Hydrogen Refueling Station in Peninsular Malaysia represents a giant leap forward in expanding the hydrogen infrastructure network and promoting the uptake of FCEVs

Images

 Source: Several news article

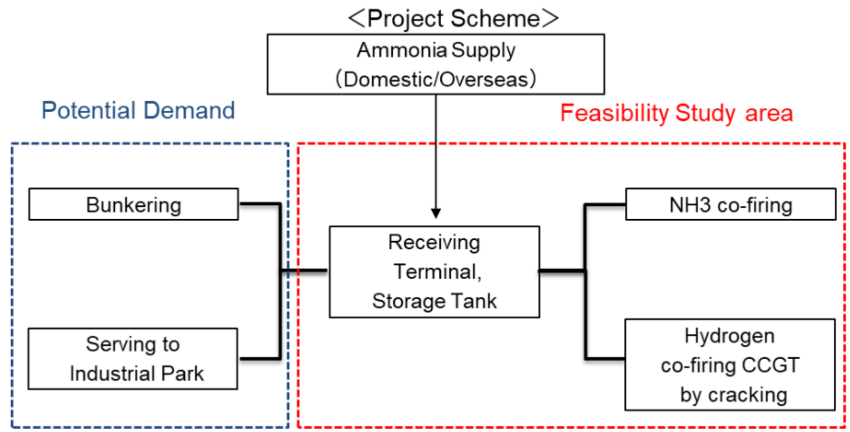
Malakoff and Itochu Signed MoU for Hydrogen/Ammonia Decarbonization Study in Johor, Malaysia

Feasibility Studies on Decarbonization using Hydrogen/Ammonia

13

Name of project	Feasibility study for decarbonization by utilizing hydrogen/ammonia
Period	MoU was signed in April 2022
Place	Malaysia
Partners	■ Malakoff ■ Itochu Corporation
Purpose	■ To understand the development of an ammonia receiving terminal and the decarbonization of coal-fired power plants owned by Malakoff through ammonia co-firing, as well as the development of a new combined cycle gas turbine power plant utilising high hydrogen content fuel subject to the outcome of the feasibility study and further discussions between both parties
Budget	■ N/A
Future plan	■ The feasibility study site will be located at Johor Straits which is essential for marine transportation, resulting in a huge potential for the development of an ammonia receiving terminal for co-firing/hydrogen usage as well as opportunities for bunkering and supply to the industrial complex nearby

Images



 Source: Several news article

Sarawak tests the world's first hydrogen-powered Smart Tram in Kuching

First hydrogen-powered Smart Tram

14

Name of project	Hydrogen-powered autonomous rapid transit (ART) smart tram
Period	Expected to commercialize in Q4 2025
Place	Kuching, Sarawak
Partners	■ Sarawak Metro (subsidiary of SEDC) ■ China Railway Rolling Stock Corporation (CRRC)
Purpose	■ The world's first hydrogen-powered tram, developed in China, is on its way from its production site in Hunan province to Malaysia where it will be a prototype for Kuching's urban transport system. A total of 38 of the 'autonomous rapid transit' (ART) vehicles are due to run on three lines across the city of Kuching from 2025. The fuel-cell units can travel 245km on a single ten-minute charge, reaching speeds of up to 70km/h and carrying up to 307 passengers at the same time.
Budget	■ N/A
Future plan	■ The smart tram will ease traffic congestion in the city, providing commuters a reliable and efficient service.

Images

 Source: Several news article

Reference

MIDA and MITI successfully organized an inaugural seminar with the theme ‘Hydrogen Economy’

Seminar on Hydrogen Economy

Name of project	Seminar on ‘Hydrogen Economy – Building a Sustainable Ecosystem in Shaping the Future of Energy’
Period	The seminar occurred on the 21st of March 2023
Place	Malaysia
Partners	■ MIDA (Malaysian Investment Development Authority) ■ MITI (Ministry of Investment, Trade and Industry)
Purpose	■ The seminar aimed to explore the significant potential of hydrogen technology and its ability to transform Malaysia’s energy, materials, and infrastructure sectors
Budget	■ N/A
Future plan	■ MITI and MIDA will actively engage relevant stakeholders to identify the right incentives and facilities, such as tax breaks, capital allowances, financial assistance, and R&D needed to attract investments

Images

 Source: Several news article

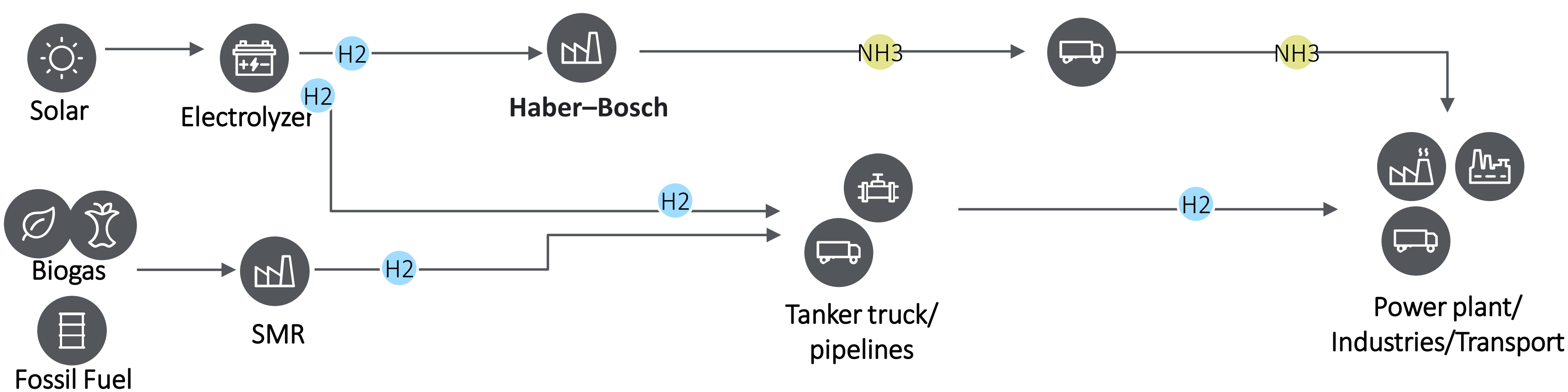
Desktop Research - ①Malaysia

1. Energy trend
2. Outlook for hydrogen
3. Policy
4. Potential players
5. Technical readiness roadmap and projects
6. **High-level business model (supply chain)**
7. Demand Forecast

Solar PV and biogas are expected for producing clean hydrogen, and providing domestic use in P MY, transportation would be in gaseous H2

Clean Hydrogen Business Model in Peninsula Malaysia in 2030s-40s

Production	Transport + Distribution + Supply	Use
■ MY government is aiming to produce clean hydrogen by **natural gas & biogas with CCUS and solar PV** ■ Start from natural gas with CCUS for establishing supply chain, but biogas + CCUS and solar PV will increase in 2030s	■ Due to the location of Hydrogen Hub in Sarawak on Borneo island, **hydrogen transport from Borneo is not expected**. ■ Distribution within P. MY is expected as well as import. So, **on-site or near location of production is expected** and then, carry mode would **likely to be compressed hydrogen or local pipeline network**	■ The Gov't **highlights the role of hydrogen in industry** for GHG emission reduction over the other sectors such as transport. ■ Industrial use and introduction to power plant are expected in early stage

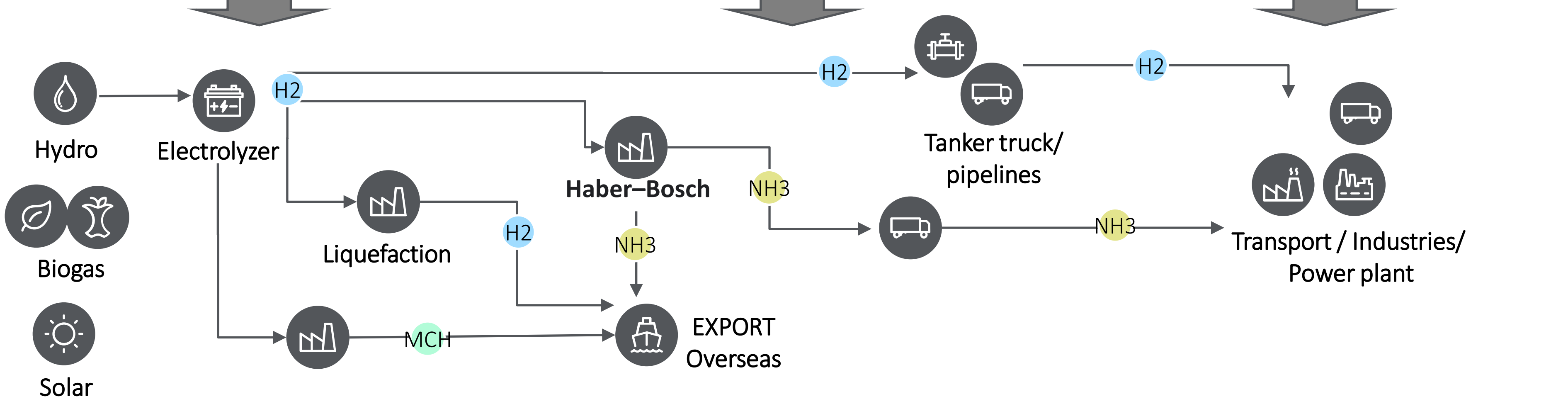


Concept	■ Reduce emission from Energy and Industry sector by taking advantage of renewables in Peninsula Malaysia such solar PV, which cannot be fully utilized through power grids
Area	■ On-site or near-site area of industrial area is preferable

Sarawak is expected to develop hydrogen industry from export to Korean and Japan as well as introduction to industrial parks

Clean Hydrogen Business Model in Sarawak in 2030s-40s

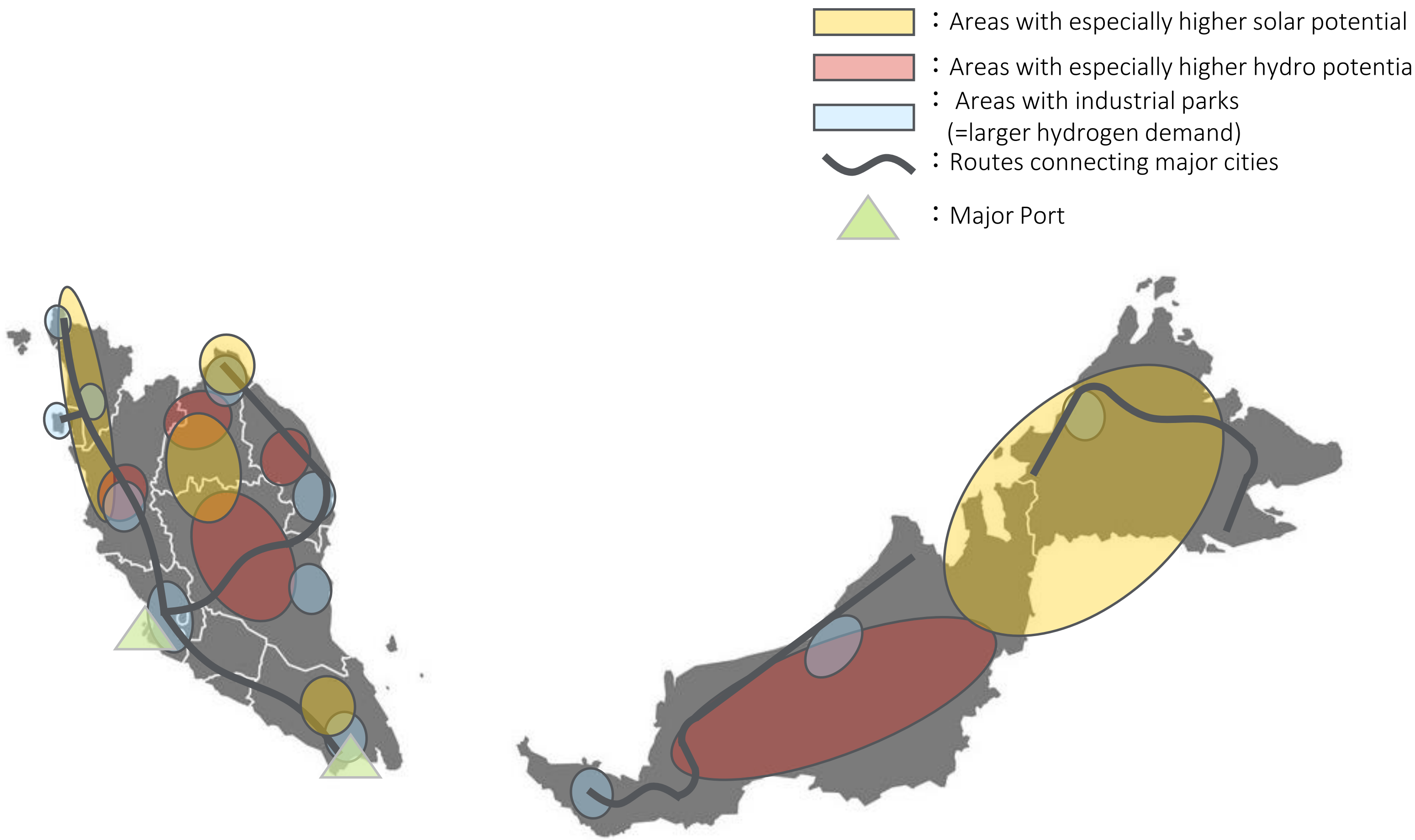
Production	Transport + Distribution + Supply	Use
■ **Hydro** energy potential are relatively high in Sarawak and Sabah ■ Sarawak state government is active to develop **hydropower, which can supply Electrolyzer** to produce hydrogen	■ Due to the far distance between Borneo island and Peninsula Malaysia, Hydrogen produced in Sarawak and Sabah would be distributed within Borneo island, or ■ Hydrogen will **be exported** mainly to Japan and Korea ■ MCH, NH3, and Li-H2 can be carriers for export	■ Hydrogen development in Sarawak and Sabah is expected to start from **export** ■ Introduction of hydrogen tech to Industrial parks in Sarawak and Sabah, including Samalaju Industrial Park (under development) is a focus for domestic use ■ As demonstration going on, early adaptation in transport sector is expected



Concept	■ Reduce emission from Energy and Industry sector by taking advantage of renewables in Malaysia such hydro power whose potential is abundant
Area	■ Kuching with near industrial areas, and Bintulu in Sarawak, where is demand center and abundant hydro and solar PV potential for production, and sufficient available land

In Sarawak, there is a large potential of hydro while consumption center is in Peninsular Malaysia, so import from Sumatra in ID is one of options

(Reference) Potential Map of Malaysia



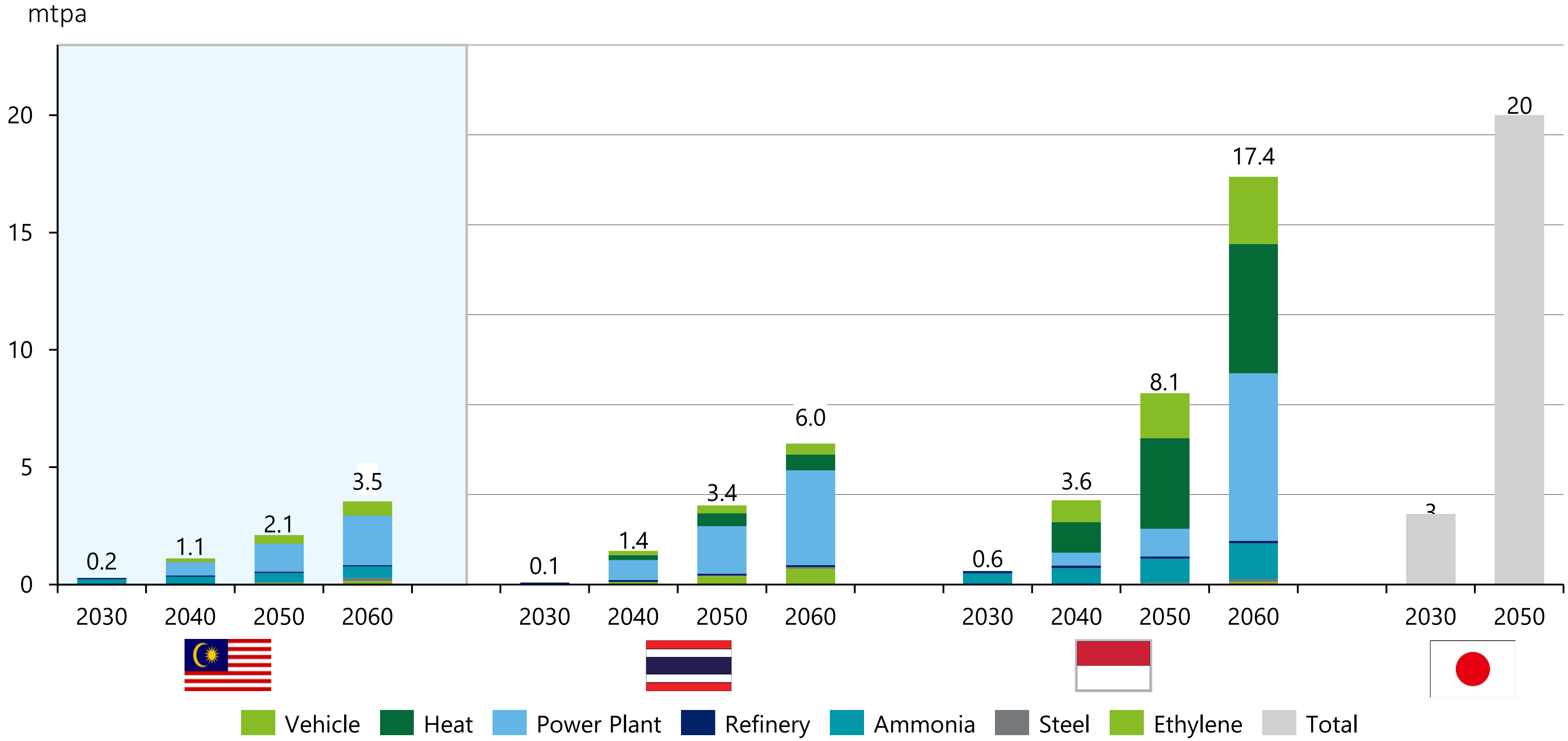
 Source: Solargis "Solar resource maps of Malaysia"

Desktop Research - ①Malaysia

1. Energy trend
2. Outlook for hydrogen
3. Policy
4. Potential players
5. Technical readiness roadmap and projects
6. High-level business model (supply chain)
7. **Demand Forecast**

For the optimistic case, Malaysia will reach 2.1 mtpa and 3.5 mtpa in 2050 and 2060 respectively, and the expected driver of the demand is the power sector

Potential Hydrogen Demand



Note that all fossil fuel in industrial final consumption is assumed to be replaced with hydrogen. In reality, some of the fuel consumption would be electrified, making hydrogen demand smaller:
(as shown by white arrow)

Source: Deloitte analysis

*Reference

Calculation assumption

Vehicles	■ **[# of cars (unit)] × [average milage per year (km/year)] × [% of hydrogen vehicles (%)] × [efficiency of hydrogen vehicles (km/kg-H2)]** ➢ [# of cars (unit)] is assumed to increase along with population ➢ [% of hydrogen vehicles (%)] is assumed to increase in a liner way from 0% in 2030 to 10% in 2050*1 and 15% in 2060/2065 for buses and trucks. Cars exclude passenger vehicles ➢ [efficiency of hydrogen vehicles (km/kg-H2)] is set at 105 km/kg for cars, 10 for buses, 20 for trucks
Heat	■ **[Final fossil fuel energy consumption for manufacturing, const., mining (TJ)] ×[% of hydrogen (%)] × [hydrogen conversion (kg-H2/TJ)]** ➢ [Final fossil fuel energy consumption for manufacturing, const., mining (TJ)] is assumed to increase along with Malaysian final consumption of energy ➢ [% of hydrogen (%)] is calculated by compound interest ration with GDP growth ratio from 2030 to 2050. For 2050 to 2060, it is assumed same with 2040 to 2050 due to data availability (EMIS)
Power plant	■ **[Capacity of natural gas power plant (GW)] ×[% of hydrogen (%)] × [hydrogen conversion (kg-H2/GW)]** ➢ [Capacity of natural gas power plant (GW)] is aligned with the governments' plans if any. Otherwise, the current capacity was assumed to continue over 2060 ➢ [% of hydrogen (%)] is set to reach 15% in 2040 (assuming co-firing and equivalent to half of injection rate) and 30% in 2050. 30% is the maximum injection rate target shown by the Japanese government for its 2030 target

*1: 10% in Heavy load vehicle is assumed in HETR

*Reference

Calculation assumption

Refinery	■ **[Capacity of refinery plant (b/d)] ×[hydrogen needed to procured (kg-H2/b/d)]** ➢ [Capacity of refinery plant (b/d)] <u>is not changed from present to 2060 for Thailand, Indonesia, and Malaysia</u> ➢ [hydrogen needed to procured (kg-H2/b/d)] is assumed based on the information of hydrogen volume procured for its refinery capacity, which is about 70kg-H2/b/d. Information of ENEOS, an oil and gas company of Japan, was used.
Ammonia	■ **[Ammonia production (t/y)] × [Hydrogen needed for ammonia production (kg-H2/t-Nm3)]** ➢ [Ammonia production (t/y)] for ID and MY are calculated by compound interest ration with GDP growth ratio from 2030 to 2050. For 2050 to 2060, it is assumed same with 2040 to 2050 due to data availability (EMIS). Thailand's ammonia production was set to zero, since ammonia plants seem to not exist. ➢ [Hydrogen needed for ammonia production (kg-H2/t-Nm3)] was set to 177kg of H2 for 823 kg of N2.
Steel	■ **[Capacity of steel production plant (Mt/y)] ×[Hydrogen introduction rate (%)]×[hydrogen needed for steel production (kg-H2/t-crude steel)]** ➢ [Capacity of steel production plant (Mt/y)] <u>is not changed from present to 2060 for all three countries.</u> ➢ [Hydrogen introduction rate (%)] is set the same as IEA forecast introduction rate following 10 years behind. ➢ [hydrogen needed for steel production (kg-H2/t-crude steel)] was set at 103kg-H2/t-crude steel
Ethylene (MTO)	■ **[Etylene production (t/y)] ×[Hydrogen introduction rate (%)]×[hydrogen needed for ethylene production using MTO (kg-H2/t-etylene)]** ➢ [Etylene production (t/y)] is set to reach 900,000 for Indonesia in 2030, aligning with the national target (target year is not shown). For Thailand, the current production volume is assumed to continue over 2060. For Malaysia, the production enhancement is expected to reach 903,000 t/y in 2025, so that the volume assumed to continue over 2060. ➢ [Hydrogen introduction rate (%)] is set the same as IEA forecast introduction rate following 10 years behind. ➢ [hydrogen needed for ethylene production using MTO (kg-H2/etylene)] was set at about 1 t-H2/t-Etylene

Challenges and Implications - ①Malaysia

There are multiple challenges to overwhelm for the successful market introduction of hydrogen in each area

Challenges

Policy	■ **Incentives :** NETR to launch RM2 billion seed fund for National Energy Transition Facility, not exclusively for hydrogen, potentially resulting in less allocation for hydrogen ■ **Policy framework**: There is a lack of policy support, defined standards, and regulations governing hydrogen. For example, the Gas Supply Act 1993 and the Renewable Energy Act 2011 may share responsibility for governing hydrogen
Technical Readiness	■ **Low maturity** ➢ Project development of hydrogen-related technologies in Malaysia is mainly dependent on foreign companies and the government, which tends to lag behind others in technology development ■ **Scale-up issues** ➢ The lack of predictability of the balance between future demand and supply makes it difficult to make progress when scaling up after demonstration stage ➢ High initial costs hinder scale-up, which results in vicious cycle of slow or none progress
Potential Player	■ **Competition to win collaborations with locals** ➢ **Restriction on foreign capital in the power sector** forces competition to win collaborations with leading local companies, and the collaboration importantly connect to domestic hydrogen procurement as well ➢ **Petronas in Peninsular Malaysia**, along with **SEDC and Sarawak Energy in Sarawak**, are crucial local partners. Their robust presence in the Malaysian hydrogen value chain positions them to potentially lead the hydrogen supply market
Demand Forecast	■ **Top-down approach** with policy and relating public data source has some limitation in the accuracy. Bottom-up market sizing provides more accurate data, but can be challenging to implement due to extensive time and resources required to collect and analyze data from each of the potential players
High-level Business (SC) Model	■ **Renewable energy source** ➢ Peninsular Malaysia – P. MY's main source will be solar, but the potential of RE is relatively lower than neighboring countries ➢ Sarawak – Sarawak's main RE is hydro, but building large hydro dam entails environmental and social concerns ■ **Lack of flexibility in green hydrogen within the nation** ➢ Due to the distance, it is **unlikely for Sarawak to export green hydrogen to Peninsular Malaysia**

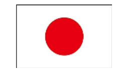
Malaysia launched NETR and a strategy dedicated for hydrogen (HETR) in 2023 and green H2 production target of up to 2.5 mtpa by 2050

Comparison among countries in Policy

Policy	Strategy dedicated for Hydrogen	➢ Malaysia launched the **National Hydrogen Economy and Technology Roadmap (HETR) in October 2023,** aimed at positioning Malaysia as a leading Hydrogen Economy Country by 2050	N/A ➢ However, DPR[*2] & MEMR[*3] **developed proposal** of RUU-EB-ET[*4] Draft Plan to support **Green Hydrogen implementations.** ➢ The government has also **appointed several ministry and SOEs** to **develop hydrogen to be used in the energy sector** as well as its production to be utilize in **electricity & electric vehicle**	➢ Hydrogen Basic Strategy was publicized in 2017 and updated in June 2023, which includes Hydrogen Industry Strategy and Hydrogen Safety Strategy. ➢ Green Growth Strategy (2021) also specified hydrogen as one of pillars
	Quantitative target	<u>NETR</u> sets three goals: ➢ **Replace grey hydrogen with blue hydrogen** as a feedstock by 2050 ➢ **Generate up to 2.5 mtpa of green hydrogen** from renewable sources like hydroelectric and solar by 2050 ➢ Establish one low-carbon hydrogen hub by 2030 and add two more by 2050, **totaling 3 hubs.** <u>HETR</u> ➢ **Export hydrogen of upto 0.5 – 1.0 mtpa** to target countries by **2030** ➢ (not target but demand forecast in 2050) BAU: 3.15 mtpa , emission driven scenario: 10.33 mtpa	N/A ➢ However, according to the most recent AEDP 2018, hydrogen is included as part of the "Alternative Fuels" category with a set target goal of 10 kilotons of oil equivalent (KTOE) in total by 2036	Hydrogen Basic Strategy sets numerical goals as; ➢ **Introducing Hydrogen up to 3 mtpa in 2030, 1.2 mtpa in 2040, and 20 mtpa in 2050**. ➢ CIF cost of H2 : JPY 30 /Nm3 in 2030 and JPY 20 /Nm3 in 2050 (which is less or equal to Gas FPP) ➢ 15 GW of Electrolyzer by Japanese manufacturer to be installed domestically and internationally ➢ Establishment of 3 large-scale and 5 mid-scale consumption center within 10 years

Malaysia launched NETR and a strategy dedicated for hydrogen (HETR) in 2023 and has started to plan more details including incentives

Comparison among countries in Policy

				
Policy	Incentives	➢ NETR to launch **RM2 billion seed fund for all National Energy Transition Facility, not exclusively for hydrogen** ➢ In NETR, **initiatives to establish financial incentive are mentioned**; • To fund elecrolyzer R&D for MY Universities and private sector • To establish financial incentives for Large-scale manufacturing of low-carbon hydrogen and electorlyzer • To provide incentives for development of HRS and purchase of FCEV	N/A However, there is possibility that Income tax incentives can be adopted because the allowance is applicable Geothermal and coal gasification	Japan's government provide **several subsidies to promote hydrogen introduction.** For example, ➢ METI provides subsidy for; demonstration project, technical development for global supply chain establishment, R&D of advanced fuel cell, and installation and O&M of HRS ➢ Ministry of Environment also provides several subsidies for ; demonstration project, purchase of FCEV, and study on decarbonized community model ➢ Green Innovation Fund, implemented mainly by NEDO also attracts private sector to promote hydrogen projects

Malaysia and Indonesia rely on foreign companies to proceed hydrogen related projects while municipalities play important roles in Japan

Comparison among countries in Technical Readiness, Players and Demand Forecast

	Malaysia	Indonesia	Japan
Technical Readiness	➢ MCH, HRS, Transport and Boiler are advanced (in demonstration) compared to Indonesia, and **almost all of them are undergoing led by foreign companies collaboration with local SOEs**	➢ Hydrogen Production by water electrizer is in demonstration stage while other advanced technologies of hydrogen is in R&D. and **almost all initiatives are conducted mainly by foreign companies**	➢ There are **many R&D, pilot, and demonstration projects by Japanese companies, which progresses technical readiness level** ➢ Japan is one of the leading countries for H2 promotion; as an example, NH3 co-firing demonstration at Hekinan CFPP, a USC CFPP, is planned in 1Q of 2024 (1,000 MW, unit 4)
Players	➢ **Petronas & its subsidiaries, and SEDC & Sarawak Energy** are key players in the market. ➢ In Sarawak, Korean and Japanese players are active for hydrogen production project while Chinese players are active in transportation sector ➢ **State government of Sarawak is also active** for promoting hydrogen projects (as well as CCS)	➢ **PERTAMINA & its subsidiaries, and SEDC & Sarawak Energy** are key players in the market. ➢ **Oil majors, namely ExxonMobil and Chevron is active** in CCS and as a result, they would be key players for SMR+CCS	➢ **Japanese companies cover total supply chain: from up- to downstream**, and there are so many players to work in Japan and overseas ➢ **Municipalities are remarkably active to establish hydrogen SC** for achieving CN toward 2050. They play an important role to connect private. They also active in promoting demonstration projects and attracting companies.
Demand Forecast	2030: 0.2 mtpa 2040: 1.1 mtpa 2050: 2.1 mtpa 2060: 3.5 mtpa **(Power > Vehicle > NH3(feedstock)**	2030: 0.6 mtpa 2040: 3.6 mtpa 2050: 8.1 mtpa 2060: 17.4 mtpa **(Power > Heat > vehicle)**	2030: 3.0 mtpa 2040: 12 mtpa 2050: 20 mtpa

Malaysia is a unique situation; different in import/export balance for Peninsular Malaysia and Sarawak, and then need to consider separately

Comparison among countries in High-level Business Model

High-level Business Model (SC)

- **Supply chain of Peninsular Malaysia and Borneo island should be considered separately** due to difference in access to renewable energy;
  - Sarawak: **Abundant Hydro potential** can supply Electrolyzer to produce hydrogen, which can be excess the demand in Sarawak. Considering the distance between P. MY and Borneo, **hydrogen can be exported** overseas as NH3, MCH and other modes as per consumers' needs
  - Peninsular Malaysia; surplus of solar PV generation and Fossil fuel/biogas with CCS can be expected. Therefore, **hydrogen can be utilized mainly for use within P. Malaysia**

- For domestic production, **Geothermal and surplus of Solar PV can be main source** for green hydrogen. Due to abundant production of fossil fuel and CCS potential sites in the nation, **fossil fuel + CCS is another option** for Indonesia.
- Considering the huge volume of demand in the future, **Indonesia will be an importer of hydrogen**, and the transportation mode will be mainly NH3 because
  - Ship transportation is required for inter-island transport
  - There are many 'young' CFPP which can be utilized for a while, so that NH3 will be co-fired at CFPPs

- Japan will be **an importer of hydrogen** due to the limitation of potential of renewable energy and fossil fuel reserve and potential CCS sites within the nation.
- Due to the well-developed industry status, the existing there is needs for a variety of hydrogen mode.
- Some of **supply chain models have been studied and demonstrated so far**. And due to establishment of new supply chain, multiple companies have collaborated for estimate demand & supply balance and testify financial feasibility. In some industrial area, companies have created hydrogen association to study co-utility and common a SC model.

To promote hydrogen in Malaysia, financial incentives, commitment by the gov't, partnership and capacity building are consideration points

Implications for Moving forward (1/2)

	Items for Consideration
Policy	■ Incentives ➢ i) **Dedicated Funding for hydrogen** technology innovation, demonstration, and pre-commercialization and ii) setting more generous **incentives for early adopters** are preferable ■ Policy ➢ **Strong leadership and commitment by the government** is required for structuring new policy framework and comprehensive regulation of hydrogen (as MOSTI is introducing for transport and storage)
Technical Readiness	■ **Insufficient technical expertise** and **high CAPEX for green hydrogen production** ➢ **Facilitate partnerships between foreign hydrogen technology providers and local manufacturers** are expected ➢ As HETR mentioned, to pursue 'some buy, some build', so covering total supply chain is not required condition but preferable ➢ **Capacity building** for human capital is also required due to new technical theme

Municipalities' inclusion, association formulation in national and industrial level, and flexibility of hydrogen procurement are consideration points

Implications for Moving forward (2/2)

	Items for Major Consideration
Potential Player	■ Inclusive Market Creation ➢ Partnership or collaboration to key players their expertise, technology, and network is a key driver for H2 penetration in the nation ■ Municipalities inclusion ➢ In Japan, municipalities play important roles for pursuing carbon neutral and promoting hydrogen projects (i.e. Kawasaki-city
Demand & Supply Forecast	■ **Demand: Bottom-up approach by formulating communication platform** ➢ Bottom-up approach is expected more accuracy for forecast. To collect more actual demand data, it is beneficial to formulate communication platform among stakeholders (i.e. **hydrogen association in i) national level and ii) industrial area** ■ Supply Forecast: ➢ Supply estimation is required to understand business feasibility for each project
High-level Business (SC) Model	■ **Flexibility of hydrogen procurement across the boarders** ➢ Exploring **import possibility from Sumatra, and other countries**, considering the geological locations of main energy consumption centers and ports ■ Renewable energy source ➢ Peninsular Malaysia – Studying biogas possibility and effective installation of Battery storage ➢ Sarawak – exploring other renewable energy options such as biogas and floating solar

Malaysia side would be expected to conduct benchmarking, R&D promotion, crating association, conduct more SC demonstration and trade consideration

Expected Next Actions

Public and Private Sectors	Politics	➢ To **benchmark** H2 related **policy and regulatory framework** in advanced countries ➢ To encourage municipalities to pursue Carbon neutrality more to generate their own momentum to promote hydrogen introduction
	Technical Readiness	➢ To study **R&D promotion direction study;** • Benchmarking advanced countries • Considering joint development program through G2G collaboration between Malaysia and Japan to develop domestic capability
	Players	➢ To create **Collaboration In national and industrial area levels (association) by participation from both public and private**, aiming; • Information sharing • Creating leading projects • Promoting joint technical development study for whole SC
	Demand forecast	• To study demand and supply balance by **top-down approach** as an initial step • To **study bottom-up approach by collecting detailed information from** the existing industrial areas through the **association** mentioned in the above
	SC	• To **promote SC demonstration projects** in collaboration with Foreign companies (preferably Japan/Korea for Sarawak and Australia for P. Malaysia, because of distance and demand and supply balance) • To start discussion about **intra-APAC trade in hydrogen/ammonia** • To study **supply potential** of neighboring countries, especially for **Sumatra**, Indonesia (including biogas)

For Japan side, public sector would be expected to assist Malaysia side's effort for technical assistance while private sector to promote PJ in collaboration

Expected Next Actions

Sector	Area	Expected Next Actions
Public Sector	Politics	• To assist Malaysian government to **design Incentives** • To establish more **agile fund utilization** scheme- i) more simplified process for application and implementation, and ii) relaxing condition for foreign companies with some special conditions • To assist Japanese companies to establish network with local key players- i.e. **assisting establishment of association**, business matching • **To encourage Japanese municipalities** to join the support MY's municipalities to pursue CN and promote hydrogen projects
	Technical Readiness	• **To assist technical development and capacity building** for hydrogen related technology by promoting joint R&D and training sessions
Private Sector	Technical Readiness Players Demand forecast SC	• To **promote demonstration project in collaboration with local private sectors** to establish win-win relationship • To cooperate with both Japanese and Malaysian companies i) to estimate detailed demand and supply forecast through establish association, creating data sharing platform , ii) to promote demonstration project • **To consider utilizing Japan's public fund** for boosting project implementation with Malaysian companies

Desktop Research - ②Thailand

Desktop Research - ②Thailand

1. Overview of Supply Chain

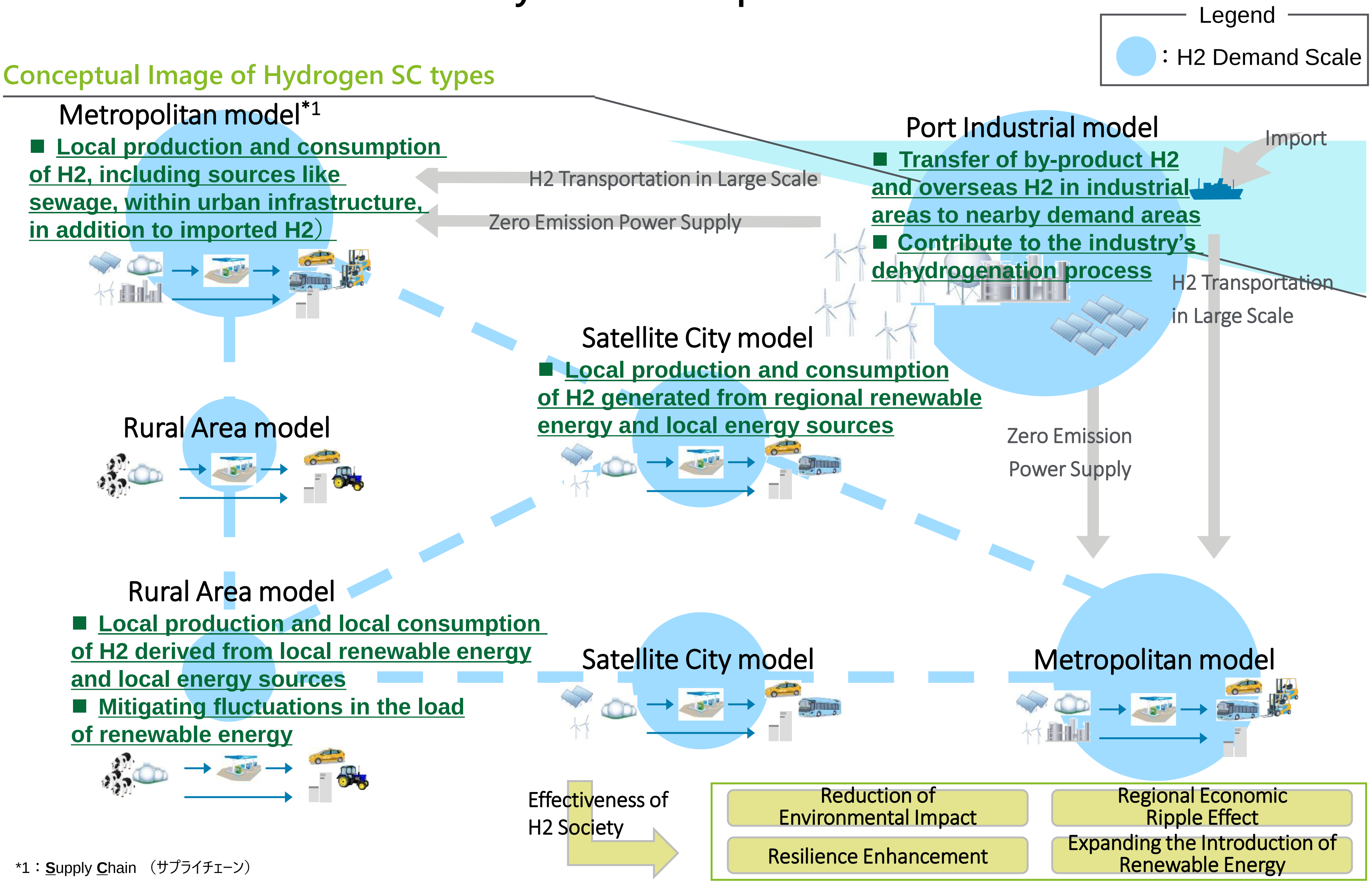
2. Demand Side

3. Supply Side

4. Public Acceptance

Supply chain type can be categorized mainly into seven types in consideration to main industry and development status of the area

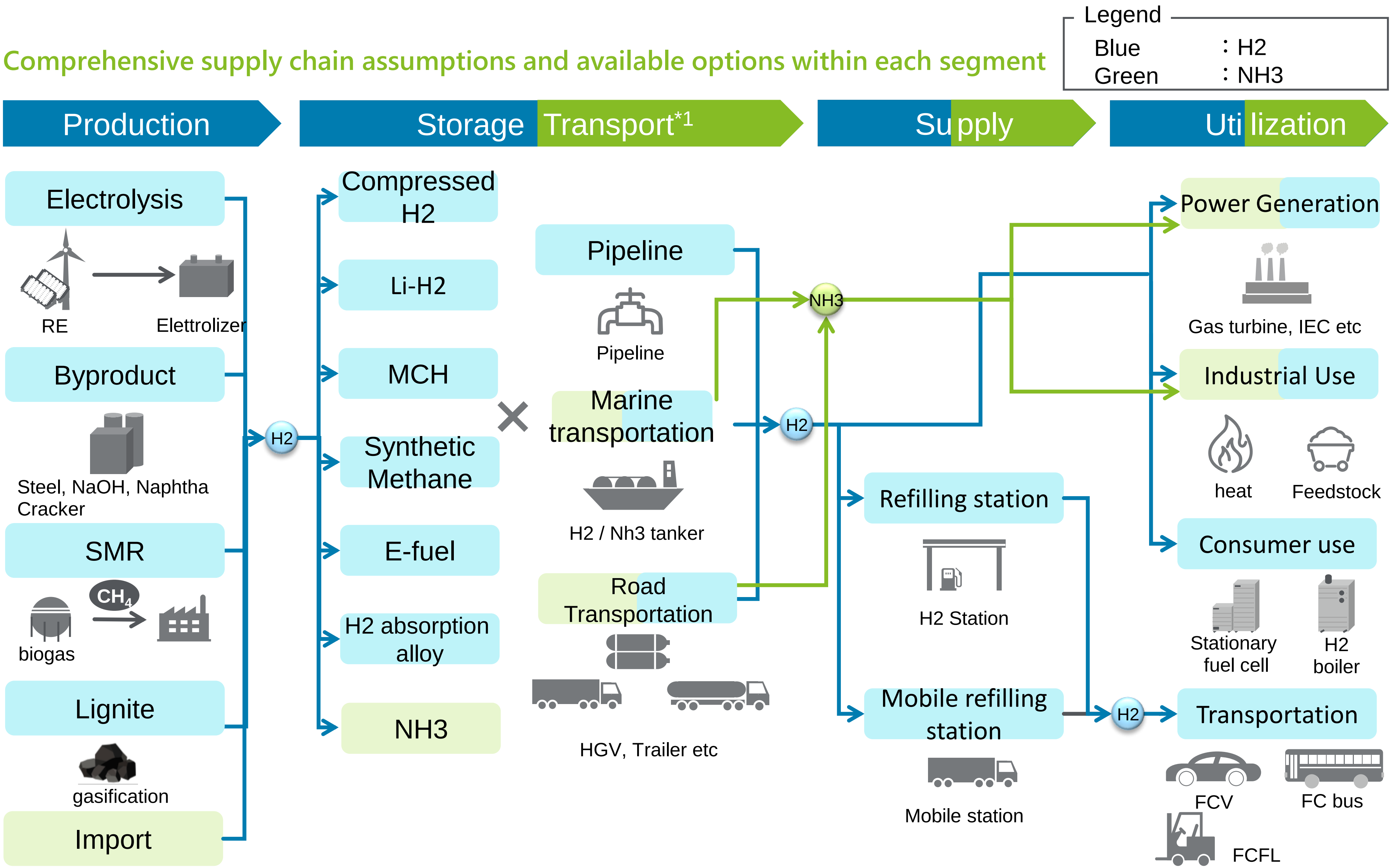
Conceptual Image of Hydrogen SC types



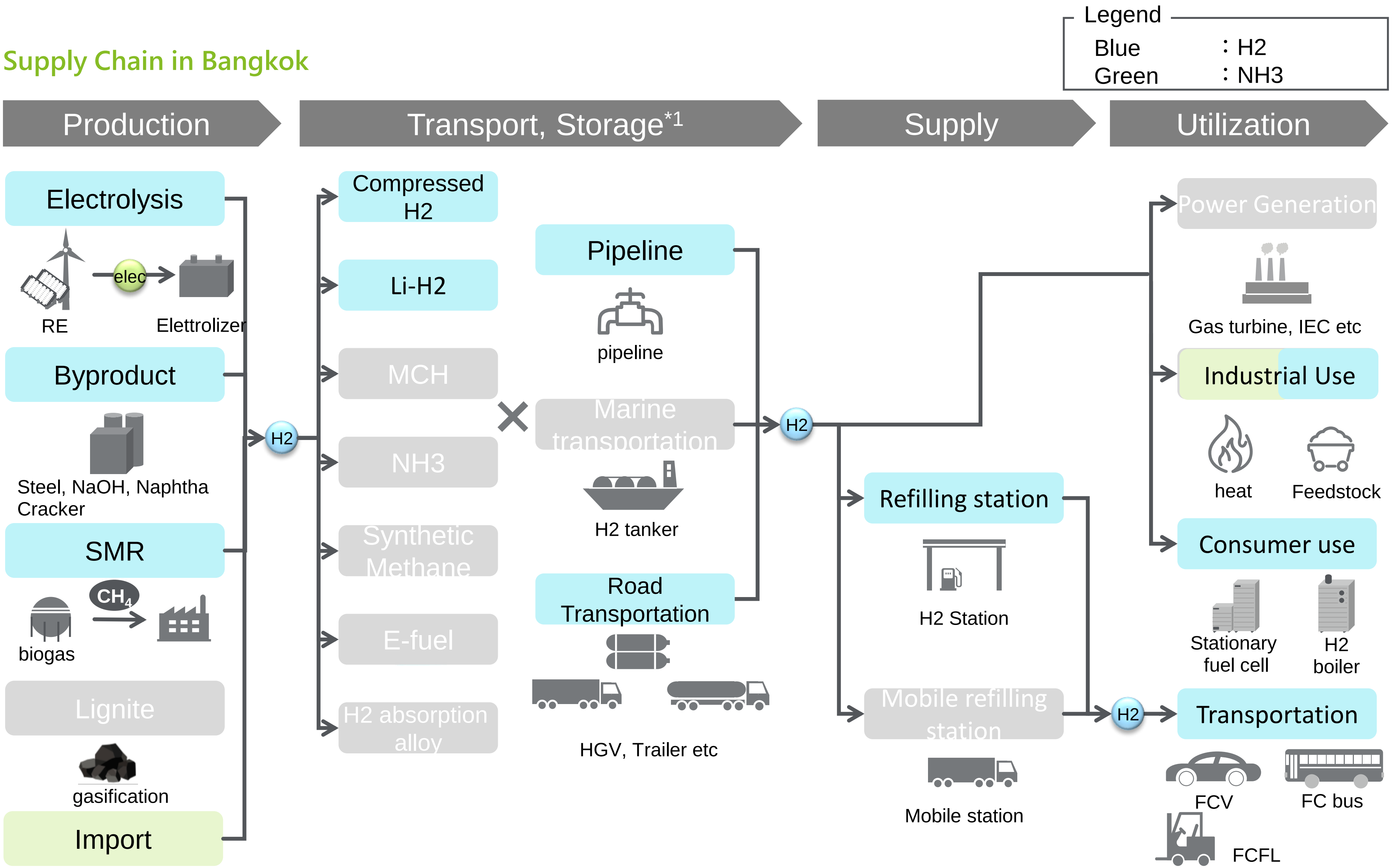
*1：Supply Chain （サプライチェーン）

Conceptual Supply Chain Model for each area was elaborated with the base model below

Comprehensive supply chain assumptions and available options within each segment



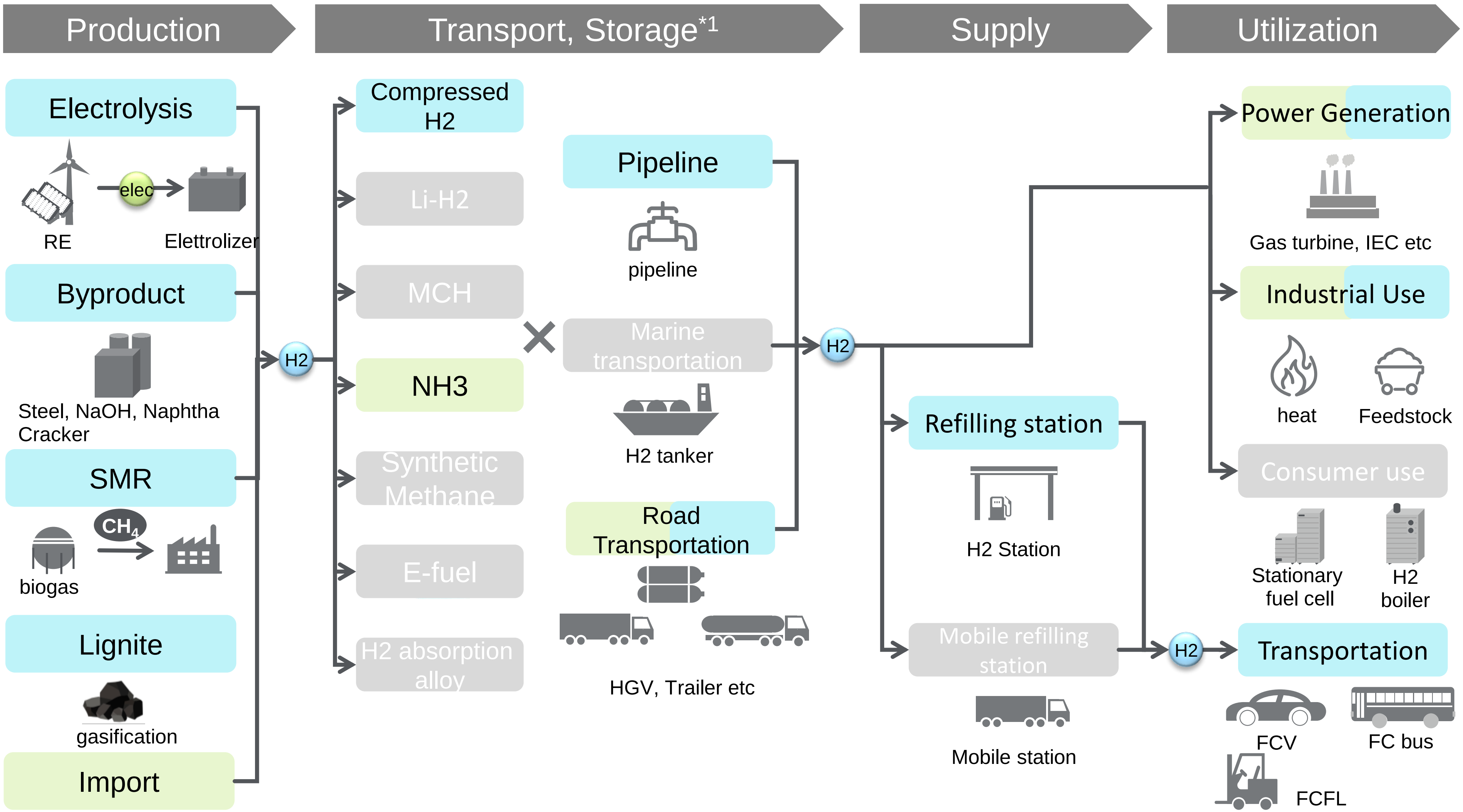
BKK: Transport and consumer use with hydrogen is envisaged in large scale, and industrial origin within the EEC, imports and RE origin would be expected



EEC: direct use of imported ammonia, by-product hydrogen, SMR and Lignite derivatives are expected due to huge consumption in heavy chemical industry

Supply Chain in EEC

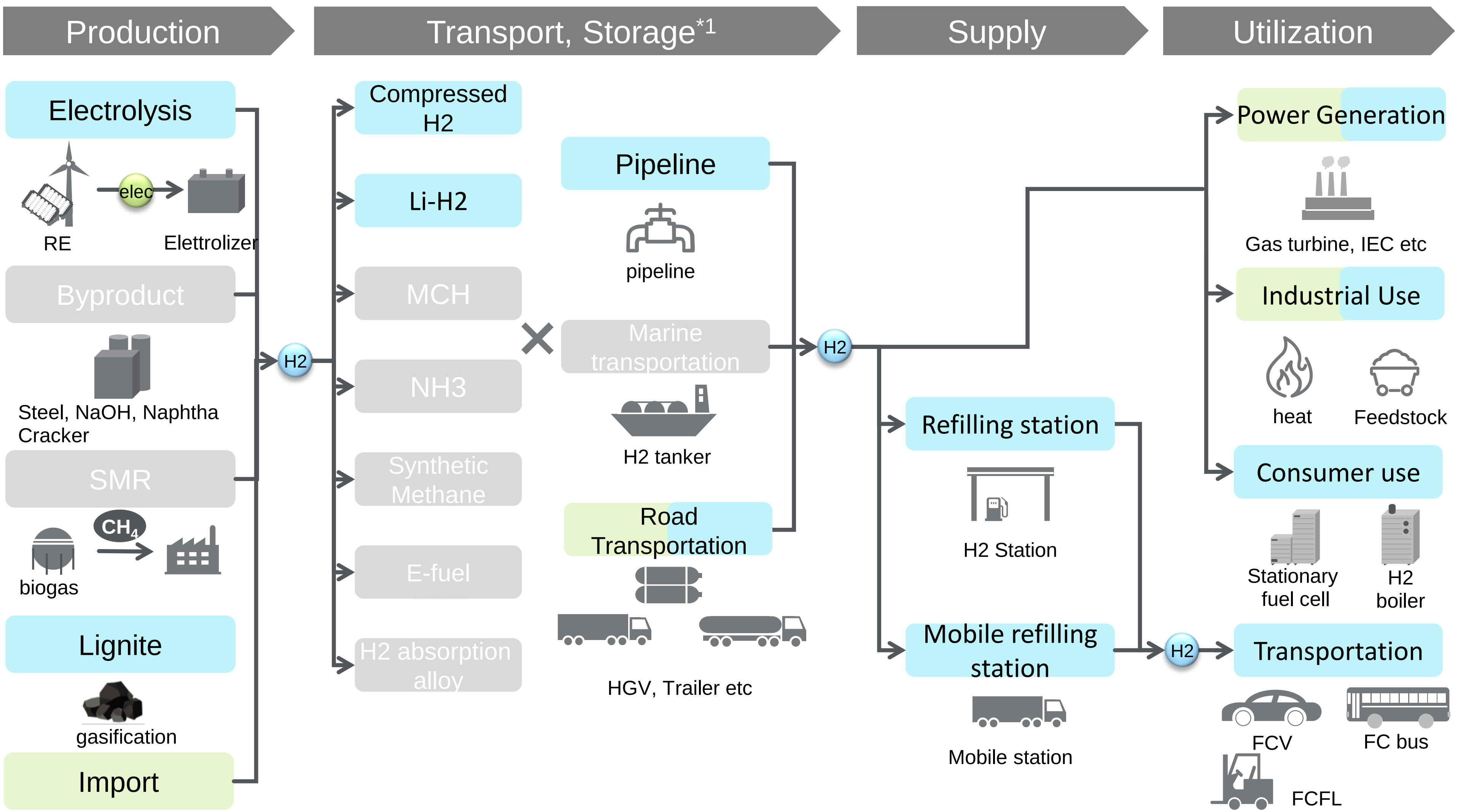
Legend
Blue : H2
Green : NH3



Chiang Mai (non heavy industry) : amount of direct use of NH3 would be limited and RE- and Lignite origin and transport from the south are expected

Supply Chain in Chiang Mai

Legend
Blue : H2
Green : NH3



Considering direct use in the power sector (majority is Gas-fired thermal) and technical development, compressed H2, Li-H2 and Ammonia would be promising in Thailand

Consideration of Hydrogen Carriers

Legend

Blue notation: Careers that can be applied in Thailand

	Compressed Hydrogen	Liquid Hydrogen	MCH	Ammonia	Synthetic Methane	e-fuel	Hydrogen storage alloy
Transportation efficiency	■ Approximately 1/200 (room temperature, 20MPaG gas)	■ Approximately 1/800 (-253℃, Liquid at atomospheric pressure)	■ Approximately 1/500 (Liquid at normal temperature and atomospheric pressure)	■ Approximately 1/1,300 (-33 ℃, liquid at atomospheric pressure)	■ Approximately 1/600 (-162 ℃ liquid at atomospheric pressure)	■ Liquid at normal temperature and atomospheric pressure	■ High efficiency per volume ■ Low efficiency per mass
Toxicity	■ none	■ none	■ Toluene is toxic	■ Toxic and corrosive	■ Non-toxic	■ Non-toxic	■ Depends on material
Major energy Loss	■ Requires compression energy	■ Liquifaction (25～35％)	■ Dehydrogenation (35-40 %)	■ Dehydrogenation (20 % or less)	■ CO2 synthesis (about 32%)	■ CO2 synthesis	■ Thermal energy is required during dehydrogenation
Direct use Possibility	■ Possible	■ Possible	■ Not possible (Dehydrogenation + purification required)	■ Not possible (Dehydrogenation + purification required) ■ Direct use as NH3	■ Directly as town gas	■ Directly use as fuel	■ Possible
Existing infrastructure Can it be used?	■ New infrastructure needed for hydrogen	■ New infrastructure needed for hydrogen	■ Infastructure fot petrol can be adaptable	■ Infrastructure technology similar to LNG can be adaptable	■ Existing LNG infrastructure can be used	■ Existing oil infrastructure can be used	■ New infrastructure needed for hydrogen
For practical use Challenges aimed at	■ Already put into practical use	■ Need to reduce costs by developing technology and increasing the size of equipment due to cryogenic temperatures	■ Further reduction of energy loss is necessary	■ It is necessary to develop technology to expand direct usage and develop dehydrogenation equipment.	■ To develop technology for higher efficiency and larger size , and to supply hydrogen derived from renewable energy at the manufacturing site.	■ Research and development towards higher efficiency and lower costs	■ Development of alloys for lower cost and higher weight density

Prepared with reference to the Agency for Natural Resources and Energy, “Hydrogen Policy Subcommittee, Ammonia and Other Decarbonized Fuel Policy Subcommittee Joint Meeting Interim Summary” (January 2020) , etc.

No detail has been disclosed from ministry of energy on the type of hydrogen carrier that the country will adopt

Hydrogen Transportation I Overview

Initial stage of hydrogen investment

- Initial investments will be among large energy companies to produce green and blue hydrogen (CCUS) to produce electricity for use in the company or within the same industrial estate area. Sometimes hydrogen is processed into fuel in the form of Synthetic Fuel for further use without having to transport or process hydrogen for use elsewhere.

Hydrogen Transportation in Thailand

- Hydrogen in Thailand is normally stored and transported for industrial purpose.
- General transportation system used in industries is as follows
    - **Pipeline**: usually close to the end users such as in industrial estate.
    - **Tube Trailer** : Hydrogen tube will be stationary installed on trucks or trailers or Hydril Tube which is mobile hydrogen fueling station. Both ends of hydril tubes is tapered and screwed for valves or fittings connection. Hydrogen gas in the tube depends on length and pressure (trailers can store up to 126,000 cubic feet at 2,640 psig)

Policy supporting Hydrogen used in Transport

- According to 15 years renewable energy development plan during 2008-2022, the hydrogen consumption of 100,000 kilograms per annum has been targeted
- Approximately 25,000 cars (4 kilograms of hydrogen per car) or can public car (buses) around 8,300 cars (12 kilograms of hydrogen per car).

Example of hydrogen project in transport by DEDE

- In Thailand, there are several researches for hydrogen development, but mostly in laboratory scale.
- In 2006, DEDE demonstrates Proton Exchange Membrane Fuel Cells (PEMFC) in tricycle called “Tuk Tuk” in order to promote the use of hydrogen.

Pipeline

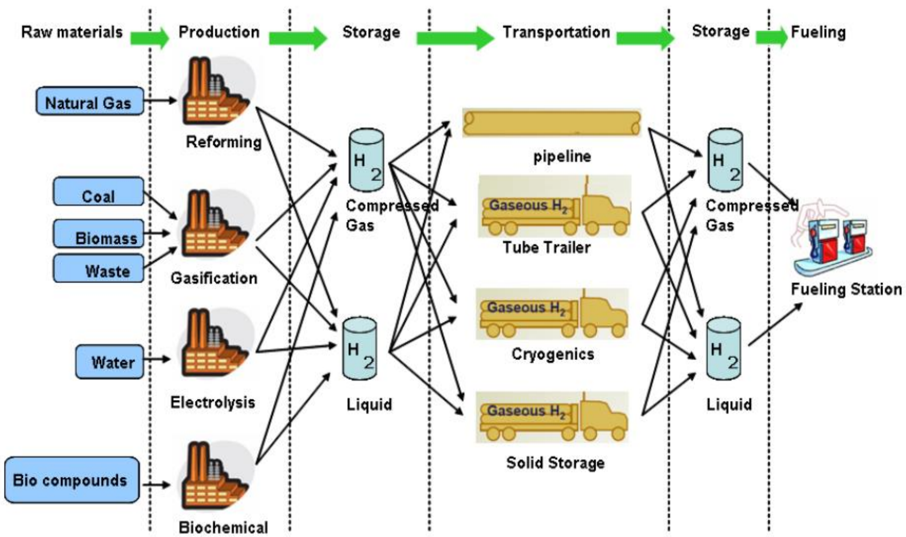
Tube Trailer

Source: DEDE

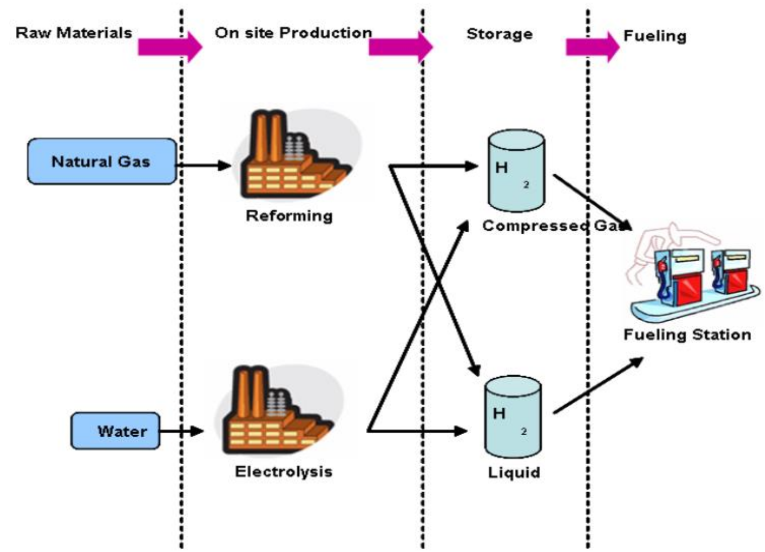
Ministry of energy has studied 2 possible hydrogen pathways which are centralized and distributed options

Study of production pathway by DEDE

A Centralized Hydrogen production pathway



B Distributed Hydrogen production pathway



Principle of hydrogen pathway selection

1 Type and quantity of raw materials

2 Hydrogen car growth rate

3 Area size

4 Distance between area for transportation cost calculation

 Source: DEDE

Sea transport seems to be the cheapest way of hydrogen transportation in current situation

Study of hydrogen transport cost

Unit cost of hydrogen transport by DEDE

	Road transport		*Pipeline*	*Sea transport*
TRANSPORT	**Liquid hydrogen**	**Tube Trailer**	**Pipeline**	**Liquid hydrogen**
COST	€ 0.13-0.15/kg	€ 0.5-0.6/kg per 100 KM	€ 0.3-0.35/kg per 1,000 KM € 0.15-0.19/kg per 200 KM (for pressure 180-250 bar)	€ 1.31/kg per 10,000 KM (Temperature -252.8 C, Pressure 6-10 bar)

Source: DEDE, Data on the report is from 2014,2021

Malaysia shows the lower hydrogen transportation cost than Thailand especially for LH_2 method that is able to transport in large volume

Study of hydrogen transport cost

Unit cost of hydrogen transport between shipping and receiving port

Shipping (cent/Nm3-km)	Receiving: Malaysia		Receiving: Thailand	
	MCH	LH_2	MCH	LH_2
Australia	2.44	2.17	2.66	2.20
Brunei	1.44	1.46	1.25	1.29
Malaysia	1.12	1.23	1.37	1.42
Indonesia	1.31	1.37	1.56	1.65
New Zealand	2.96	2.05	3.04	1.91

Shipping cost by IEA

LOHC	Lower than $2.0-2.5/kg-H2 by 2030
Ammonia	Lower than $1.9-2.2/kg-H2 by 2030

Note: cost include investment & operational costs (converting, storing, shipping, converting back)

Key Highlight

- LH_2 has the advantage due to its significant volume and long distances
- MCH is more applicable with transporting small and mid size hydrogen amount over short-middle distance

Key Assumption

- Target year 2030-2050
- Transport amount 10,000 Nm3/hour
- Transport by ship (MCH by chemical tanker, LH_2 by liquid hydrogen ships)

Source:Economic Research Institute for ASEAN and East Asia (ERIA), Note: LOHC = Liquid organic hydrogen carriers

Many hydrogen projects in Indonesia choose the Ammonia as the hydrogen carrier

Hydrogen Project I Carrier type

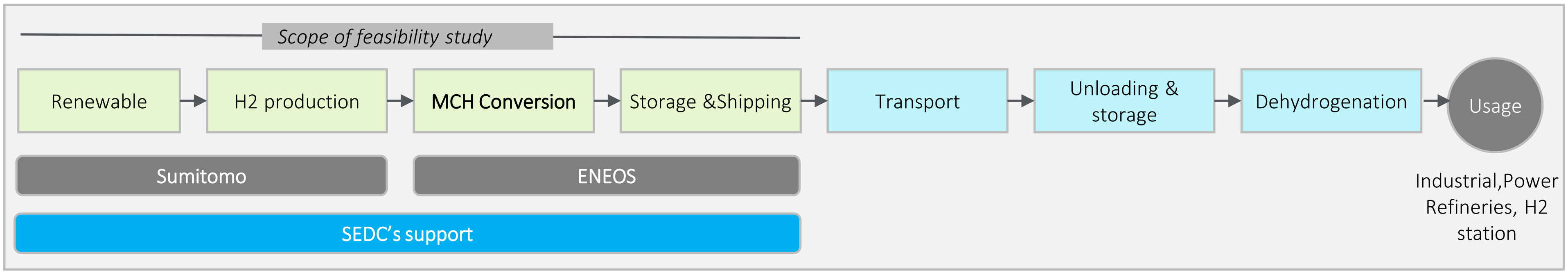
Project/Announcement	Company	Carrier	Key Highlight	Date
1 Joint development study on green hydrogen & Ammonia	• PT Pupuk Indonesia, PT PLN (Persero) and ACWA Power Company	Ammonia	• Maximum capacity of 200 MW will be established in East Java • See the **possibility of using ammonia as hydrogen carrier for transporting hydrogen** in the future.	07/2023
2 $1.2 billion project to produce green hydrogen in North Sumatra, Indonesia	• Samsung, Hyundai, Korea Gas corporation	Ammonia	• Utilize green geothermal power from geothermal power plant • Supply the green hydrogen as green fuel for steel and cement making factories • **Hyundai Glovis will work on green ammonia shipping**	03/2022
3 To produce hydrogen as energy carrier along with Ammonia from coal	• Ministry of Energy and Mineral Resource, Indonesia's government	Hydrogen, Ammonia	• Currently, government is in initial stage of hydrogen study • Main use will be in industrial and transportation sectors • In energy transition roadmap, the first commercial use of hydrogen of 328 megawatt will take place in 2031-2035	02/2022

 Source: Published news

Various Malaysia's trial projects show the adoption of MCH and LH_2 for transporting hydrogen

Hydrogen Project I Carrier type

Project/Announcement	Company	Carrier	Key Highlight	Date
1 Establishment of a CO2-free hydrogen supply chain	• SEDC Energy, Sumitomo Corporation, Eneos	MCH	• To produce **1,000 tonnes per year and convert to MCH (using chemical tanker) for export** • Expect to scale up to 10,000 tonnes per year	10/2020



2 H2biscus	• SEDC Energy, Samsung Engineering, Lotte Chemical, POSCO holding	Ammonia	• To produce **green Ammonia of 630k tonnes, 600k tonnes of blue Ammonia** • Potential of supply at least 900MW of renewable power • Expect to start production by end of 2027 • For domestic use and export to South Korea • **Ammonia will be the hydrogen carrier to transport**	01/2022

 Source: DNV

Various Malaysia's trial projects show the adoption of MCH and LH_2 for transporting hydrogen

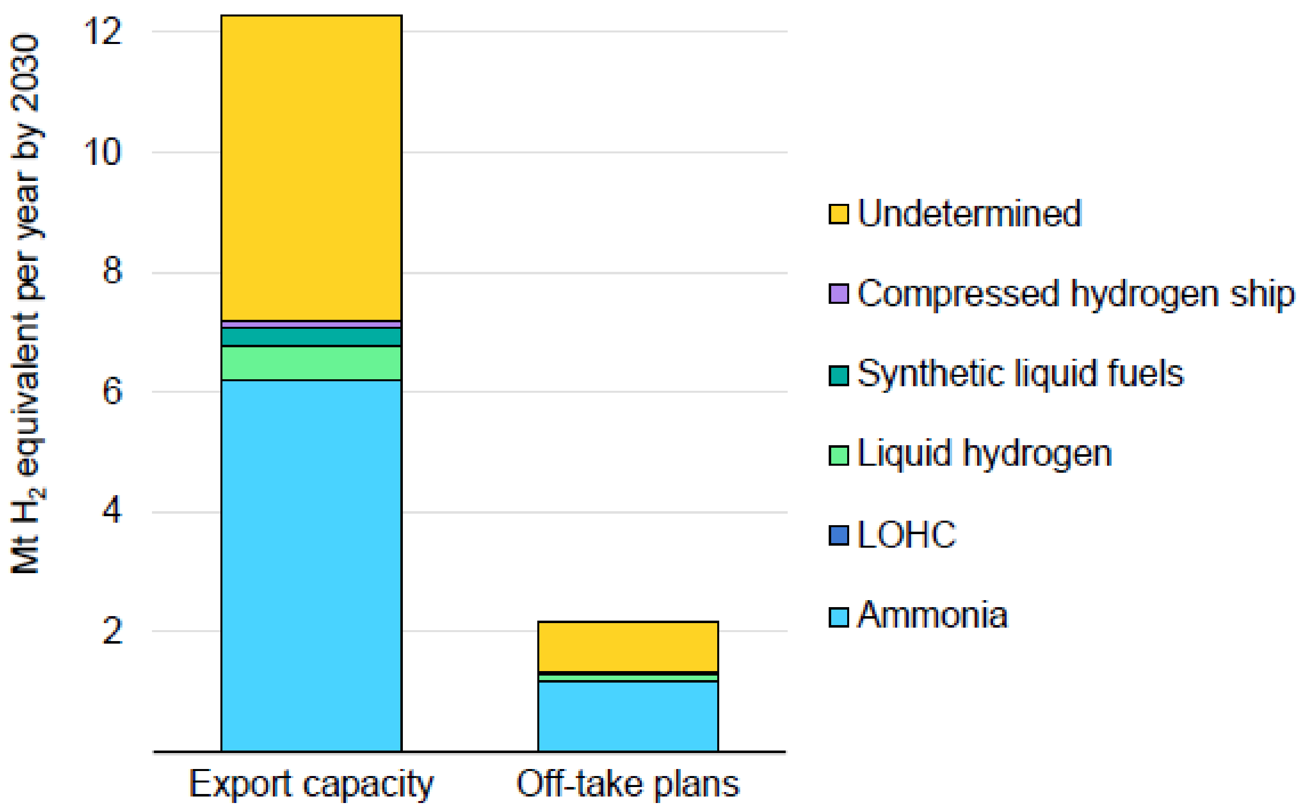
Hydrogen Project I Carrier type

Project/Announcement	Company	Carrier	Key Highlight	Date
3 Samalaju Hydrogen plant	• SEDC Energy, H2X Global, Thales New Energy	Liquid/ Ammonia	• To produce and export **liquid hydrogen of 170k tones** or Ammonia of 970k tonnes • Production is done through electrolysis • Plant's capacity is 1.3GW • Shipment is expected to start in 2024 and plan to export to Europe	06/2022
4 Petronas's MCH project	• Petronas, Eneos	MCH	• Joint feasibility study on green hydrogen production and conversion • **Potentially be the first commercial scale hydrogen-to-MCH in the world** • Plant's capacity is up to 50,000 tonnes per annum by 2027 to **export in MCH form to Japan** • Investment final decision will be made by end of 2023 • Project is funded by Japanese government	03/2022

Source: DNV

Ammonia is dominant for carrier mode of international transportation, while undetermined part is 2nd largest in the modes

(Reference) Discussion on Hydrogen Carrier by 2030



Thailand is expected to use hydrogen commercially by 2030

Hydrogen production in Thailand

Overview

- According to the Ministry of Energy has set a policy to promote the use of **renewable energy to 20.3% of the final energy consumption** in 2022

- Thailand has set to use hydrogen energy in **the transportation sector in the amount of 100,000 kg in 2017 onwards** to replace oil imports

Sector	Targe usage amount	Targe usage amount (Ktoe)
Energy generation	3.5 Kw	1
Transportation	100,000 kg	124

Goal

- Thailand is **ready to use hydrogen commercially by 2030** to achieve the carbon neutrality in 2050

Strategy

1. Promote the H2 usage in power plant, industrial factory
2. Promote R&D in domestic market to reduce hydrogen import
3. Prepare the readiness of infrastructure (storage, delivery, usage)
4. Prepare on law & regulation related to hydrogen

Hydrogen Timeline

2021	2031	2041
Grey Hydrogen Steam reforming	**Blue Hydrogen** Steam reforming w/ CCS	**Green Hydrogen** Electrolyzer

Current Situation in Thailand

No exact number is published on the hydrogen production level in Thailand

Biogas SMR	Thailand has experienced in conducting the the pilot project of biogas SMR production done by ministry of energy in 2007:. Capacity is **50 liter/day**
Electrolysis	EGAT project with ACWA power and PTT: **225,000 tonnes** of green H2/year

 Source: Ministry of Energy

Thailand is expected to produce 0.2 million tonnes of hydrogen by 2050

(Reference) Hydrogen production in Thailand

Current situation in Thailand

- **BIG plan to build 2nd hydrogen plant located in Map Tha phut (2019)**
  - Investment over 500 MM thb with production capacity of 12,000 tonnes per year
  - Low carbon hydrogen type
  - To be used in the propylene oxide production process (Petrochemical industry)
  - Mention on the possibility of usage in automobile industry

Current situation in SEA

- **Production:** Contributing 3 million metric tons of hydrogen (3%) of the global production
  - Predominantly derived from natural gas
  - major hydrogen producers are Indonesia and Malaysia
- **Demand:** currently around 3.2 million tonnes/year, mostly coming from the petrochemical industry and supplied by domestic production.
- **IEA and Agora's projection**:
  - Ammonia will supply up to 10% of SEA's power generation in 2050.
  - SEA can produce 50-500 million tonnes of hydrogen and the price will be below 2 USD/kg by 2030
  - Expect that Thailand can produce 0.2 million tonnes of hydrogen from domestic renewable energy source by 2050

List of Local hydrogen producers in Thailand

- **NBC public company**
  - Produce Ammonium Hydroxide which is used for many industries e,g, automotive, chemical
  - Production capacity is 1,000 tonnes/month (12,000 tonnes/year)
- **Thai industrial gas (Linde)**
  - Capacity to produce liquefied gas ; 800 tonnes/day (292,000 tonnes/year)
- **Bangkok Industrial gas (BIG)**
  - Hydrogen production capacity: 12,000 tonnes per year
- **Air liquide**
- **Air product industrial**

Note: Total number based on available data is 316,000 tonnes/year

 Source: Department of Alternative Energy Development and Efficiency, IEA, Agora energiewende

Major Thai energy company is actively investing and collaborating with foreign company to produce and co-study on hydrogen

(Reference) Hydrogen's MOU/collaboration in Thailand (2023)

1 EGAT MOU with CSIRO to study on CCUS and hydrogen for 1 year(August,2023)

- Production, storage, transport, electricity production
- CSIRO is leading scientific research organization in Australia specializing in CCUS

2 EGCO collaborates with DGA to study business development related to hydrogen in Australia (July, 2023)

- The project also involves the green hydrogen production from Australia's plant owned by EGCO
- The production capacity is 113 MW
- DGA is the company under Mitsubishi

3 PTTEP and its partners win the bid in Oman for a large-scale green hydrogen production concession (June,2023)

- Target production is 220,000 tons/year
- The alliance includes South Korea and France company e.g. Posco, Samsung
- The concession period is 70 years
- Production capacity is 5 GW

4 GPSC and Meranti signed MOU to join study on renewable energy and Hydrogen for steel production (June,2023)

- Expect to utilize solar, wind energy to produce and Hydrogen for increasing efficiency
- Aim to start production by 2027
- The steel production with clean energy can reduce up to 3 million tonnes/year
- GPSC is the company under PTT

 Source: Energynewscenter

Desktop Research - ②Thailand

1. Overview of Supply Chain

2. Demand Side

3. Supply Side

4. Public Acceptance

Thailand's National Energy Plan 2023 has not been released yet but the draft version indicates the utilization of hydrogen in the county

Reference-Thailand's National Energy Plan 2023

Current status

- Pending for the Minister of Energy to approve the final round of public hearing before present the finalized version to new cabinet for approval (June,2023)

Goal

- Carbon Neutrality by 2050
- Net zero greenhouse gas emission by 2065

Highlight

- Plan to invest in new business to support energy transition for 5 years worth 54 billion THB.

Draft of National Energy Plan 2023

Strategy

1. Electricity
    - increase the ratio of renewable energy from new electricity factory to be at least 50%
    - Grid modernization
    - Encourage electricity trading (Prosumer)
    - Encourage to produce ZEV 30% of all car production by 20230
2. Natural gas
    - Become LNG trading hub
3. Oil
    - Improve energy plan for transport sector
    - Bio fuel and EV
4. Renewable Energy
    - Encourage on producing and consuming renewable energy
    - Improve the efficiency of energy usage

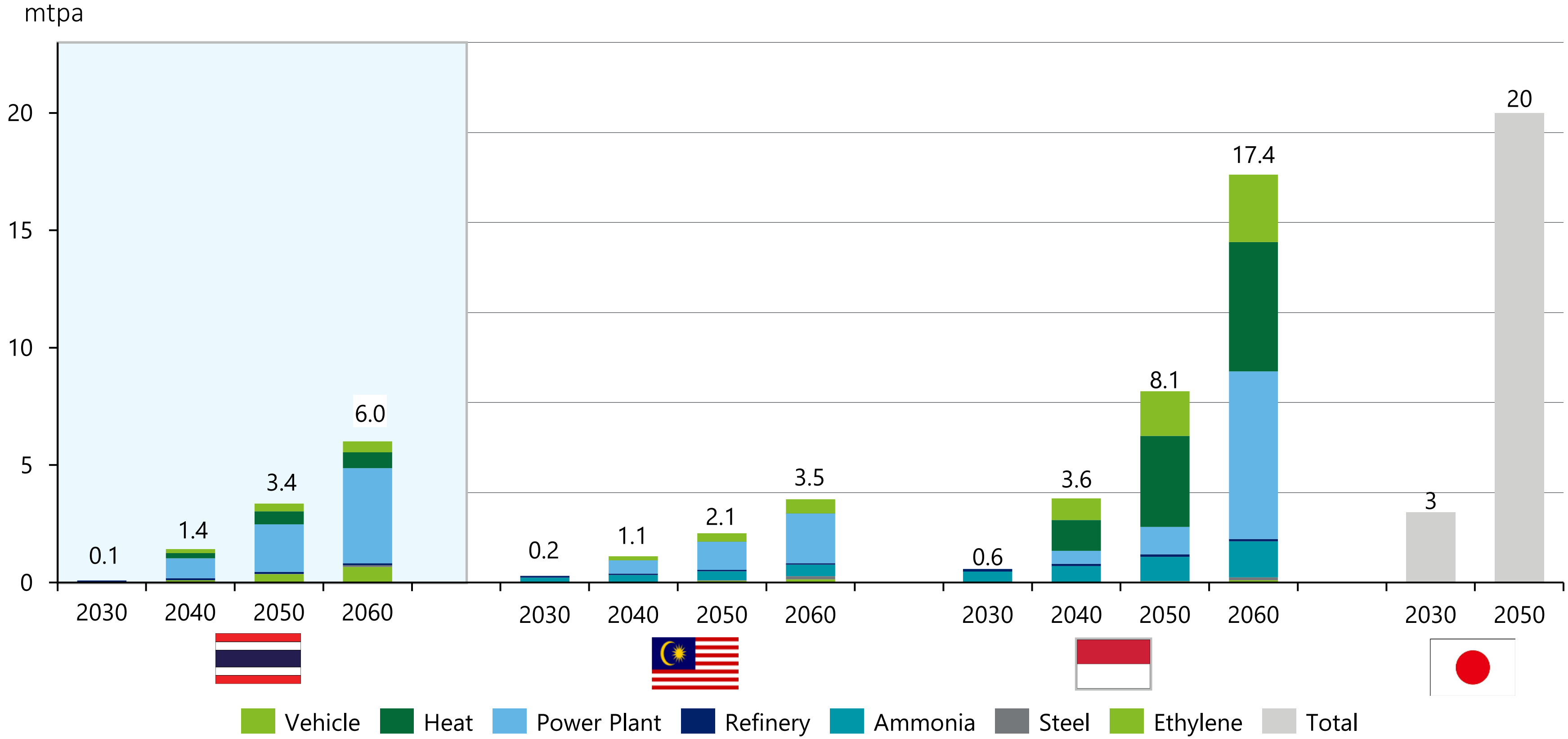
Lastest Update

- The new Power Development Plan (PDP) is expected to establish a target of utilizing hydrogen for electricity generation, aiming to reach a 20% utilization rate by the year 2037.
    - The existing infrastructure (natural gas pipeline) can support the 20% usage level
    - Start to use blue hydrogen (SMR w/ CCS) in 2031
    - The adoption of hydrogen will be lead by government before passing to the private sector

 Source: Ministry of Energy

Thailand will reach 3.4 mtpa and 6.0 mtpa in 2050 and 2060 respectively in demand forecast, and the expected driver of the demand is the power sector

Potential Hydrogen Demand



Note that all fossil fuel in industrial final consumption is assumed to be replaced with hydrogen. In reality, some of the fuel consumption would be electrified, making hydrogen demand smaller:
(as shown by white arrow)

Source: Deloitte analysis

*Reference

Calculation assumption

Vehicles	■ **[# of cars (unit)] × [average milage per year (km/year)] × [% of hydrogen vehicles (%)] × [efficiency of hydrogen vehicles (km/kg-H2)]** ➢ [# of cars (unit)] is assumed to increase along with population ➢ [% of hydrogen vehicles (%)] is assumed to increase in a liner way from 0% in 2030 to 10% in 2050[*1] and 15% in 2060/2065 for buses and trucks. Cars exclude passenger vehicles ➢ [efficiency of hydrogen vehicles (km/kg-H2)] is set at 105 km/kg for cars, 10 for buses, 20 for trucks
Heat	■ **[Final fossil fuel energy consumption for manufacturing, const., mining (TJ)] ×[% of hydrogen (%)] × [hydrogen conversion (kg-H2/TJ)]** ➢ [Final fossil fuel energy consumption for manufacturing, const., mining (TJ)] is assumed to increase along with Malaysian final consumption of energy ➢ [% of hydrogen (%)] is calculated by compound interest ration with GDP growth ratio from 2030 to 2050. For 2050 to 2060, it is assumed same with 2040 to 2050 due to data availability (EMIS) ➢ For 2060, it is assumed that heat in industry be electrified and adopt approx. 35% of heat will be supplied by electricity
Power plant	■ **[Capacity of natural gas power plant (GW)] ×[% of hydrogen (%)] × [hydrogen conversion (kg-H2/GW)]** ➢ [Capacity of natural gas power plant (GW)] is aligned with the governments' plans if any. Otherwise, the current capacity was assumed to continue over 2060 ➢ [% of hydrogen (%)] is set to reach 15% in 2040 (assuming co-firing and equivalent to half of injection rate), 30% in 2050, and 50% in 2060. Considering co-firing blending ration of 30%, it is assumed that half of GFPP is replaced its burner to co-firing burner in 2040, 100% of GFPP is converted to co-firing burner in 2050, and half of GFPP is replaced to 100% H2 combustion FPP in 2060.

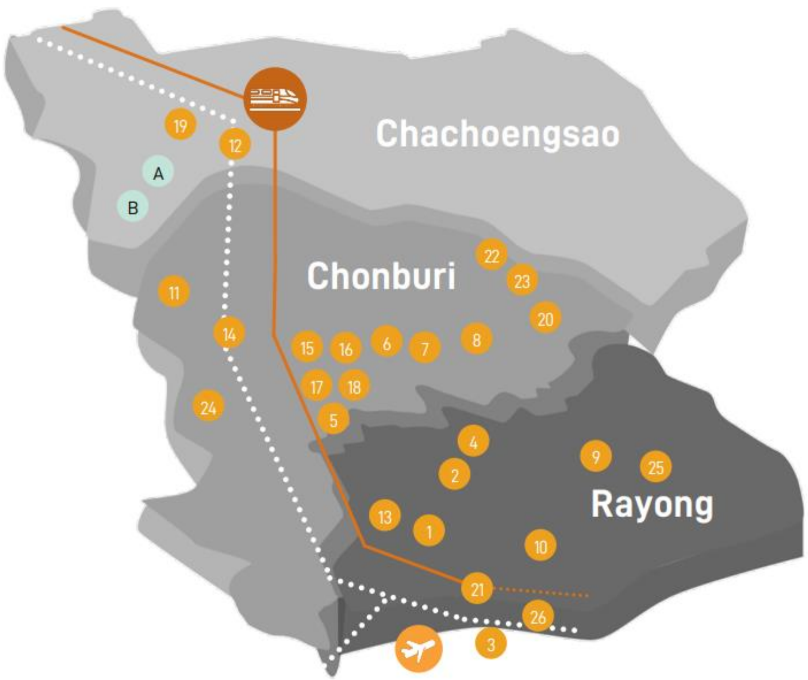
**1: 10% in Heavy load vehicle is assumed in HETR*

*Reference
Calculation assumption

Refinery	■ **[Capacity of refinery plant (b/d)] ×[hydrogen needed to procured (kg-H2/b/d)]** ➢ [Capacity of refinery plant (b/d)] is not changed from present to 2060 for Thailand, Indonesia, and Malaysia ➢ [hydrogen needed to procured (kg-H2/b/d)] is assumed based on the information of hydrogen volume procured for its refinery capacity, which is about 70kg-H2/b/d. Information of ENEOS, an oil and gas company of Japan, was used.
Ammonia	■ **[Ammonia production (t/y)] × [Hydrogen needed for ammonia production (kg-H2/t-Nm3)]** ➢ [Ammonia production (t/y)] for ID and MY are calculated by compound interest ration with GDP growth ratio from 2030 to 2050. For 2050 to 2060, it is assumed same with 2040 to 2050 due to data availability (EMIS). Thailand's ammonia production was set to zero, since ammonia plants seem to not exist. ➢ [Hydrogen needed for ammonia production (kg-H2/t-Nm3)] was set to 177kg of H2 for 823 kg of N2.
Steel	■ **[Capacity of steel production plant (Mt/y)] ×[Hydrogen introduction rate (%)]×[hydrogen needed for steel production (kg-H2/t-crude steel)]** ➢ [Capacity of steel production plant (Mt/y)] is not changed from present to 2060 for all three countries. ➢ [Hydrogen introduction rate (%)] is set the same as IEA forecast introduction rate following 10 years behind. ➢ [hydrogen needed for steel production (kg-H2/t-crude steel)] was set at 103kg-H2/t-crude steel
Ethylene (MTO)	■ **[Etylene production (t/y)] ×[Hydrogen introduction rate (%)]×[hydrogen needed for ethylene production using MTO (kg-H2/t-etylene)]** ➢ [Etylene production (t/y)] is set to reach 900,000 for Indonesia in 2030, aligning with the national target (target year is not shown). For Thailand, the current production volume is assumed to continue over 2060. For Malaysia, the production enhancement is expected to reach 903,000 t/y in 2025, so that the volume assumed to continue over 2060. ➢ [Hydrogen introduction rate (%)] is set the same as IEA forecast introduction rate following 10 years behind. ➢ [hydrogen needed for ethylene production using MTO (kg-H2/etylene)] was set at about 1 t-H2/t-Etylene

Most of industrial estate are located in Chonburi

(Reference) List of promoted zones for specific industries



1. WHA Rayong Industrial Estate
2. Eastern Seaboard I.E. (Rayong)
3. WHA Eastern Industrial Estate (Map Ta Phut)
4. WHA Eastern Seaboard I.E.1
5. WHA Chonburi I.E.1
6. WHA Chonburi I.E.2
7. WHA Eastern Seaboard I.E.2
8. WHA Eastern Seaboard I.E.3
9. WHA Eastern Seaboard I.E.4
10. CPGC I.E. (Rayong)
11. Amata City Chonburi I.E.
12. Amata City Chonburi I.E. (2nd Project)
13. Amata City Rayong I.E. 21
14. Pinthong Industrial Estate
15. Pinthong Industrial Estate (Laem Chabang)
16. Pinthong Industrial Estate (3rd Project)
17. Pinthong Industrial Estate (4th Project)
18. Pinthong Industrial Estate (5th Project)
19. TFD I.E. (2nd Project)
20. Yamato Industries I.E.
21. Smart Park I.E.
22. Asia Clean
23. Rojana Nongyai
24. Rojana Lamchabang
25. WHA Industrial Estate (Rayong)
26. EGCO Rayong Industrial Estate

Source: EEC

Most of major industrial estate in Thailand is located in EEC region

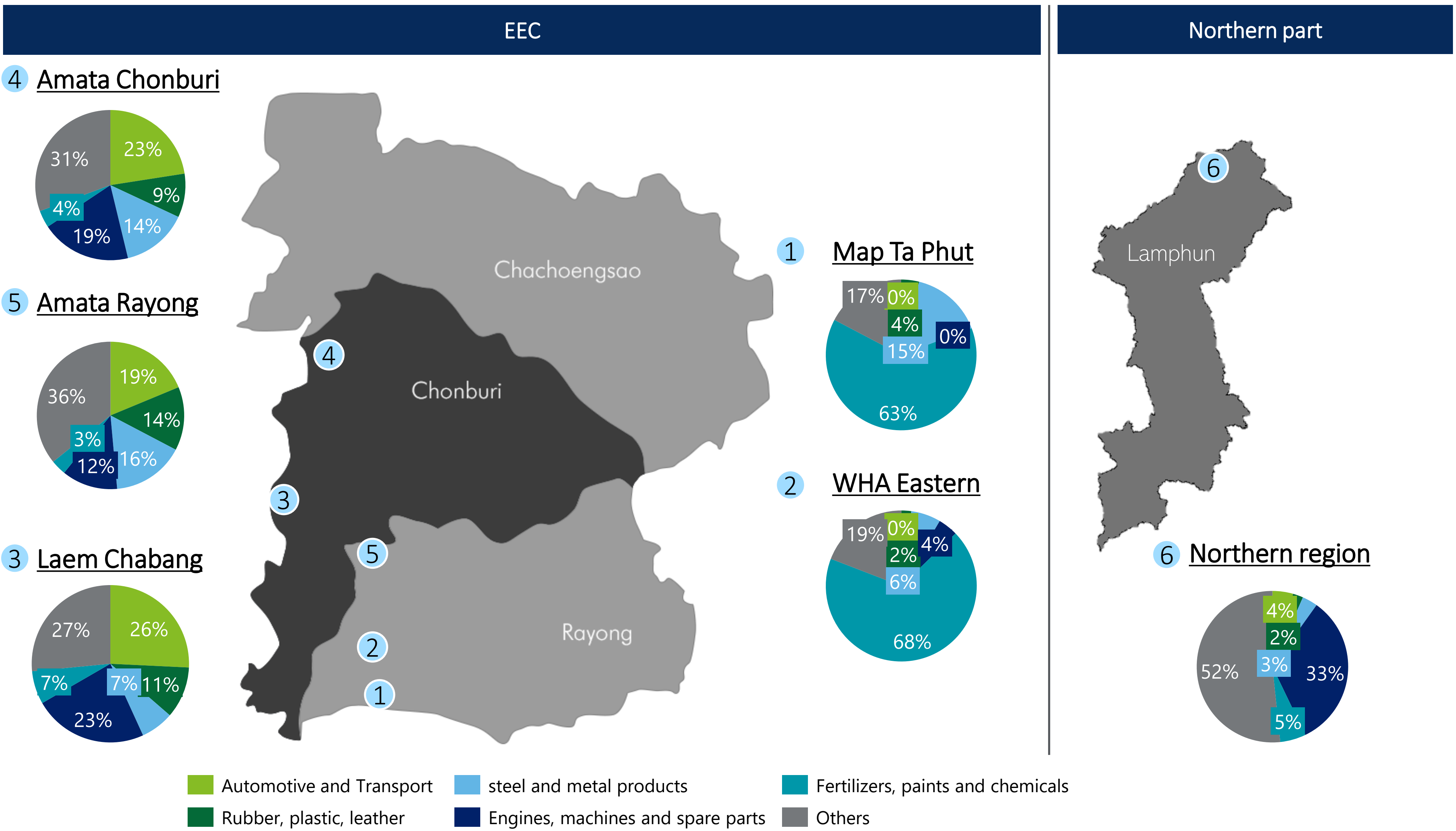
(Reference) Location of Industrial Estate

#	Industrial Estate	Location	Area (rai)	Industry focus	Key Highlight
1	Map Ta Phut Industrial Estate	Rayong	8,558	Chemicals	Be the 8th largest petrochemical industry hub in the world
2	WHA Eastern Industrial Estate	Rayong	3,747	Chemicals	Suit for **petrochemical**, steel and metal industry
3	Laem Chabang Industrial Estate	Chonburi	3,556	Automotive and Transport	Most companies are **Automotive and electronic parts** industry
4	Amata City Chonburi Industrial Estate	Chonburi	15,567	Automotive and Transport	Be the member of the **ASEAN Smart City** Network
5	Amata City Rayong Industrial Estate	Rayong	16,984	Automotive and Transport	Located near city center, airport, port
6	Northern Region Industrial Estate	Lamphun	1,788	Non heavy industry	Located 25 km from Chiangmai province

Source: EEC

Map Ta Phut and WHA Eastern are the center of Chemical industry while Amata and Leam Chabang focus more on Automotive

(Reference) Industry ratio by each industrial estate

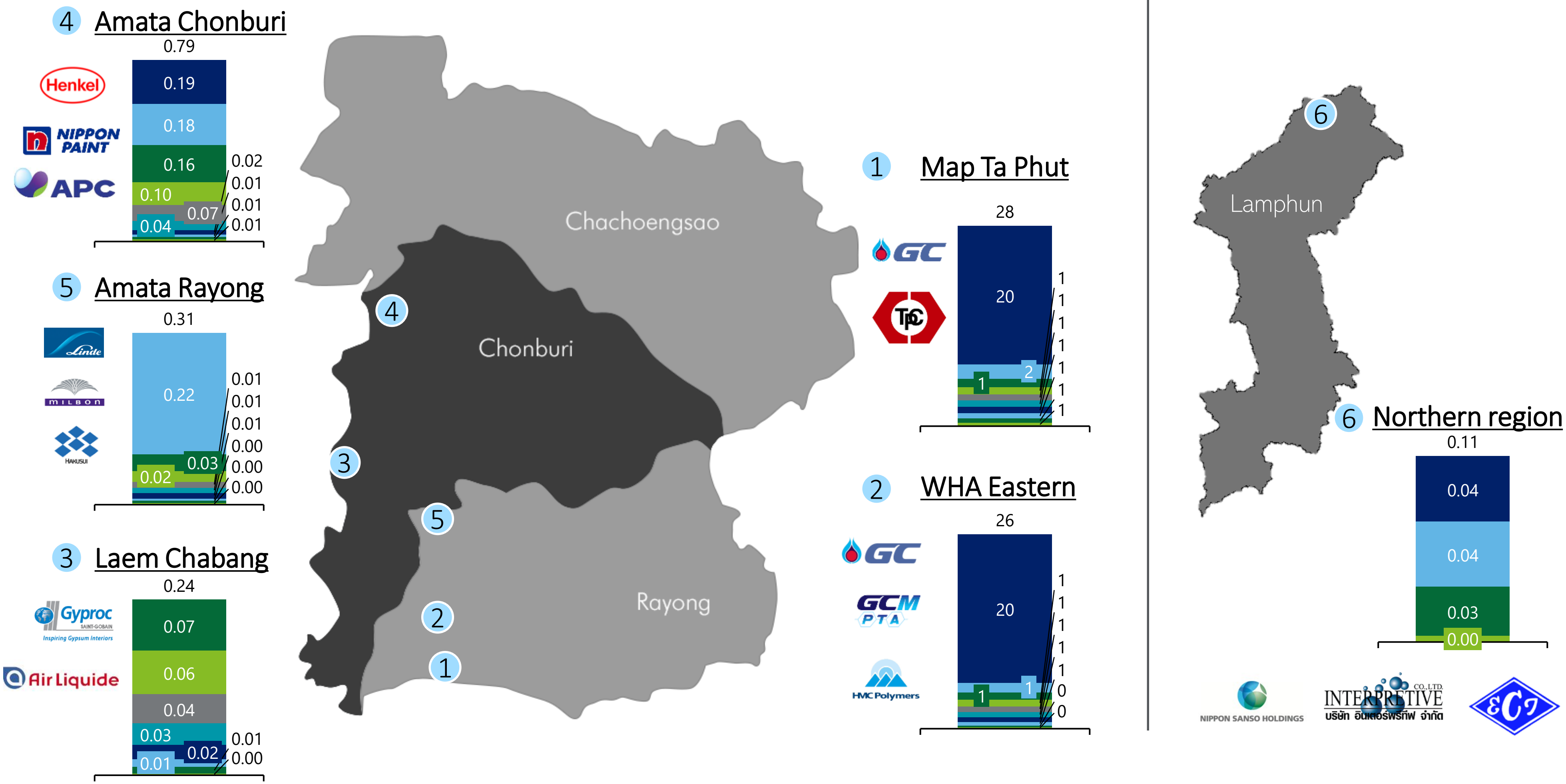


 Source: Industrial website, Deloitte Analysis

The top revenue contributor “PTTGC” is located in both Map Ta Phut and WHA Eastern

(Reference) Top companies in Chemical industry (Fertilizers, paints and chemicals) I Revenue (Billion THB)

EEC	Northern part



 Source: Industrial website, Deloitte Analysis

The top revenue contributor “PTTGC” is located in both Map Ta Phut and WHA Eastern

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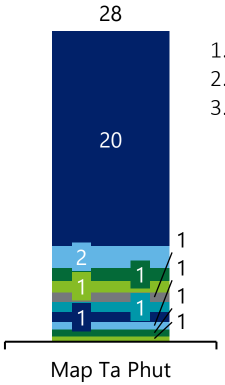
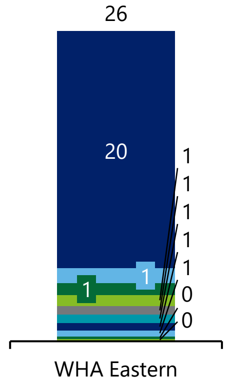
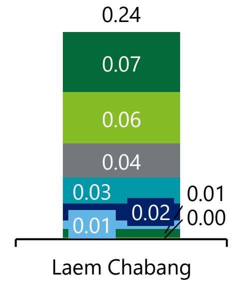


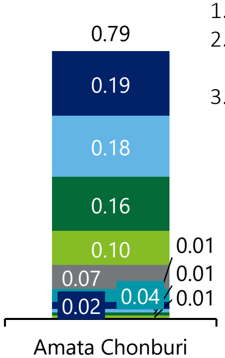
1. PTT Global Chemical Plc
2. Rayong Olefins Co Ltd
3. Thai Plastic And Chemicals Plc



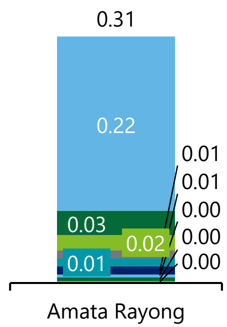
1. PTT Global Chemical Plc
2. GC-M PTA Co Ltd
3. HMC Polymers



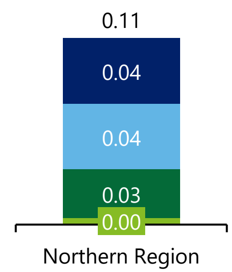
1. Thai Gypsum Products Public Company Limited
2. Air Liquide (Thailand) Co., Ltd.
3. Sadesa (Thailand) Co., Ltd.



1. Henkel (Thailand) Co., Ltd.
2. Nippon Paint (Thailand) Co., Ltd.
3. Asia Pacific Petrochemical Company Limited



1. Linde (Thailand) Public Company Limited
2. Hakusui Chemical (Thailand) Co., Ltd.
3. Milbon (Thailand) Co., Ltd.



1. Nippon Sanso Co., Ltd. (Thailand)
2. Electro Ceramics (Thailand) Co., Ltd.
3. Interpretive Co., Ltd.

 Source: D&B Hoovers, DBD

Revenue of top companies in Chemical industry is over 55 Billion THB (1.5 billion USD). Main contributors are from Map Ta Phut and WHA Eastern area

(Reference) Top companies in Chemical industry (Fertilizers, paints and chemicals)

Map Ta Phut

No.	Company	Revenue (Billion THB)
1	PTT Global Chemical Plc	19.5
2	Rayong Olefins Co Ltd	2.0
3	Thai Plastic And Chemicals Plc	1.2
4	HMC Polymers Co Ltd	1.0
5	Dow Chemical (Th)	0.9
6	Siam Polyethylene Co Ltd	0.9
7	Covestro (TH) Co Ltd	0.9
8	Aditya Birla Chemicals (Thailand) Limited	0.7
9	Bangkok Sythetics Co Ltd	0.6
10	Siam Synthetic Latex Co Ltd	0.5
	Total	**28.3**

WHA Eastern

No.	Company	Revenue (Billion THB)
1	PTT Global Chemical Plc	19.5
2	GC-M PTA Co Ltd	1.2
3	HMC Polymers	1.0
4	Dow Chemical (Th)	0.9
5	Global Green Chemicals	0.7
6	Aditya Birla Chemical	0.7
7	Bangkok Synthetics Co Ltd	0.6
8	PTT Asahi	0.5
9	GC Polyols Co Ltd	0.2
10	Thai Pet Resin Co Ltd	0.2
	Total	**25.6**

Laem Chabang

No.	Company	Revenue (Billion THB)
1	Thai Gypsum Products Public Company Limited	0.07
2	Air Liquide (Thailand) Co., Ltd.	0.06
3	Sadesa (Thailand) Co., Ltd.	0.04
4	Thai Dnt Paint Manufacturing Company Limited	0.03
5	Pq Chemicals (Thailand) Co., Ltd.	0.02
6	Thailon Techno Fiber Limited	0.01
7	Yamato Chemicals (Thailand) Co., Ltd	0.01
8	Kentop (Thailand) Co.,Ltd	0.002
	Total	**0.25**

Amata Chonburi

No.	Company	Revenue (Billion THB)
1	Henkel (Thailand) Co., Ltd.	0.19
2	Nippon Paint (Thailand) Co., Ltd.	0.18
3	Asia Pacific Petrochemical Company Limited	0.16
4	Jotun Thai Co., Ltd.	0.10
5	Thai Daizo Aerosol Co., Ltd.	0.07
6	Thai-Japan Gas Co., Ltd.	0.04
7	Three Bond Manufacturing (Thailand) Co., Ltd.	0.02
8	Chukyo Yushi (Thailand) Co., Ltd.	0.01
9	Musashi Paint Manufacturing (Thailand) Co., Ltd.	0.01
10	Toyobo Chemicals (Thailand) Co., Ltd.	0.01
	Total	**0.80**

 Source: D&B Hoovers, DBD

Revenue of top companies in Chemical industry is over 55 Billion THB (1.5 billion USD). Main contributors are from Map Ta Phut and WHA Eastern area

(Reference) Top companies in Chemical industry (Fertilizers, paints and chemicals)

Amata Rayong

No	Company	Revenue (Billion THB)
1	Linde (Thailand) Public Company Limited	0.22
2	Hakusui Chemical (Thailand) Co., Ltd.	0.03
3	Milbon (Thailand) Co., Ltd.	0.02
4	Louyang Longmen Ferro-alloy Factory (Thailand) Co., Ltd.	0.01
5	Pnp Chemitech Company Limited	0.01
6	Pattanaphan Chemical Tech Co., Ltd.	0.01
7	Ouchi (Thailand) Co., Ltd.	0.004
8	Amata BIG Industrial Gas Co., Ltd.	0.004
9	Sakura Printing Technology Co., Ltd.	0.003
	Total	**0.31**

Northern region

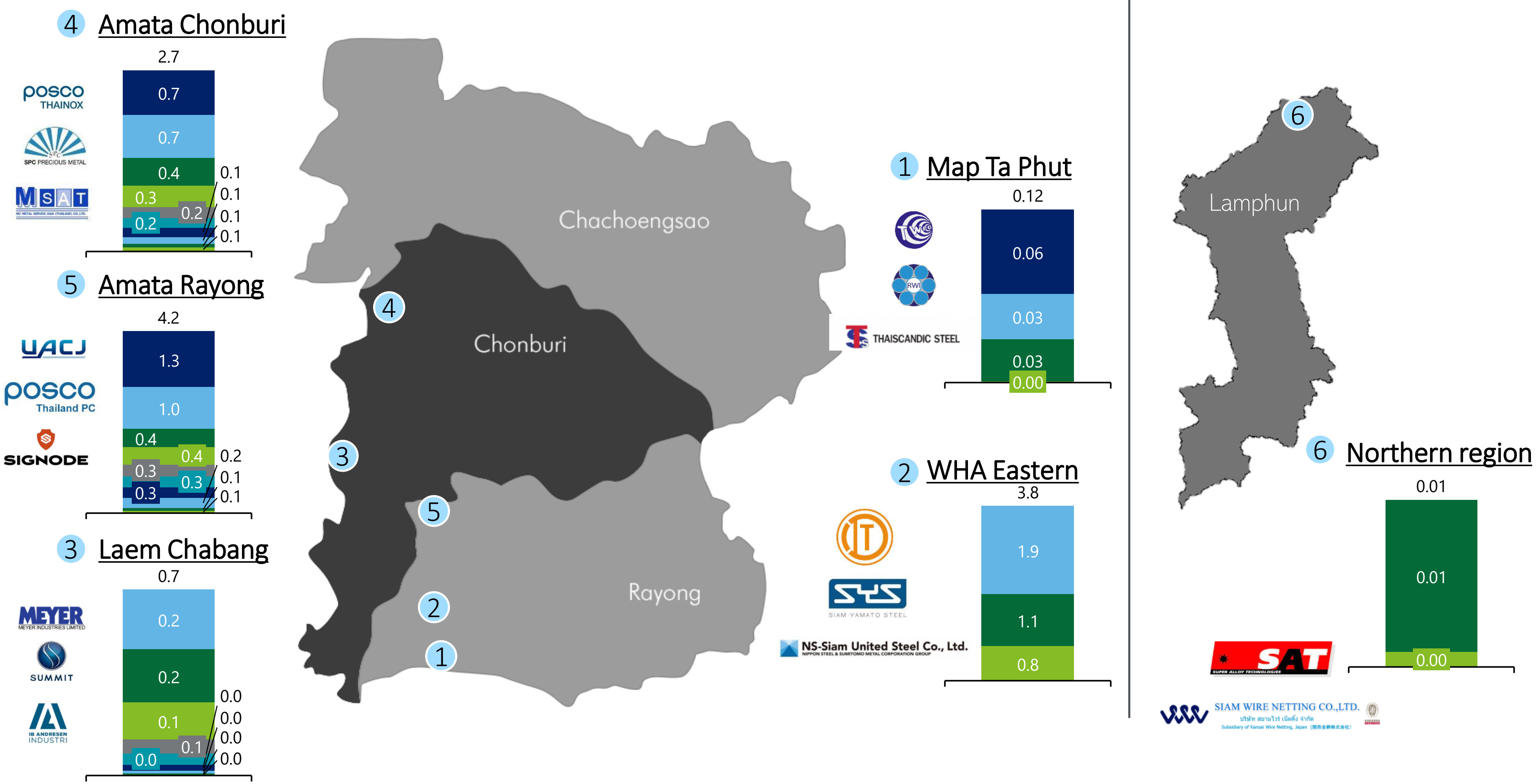
No	Company	Revenue (Billion THB)
1	Nippon Sanso Co., Ltd. (Thailand)	0.04
2	Electro Ceramics (Thailand) Co., Ltd.	0.04
3	Interpretive Co., Ltd.	0.03
4	San-esu Eng (Thailand) Co.,Ltd.	0.004
	Total	**0.11**

 Source: D&B Hoovers, DBD

WHA Eastern and Amata Rayong show high potential for hydrogen demand

(Reference) Top companies in Steel and Metal industry I Revenue (Billion THB)

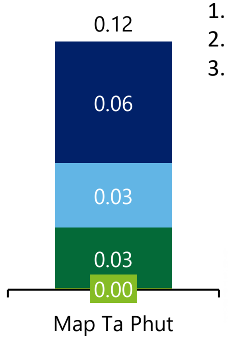
EEC	Northern part



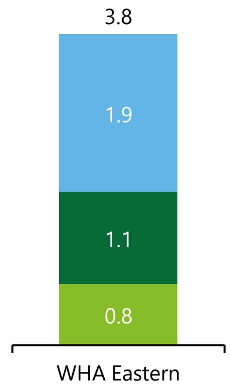
 Source: Industrial website, Deloitte Analysis

WHA Eastern and Amata Rayong show high potential for hydrogen demand

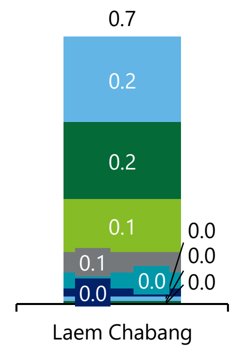
(Reference) Top companies in Steel and Metal industry I Revenue (Billion THB)



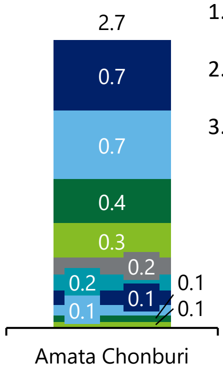
1. Thai Wire Products Plc
2. Thai-scandic Steel Co Ltd
3. Rayong Wire Industries Co Ltd



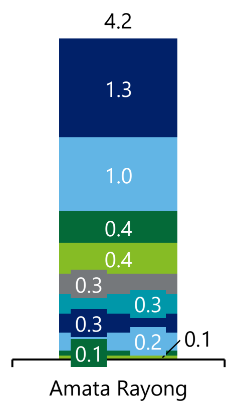
1. Italian Thai Development Corp
2. NS-siam United Steel Co Ltd
3. Siam Yamato Steel



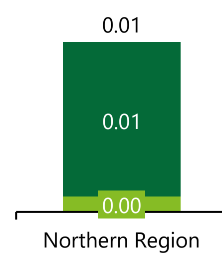
1. Meyer Industries Limited
2. Summit Advanced Materials Co., Ltd.
3. IB Andresen Industry (Thailand) Company Limit



1. Posco-thainox Public Company Limited
2. MC Metal Service Asia (Thailand) Co., Ltd.
3. S.P.C Precious Metal Company Limited



1. UACJ (Thailand) Co., Ltd.
2. Signode Systems (Thailand) Co., Ltd.
3. POSCO (Thailand) Co., Ltd.



1. Siam Wire Netting Co., Ltd.
2. Super Alloy Technologies Company Limited

 Source: D&B Hoovers, DBD

Revenue of top steel and metal companies is more than 11 Billion THB (314 Million USD) indicating high potential demand for hydrogen consumption

(Reference) Top companies in Steel and Metal industry

Map Ta Phut

No.	Company	Revenue (Billion THB)
1	Thai Wire Products Plc	0.06
2	Thai-scandic Steel Co Ltd	0.032
3	Rayong Wire Industries Co Ltd	0.03
4	Siam Yamato Steel Co Ltd	0.001
	Total	**0.12**

WHA Eastern

No.	Company	Revenue (Billion THB)
1	Italian Thai Development Corp	1.91
2	NS-siam United Steel Co Ltd	1.12
3	Siam Yamato Steel	0.75
	Total	**3.87**

Laem Chabang

No.	Company	Revenue (Billion THB)
1	Meyer Industries Limited	0.21
2	Summit Advanced Materials Co., Ltd.	0.19
3	IB Andresen Industry (Thailand) Company Limit	0.13
4	MSM (Thailand) Co., Ltd.	0.05
5	Meyer Aluminium (Thailand) Company Limited	0.04
6	P.S. Metal Works Co., Ltd.	0.02
7	Hadley (Thailand) Co.,Ltd.	0.01
8	Nico Steel Centre (Thailand) Company Limited	0.005
9	Arezzo Refinery Company Limited	0.003
	Total	**0.66**

Amata Chonburi

No.	Company	Revenue (Billion THB)
1	Posco-thainox Public Company Limited	0.67
2	MC Metal Service Asia (Thailand) Co., Ltd.	0.65
3	S.P.C Precious Metal Company Limited	0.42
4	Oriental Copper Company Limited	0.33
5	Amagasaki Pipe (Thailand) Co., Ltd.	0.16
6	Hanwa Steel Service (Thailand) Co., Ltd.	0.15
7	Toyota Boshoku Siam Metal Company Limited	0.14
8	Nippon Steel And Sumikin Pipe (Thailand) Co., Ltd.	0.10
9	Yamaha Motor Parts Manufacturing (Thailand) Co., Ltd.	0.06
10	Copper Cord Industry Company Limited	0.06
	Total	**2.78**

 Source: D&B Hoovers, DBD

Revenue of top steel and metal companies is more than 11 Billion THB (314 Million USD) indicating high potential demand for hydrogen consumption

(Reference) Top companies in Steel and Metal industry

Amata Rayong

No.	Company	Revenue (Billion THB)
1	UACJ (Thailand) Co., Ltd.	1.28
2	Signode Systems (Thailand) Co., Ltd.	0.96
3	POSCO (Thailand) Co., Ltd.	0.42
4	Sumitomo Electric Wiring Systems (Thailand) Co., Ltd.	0.40
5	Prime Steel Mill Company Limited	0.27
7	New Thai Wheel Menu Manufacturing Co., Ltd.	0.25
8	Shinjin SM (Thailand) Co., Ltd.	0.25
9	POSCO Coated Steel (Thailand) Co., Ltd.	0.23
10	Sumiden Steel Wire (Thailand) Co., Ltd.	0.07
	Pacific Sheet and Coil (Thailand) Co., Ltd.	0.05
	Total	**4.18**

Northern region

No.	Company	Revenue (Billion THB)
1	Siam Wire Netting Co., Ltd.	0.01
2	Super Alloy Technologies Company Limited	0.001
	Total	**0.01**

 Source: D&B Hoovers, DBD

Desktop Research - ②Thailand

1. Overview of Supply Chain
2. Demand Side
3. **Supply Side**
4. Public Acceptance

Domestic Supply

International Supply

Thailand has potential of domestic hydrogen production in a various measures, including electrolysis, SMR with biogas, byproducts and lignite gasification

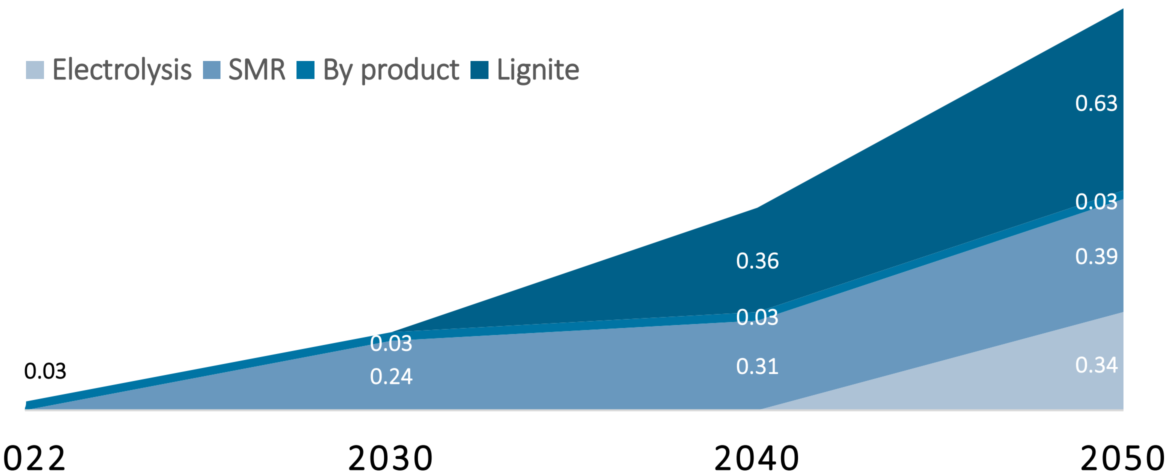
Domestic Hydrogen Production

Domestic Hydrogen Production

Electrolysis	Renewable Energy	Surplus of solar PV generation to be considered
Steam Methane Reforming	Bio	Hydrogen production from biogas derived from poultry manure and waste food > Fermi estimation
Byproduct	Steel	COG from coke ovens (BFG/LDG has low hydrogen concentration and no external sales potential)
	Oil Refinery	Catalytic reforming of heavy naphtha hydrogen production (mainly steam reforming) for desulphurisation and hydrocracking
	Naphtha Cracking	Thermal cracking of naphtha in the ethylene production process (naphtha cracking).
	Sodium Hydroxide (NaOH)	Electrolysis of saline solution
Lignite	Gasification	Gasification of lignite (Mae Moh) plus carbon capture and storage (CCS), referencing Victorian lignite study

Domestic hydrogen supply potential is projected as 1.39 mtpa in 2050 in consideration to Electrolysis, SMR-Biogas, Byproduct and Lignite

Domestic Hydrogen Production Estimation



Unit: mtpa

	2022	2030	2040	2050
Domestic Hydrogen Production	0.03	0.27	0.70	1.39
Electrolysis	0	0	0	**0.34**
Steam Methane Reforming- Biogas	0 (0.18: potential)	0.24 (+0.8: crop residue0.8)	0.31 (+0.8: crop residue0.8)	0.39 (+0.8: crop residue0.8)
Byproduct (external sales)	0.03	0.03	0.03	0.03
Lignite	0	0	0.36	0.63

Domestic Hydrogen Production

- **Electrolysis**
- Steam Methane Reforming- Biogas
- Byproduct
- Lignite

Supply Amount

Unit: mtpa

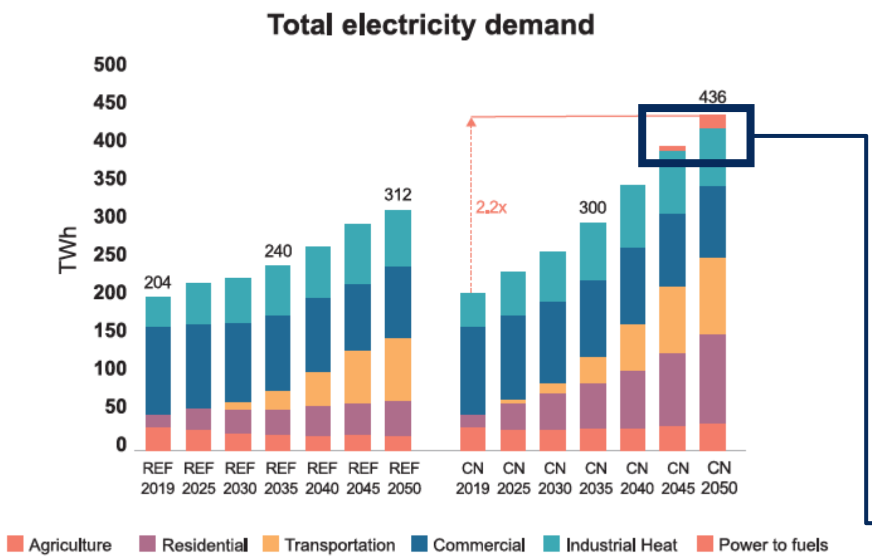
	2022	2030	2040	2050
Domestic Hydrogen Production	0.03	0.27	0.70	1.39
Electrolysis	0	0	0	0.34
Steam Methane Reforming- Biogas	0 (0.18: potential)	0.24	0.31	0.39
Byproduct	0.03	0.03	0.03	0.03
Lignite	0	0	0.36	0.63

Green Hydrogen of 0.14 mtpa in 2045 and 0.34 mtpa in 2050 would be produced considering studied energy system toward CN 2050

Domestic Supply-Green Hydrogen

Green Hydrogen Production (mtpa) = Electricity required for 1 Nm3 of H2 production 4.44 kWh/Nm3 × Electricity consumption for electrolyzer (kWh) × Conversion factor 11.14 Nm3/kg

Higher heating value (H2) 12.8 MJ / Nm3 / Heating value (elec) 3.6 MJ / kWh ÷ Electrolyzer efficiency (HHV) 80 %

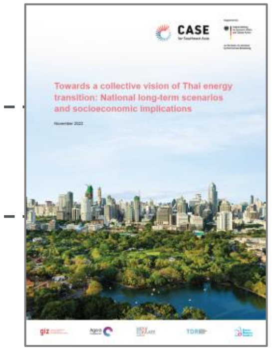


	Electricity to Fuel (GWh)		H2 Production capacity (mtpa)
year	Forecast toward CN 2050	Ref PDP2018	
2023	0	0	0
2030	0	0	0
2040	0	0	0
2045	7,030	0	0.14
2050	16,790	0	0.34

Source: Deloitte analysis based on GIZ (2022) "Towards a collective vision of Thai energy transition: National long-term scenarios and socioeconomic implications"

Study on energy transition toward carbon neutrality 2050 was conducted by German Government and importance of flexible operation including hydrogen is insisted

Domestic Supply- Energy Transition Study toward Carbon Neutrality



Document Name: Towards a collective vision of Thai energy transition: National long-term scenarios and socioeconomic implications

Year of publishment: Nov 2022

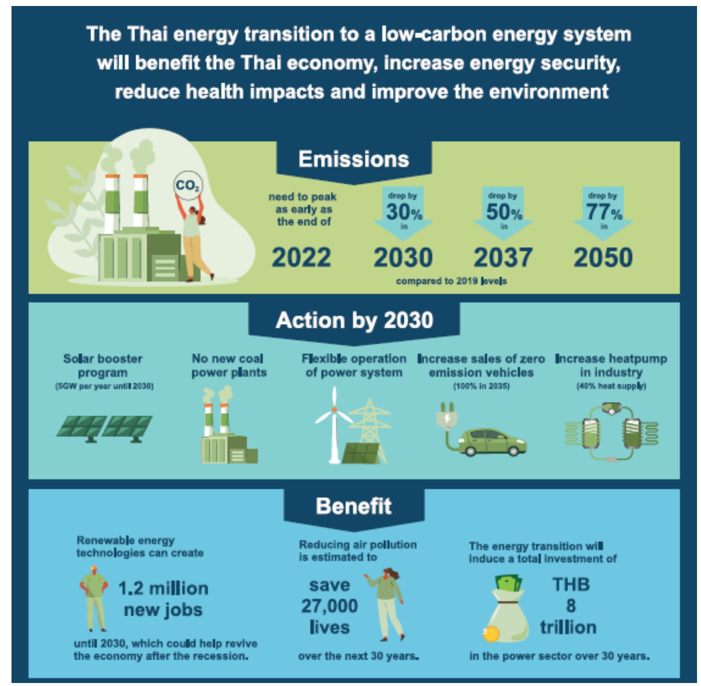
Issued by: CASE for Southeast Asia (GIZ: Deutsche Gesellschaft für Internationale Zusammenarbeit)

Background & Purpose

- CASE studied the long term vision about CN achievement toward 2050, focusing on energy transition
- CASE is funded by GIZ and German Government as the bilateral cooperation

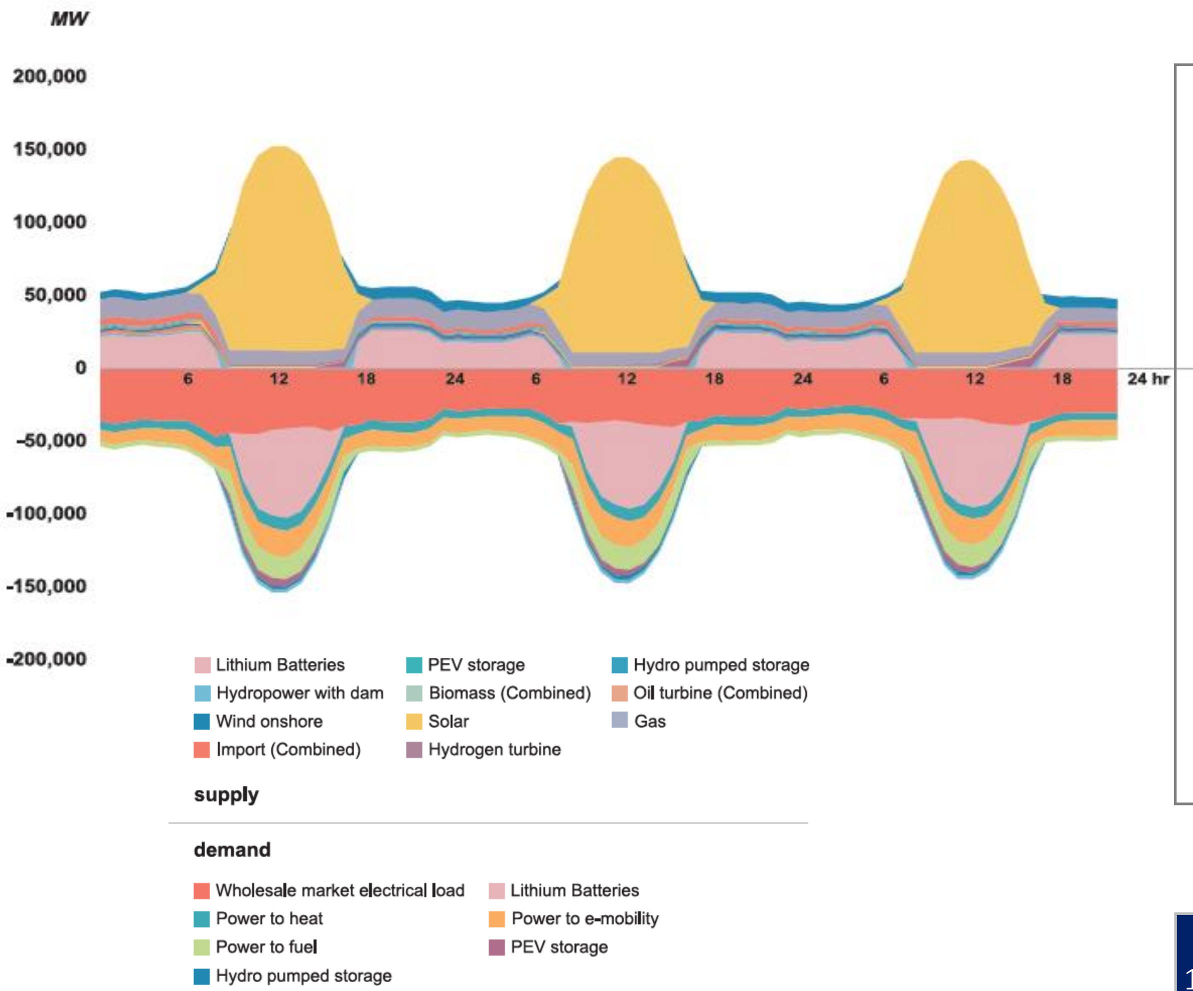
Summary

- Achieving Thailand's vision of carbon neutrality with a cost-efficient transition will depend on today's choices and policy actions, which will shape the energy system in the next decades.
- The transition to a low-carbon energy system will benefit the Thai economy, increase energy security, reduce health impacts and improve the environment.
- The energy transition represents an opportunity to modernise the Thai energy system and will require a comprehensive program of investments.
- The road to climate neutrality requires the transformation of all sectors, which in turn calls for cross-ministerial dialogue and integrated planning.



16,790 GWh for one year in 2050 to produce hydrogen is assumed in consideration to variable renewable energy generation, EVs and batteries

Hourly generation and demand profile for an exemplary 3 days in 2050

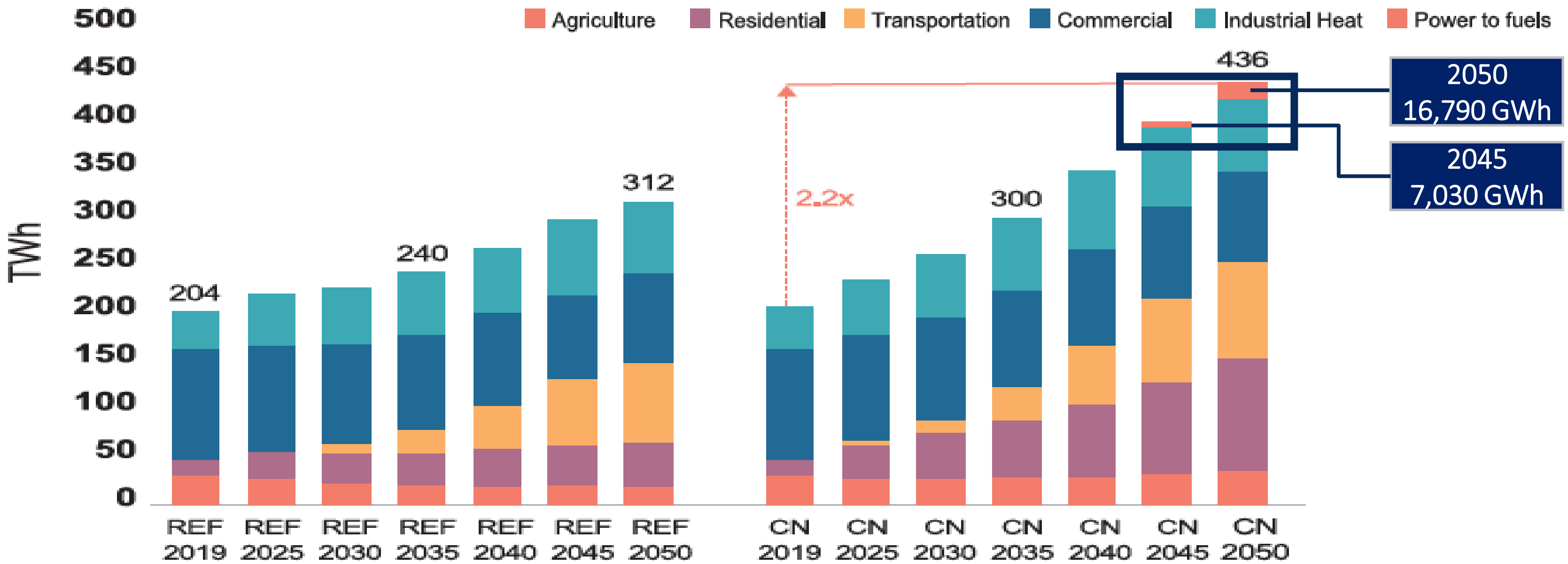


- Production of synthetic fuels (e.g., green hydrogen)
  - important flexible demand which is primarily produced during solar generation hours
  - Generation of 138 GWh for 3 days (16,790 GWh) with peak demand of 16 GW is assumed to consuming elec.
- Battery storage
  - flexible load with a peak of 60 GW. In one day, 330 GWh of electrical power is stored in batteries
- Optimal EV charging
  - helps to optimize power system operation. Smart charging works by increasing the charge during high solar hour while decreasing during the evening which have high inflexible peak power load

16,790 GWh for one year in 2050 to produce hydrogen

7,030GWh and 16,790 GWh are expected to consumed for Power to Fuels in CN scenario while no amount is assumed in reference scenario

Total Electricity Demand by Scenario

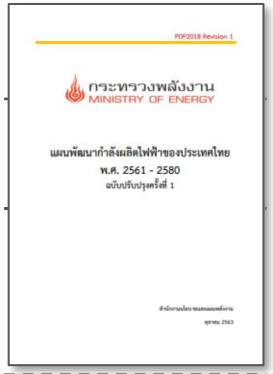


	Reference	CN
Power Generation	• Increase RE to at least 30% at 2030, based on existing policy • Based on revised PDP2018 Rev.1 during 2021-2030 announced in Nov 2021	• Faster deployment of RE and storage, including at utility scale and prosumers • Phase out of coal power plant • Flexible system operation
Transmission	• Increase interconnection based on existing plan	• Increase interconnection based on optimization
Energy Demand	• Reduce intensity more than 30% using modern technologies and energy management innovations • 100% zero emission vehicle sales in 2035 • Fuel switch from coal to biomass, electrification of heat	• Increase efficiency by higher efficiency rating and benchmarked technology in ASEAN or beyond • 100% zero emission vehicle sales in 2030 • Fuel switch from coal to biomass, electrification of heat Hydrogen for heat generation in industry

Reference

Thailand's Government shows the long-term electricity generation plan in PDP (PDP2018 Rev.1)

Thailand's Power Development Plan (PDP)



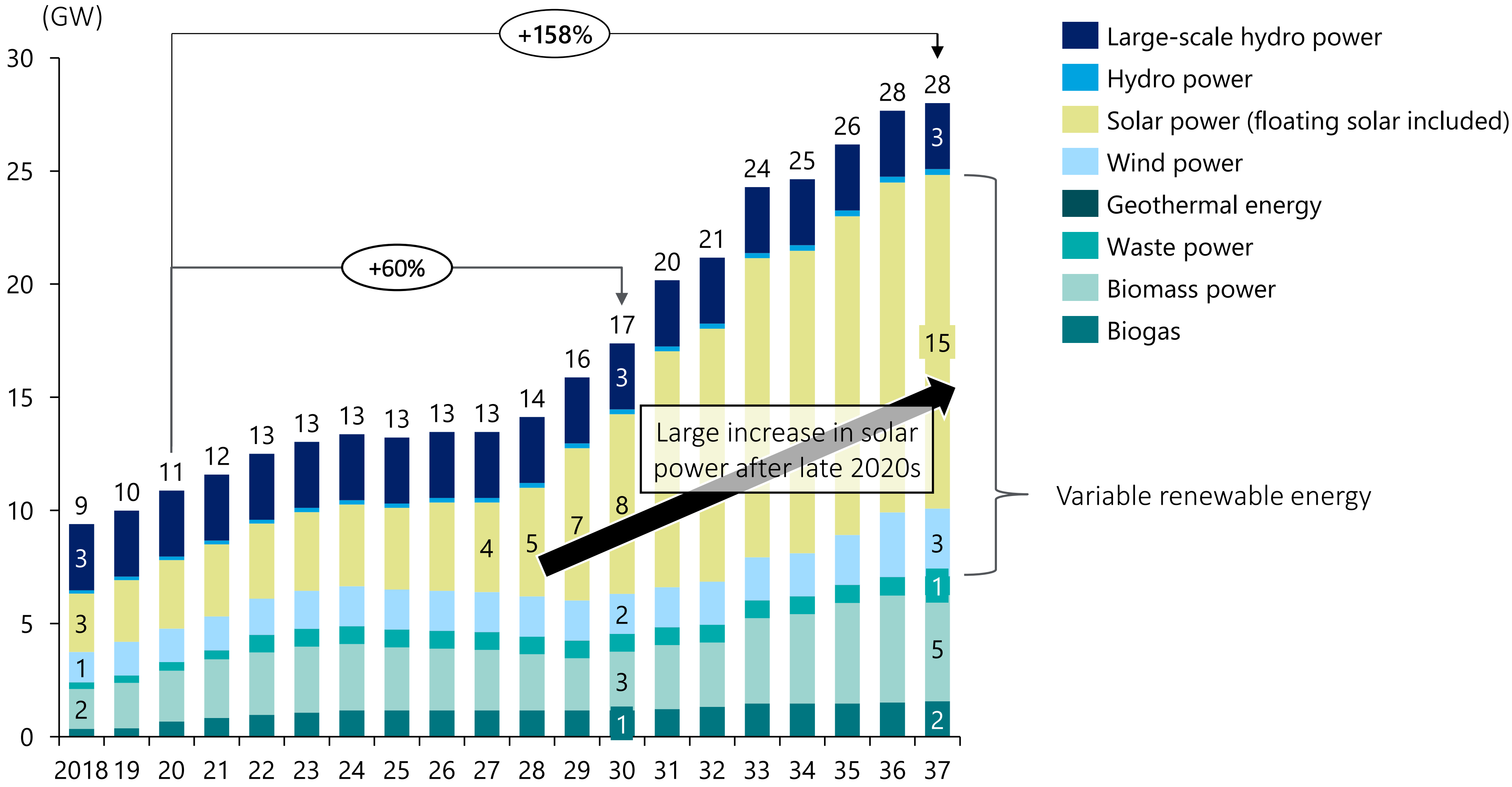
Document Name	Thailand's Power Development Plan 2018-2037 Revision1 (PDP2018 Rev.1)		
Year of publishment	2018	Issued by	Ministry of Energy
Background	■ Ministry of Energy had been publishing PDPs, and PDP2018 needed adjustment because of the publishment of new Alternative Energy Development Plan (AEDP)		
Purpose	■ To show the long-term electricity generation blueprint of Thailand's energy transition ➢ includes the development of new power plants in the country ➢ the development of power transmission systems ➢ the purchase of electricity from neighboring countries		
Summary	■ The plan prioritizes three different areas, which includes energy security, economy, and ecology, for the next decades ■ It mentions energy sources such as hydro power, biomass power, solar power, waste power, natural gas, and coal, and 25.7 percent of the total energy is expected to be generated from renewable sources ■ Apart from electricity generating plan, It also includes energy efficiency measures		

Source: Ministry of Energy (2020) "The Direction of Electricity Policy in Thailand", Ministry of Energy (2018) "Thailand's Power Development Plan 2018-2037 Revision1"

Reference

Renewable energy capacity is planned to double, with a considerable solar energy capacity increase after the late 2020s onward

Renewable energy capacity prospect in Thailand



 Source: Ministry of Energy (2018) "Thailand's Power Development Plan 2018-2037 Revision1"

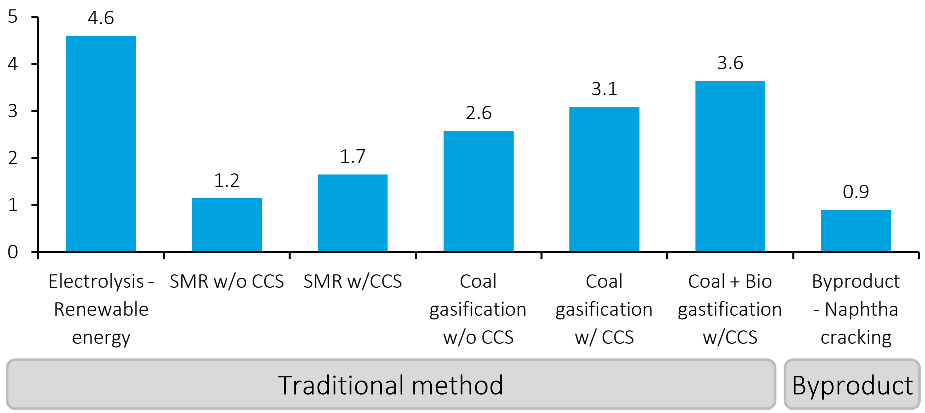
Cost Information

Electrolysis remains the most expensive method of hydrogen production in the future

Hydrogen production cost analysis I Overview

Current average price (2020-2021)

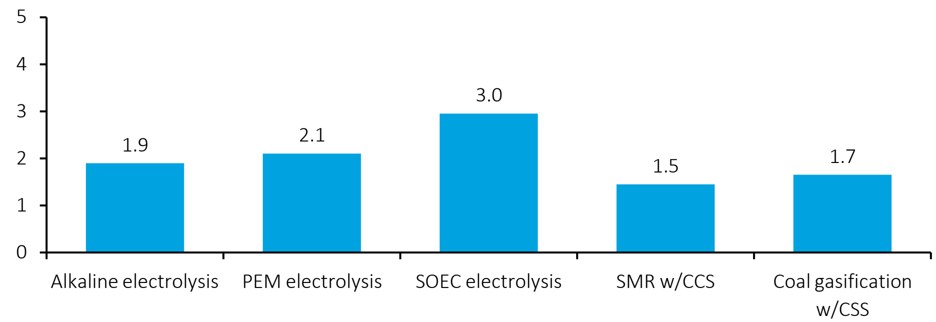
Unit: $/Kg of H2



Key Highlight	
Electrolysis	• Expensive because it is required a significant amount of electricity • Less efficiency due to energy loss
Coal gasification	• More expensive than SMR due to more complex process of production
Coal+Bio gasification	• More expensive due to integrating biogas into gasification process

Future average price (2025-2030)

Unit: $/Kg of H2



Key Highlight
• Hydrogen cost from all type of electrolysis are expected to lower down to $2-3/USD

 Source: IEA, U.S. Department of Energy, European commission

Average cost of electrolysis is at $4.59/kg which can be varied based on renewable energy source and electricity price

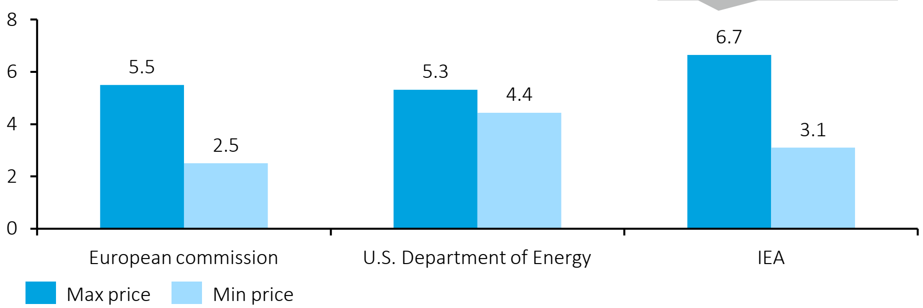
Hydrogen production cost analysis I Electrolysis

Electrolysis

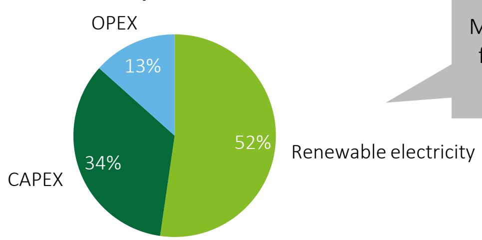
Average cost of green hydrogen by electrolysis

Unit: $/Kg of H2

Average cost is approximately **$4.59/kg** of H2



Cost component



Majority of the cost is from **electricity and electrolyzer**

Main Cost component	Detail
1. Renewable electricity	-
2. CAPEX	Electrolyser plant (infrastructure)
3. OPEX	Labour, maintenance, water supply

Hydrogen costs for PEM electrolysis from various energy source

Hydrogen cost of production will be different depending on source of energy, electricity price and location

	Electricity Cost (¢/kWh)	Capacity Factor	System CapEx ($/kw)	H2 Cost ($/kg)
Solar PV Utility Los Angeles, CA	3.2	31.8%	1,000	$6.09
Solar PV Utility Daggett, CA	2.9	35.1%	1,000	$5.54
Wind Onshore Utility, Class 6	3.8	38.0%	1,000	$5.76
Wind Onshore Utility, Class 1	2.8	52.1%	1,000	$4.22

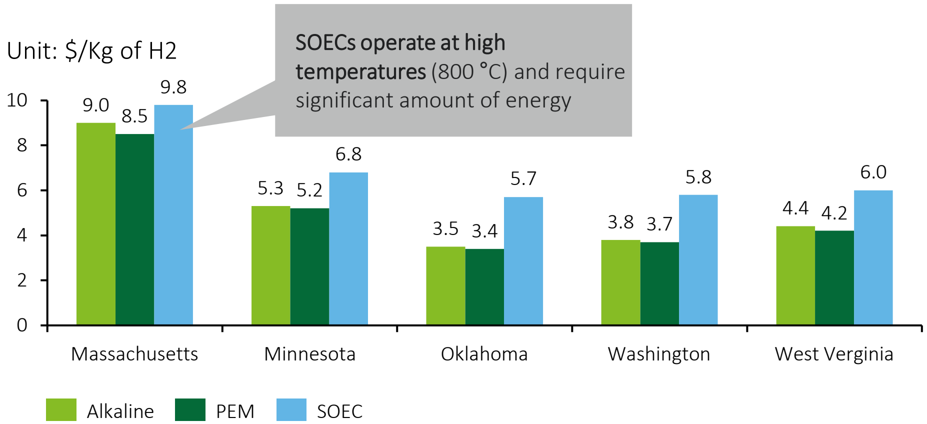
 Source: IEA, U.S. Department of Energy, European commission, Published research

SOEC electrolysis, the most efficient method, shows the highest cost of production especially from the location with high electricity cost

Hydrogen production cost analysis I Electrolysis

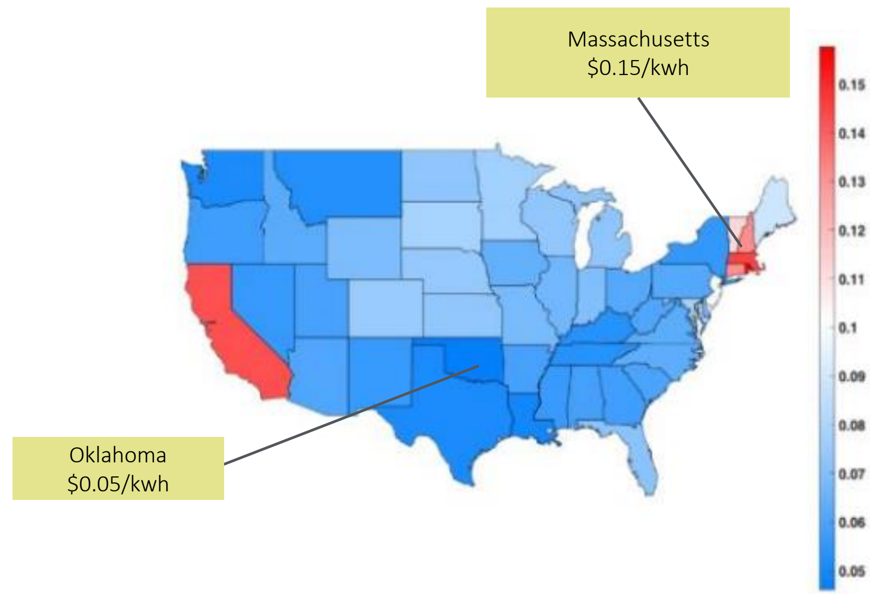
Electrolysis

Example of hydrogen production cost by electrolyzer in 2020 I U.S.A. state



Cost	Key Highlight
Average cost of LCOH in 2020 • Alkaline: $4.6/kg • PEM: $4.5/kg • SOEC: $6.3/kg	• **Electricity is accounted approximately 50%** of total LCOH • Massachusetts state has the highest electricity cost among others • **In 2050**, given same production capacity, **SOEC will become the cheapest technology** due to its high efficiency and also produce the lowest carbon footprint

Levelized cost of industrial electricity I U.S.A. state



Blue: indicate low electricity rate
Red: indicate high electricity rate

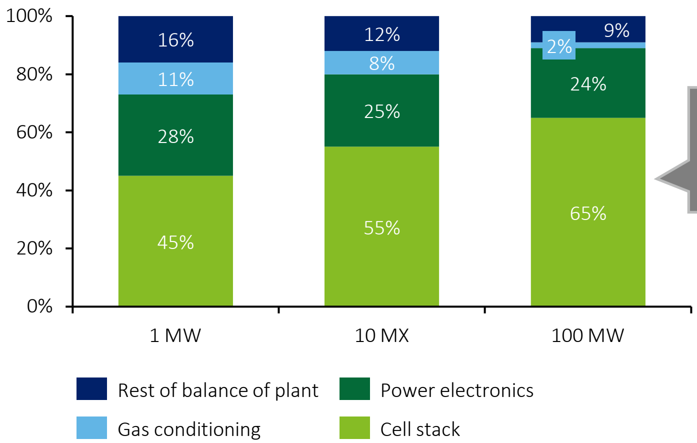
 Source: EIA

Electrolyzer investment cost per kw can be reduced by increasing the size

Hydrogen production cost analysis I Electrolysis

Electrolysis

Cost breakdown by alkaline eletrolyzer component



Main cost is **Cell stack** which works by converting chemical energy to electricity

- **Investment cost (USD/kW) is lower** when we increase the size of electrolyzer
  - **Size 1MW**: ~ $1,050/kw
  - **Size 10 MW**: ~ $620/kw
  - **Size 100 MW**: ~ $480/kw

Other cost for hydrogen production by electrolysis

Water transport (from desalination plant to inland) costs would increase the total costs for hydrogen by approximately **$0.05-0.06**/kg H2 for 100 km distance

Direct seawater electrolysis is not yet commercially available

 Source: IRENA, IEA

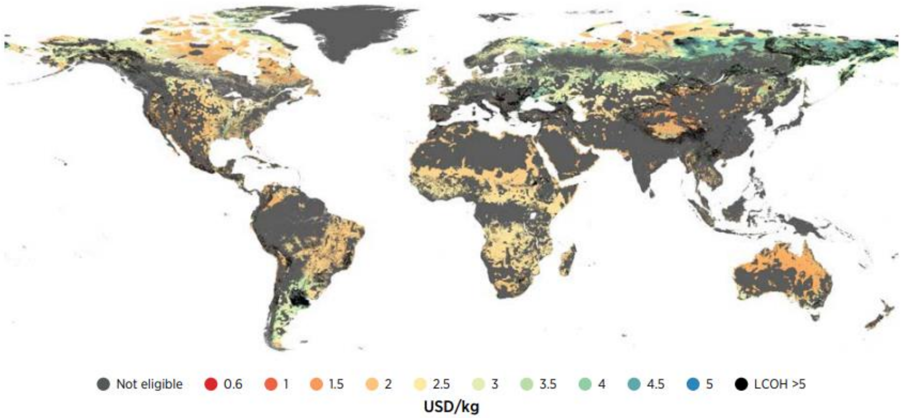
With the assumption of lower renewable energy cost in 2050, LCOH is expected to decrease to $1/kg on average

Hydrogen production cost analysis I Future Outlook

Electrolysis

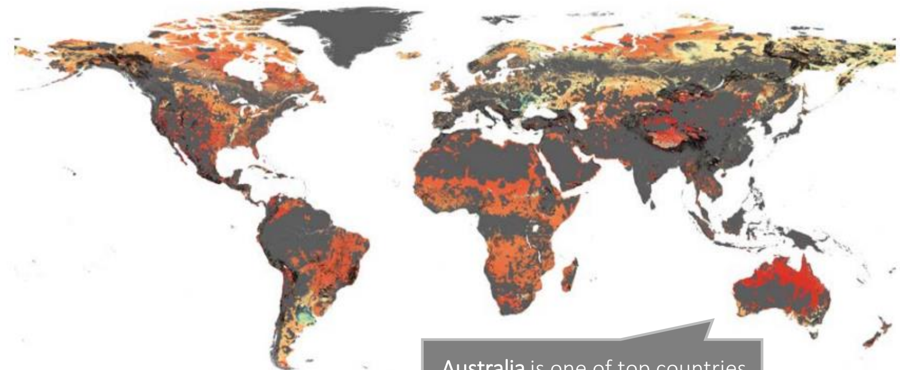
Global levelised cost of hydrogen (LCOH)

2030



2050

Assumption based on lower cost of renewable energy by 90% in 2050



Australia is one of top countries with lowest hydrogen production cost in 2050

Estimated hydrogen price in 2050 by countries

Country	Price ($/kg)	Country	Price ($/kg)
Australia	0.6	New Zealand	1
Brunei	N/A	Oman	N/A
India	0.6	Pakistan	1
Indonesia	1	Saudi Arabia	1
Kazakhstan	1.5	UAE	N/A
Malaysia	N/A	Vietnam	1

In 2050, capital cost gap between region is expected to go down due to

1. More countries develop domestic experience and exchange lessons learned with others
2. Entire supply chain will be scaled up benefiting from EOS
3. Associated risk from building the plant facility will be decreasing

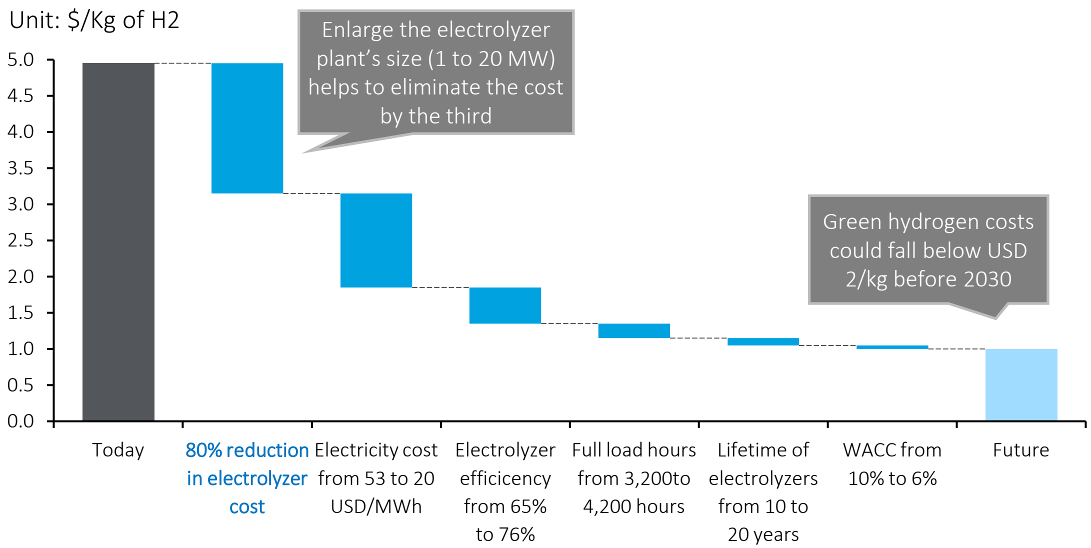
Note: Estimated hydrogen price in 2050 is based on price on the IRENA's map
Source: IRENA

According to IRENA, lower cost of electrolyzer and electricity have a potential to cut hydrogen production costs by 80%

Hydrogen production cost analysis I Future Outlook

Electrolysis

Hydrogen production cost by electrolysis today vs future



How to reduce electrolyzer cost

Increase module size of electrolyzer can take advantage of bulk purchasing of materials, component, equipment resulting in lower unit cost

Improve the Innovations in stack design involves a combination of engineering innovations, materials selection, and process optimization

Cost indicator for electrolyzer technologies

	2020			2050		
	Alkaline	PEM	SOEC	Alkaline	PEM	SOEC
Capital costs estimate for **large stack**(>1MW) (USD/KW)	270	400	>2,000	<100	<100	<200
Capital costs estimate for **entire systems** (>10MW) (USD/KW)	500-1,000	700-1,400	-	<200	<200	<300

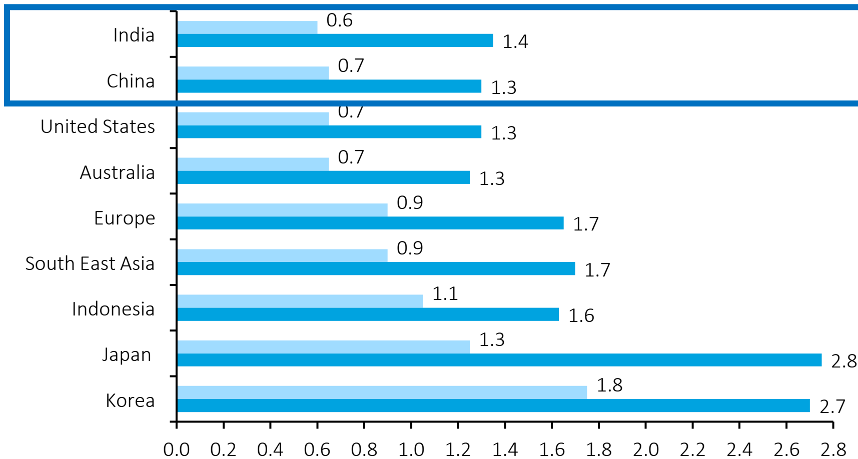
 Source: IRENA

India and China could be ideal location for hydrogen source that Thailand can import due to its lower production cost and high capacity

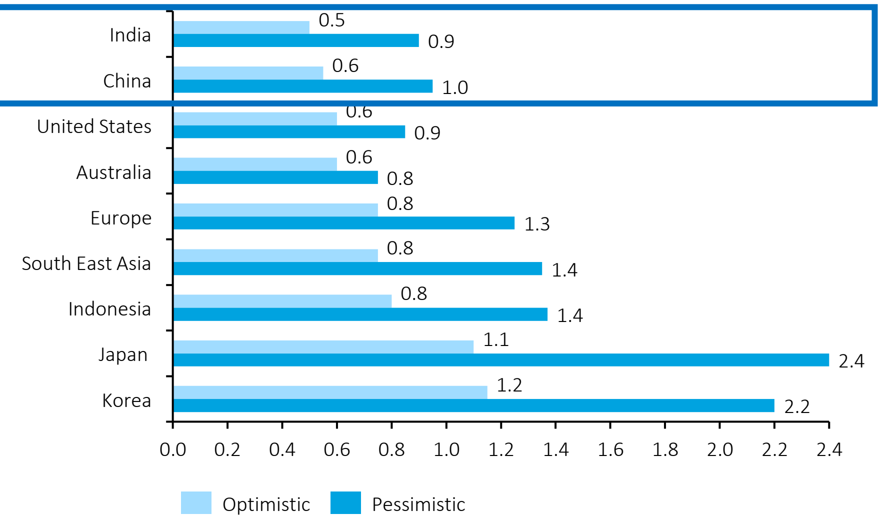
Hydrogen production cost analysis I Future Outlook

Electrolysis

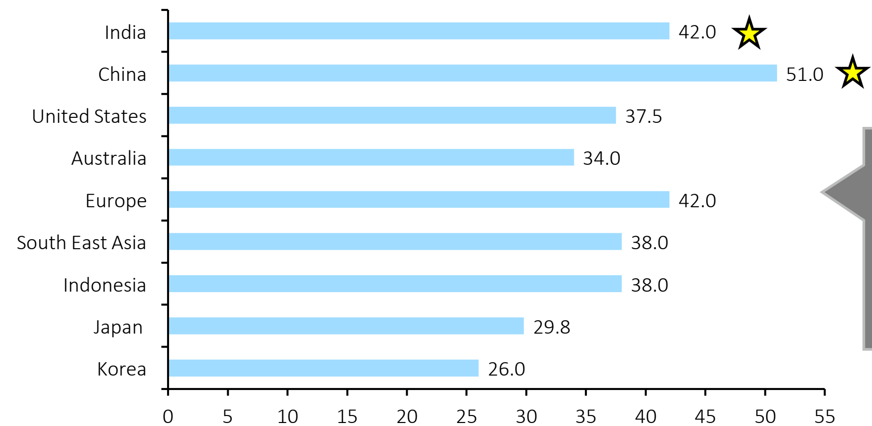
Electrolyzer cost (USD/Kg) in 2050



Electricity cost (USD/Kg) in 2050

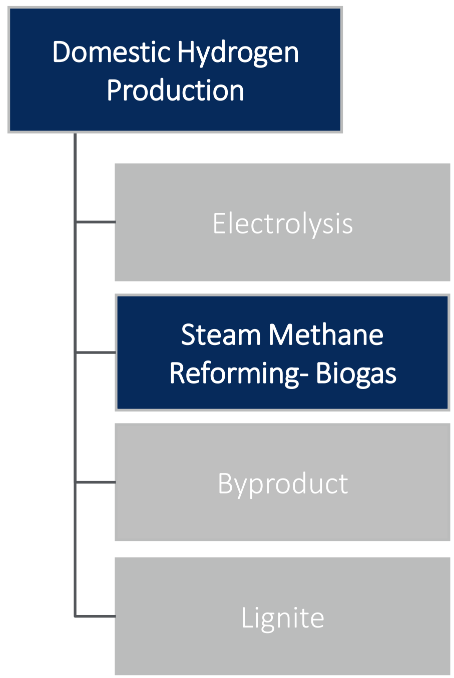


Electrolyzer capacity factor (%)



- Meaning : **ratio of actual output and maximum output** from production
- 100% : produce continuously without downtime
- Less than 100% = possibly facing factors e.g. **maintenance, shutdowns, or variations in electricity supply**

 Source: IRENA


Domestic Hydrogen Production
Electrolysis
Steam Methane Reforming- Biogas
Byproduct
Lignite

Supply Amount

Unit: mtpa

	2022	2030	2040	2050
Domestic Hydrogen Production	0.03	0.27	0.70	1.39
Electrolysis	0	0	0	0.34
Steam Methane Reforming- Biogas	0 (0.18: potential)	0.24	0.31	0.39
Byproduct	0.03	0.03	0.03	0.03
Lignite	0	0	0.36	0.63

Due to Single year data is available only, so the projection is to be estimated by GDP growth.

Domestic Supply- Feedstock of Biogas in Thailand (in 2011)

Forecast of Biogas Production

Calculation for hydrogen Production

		Biogas Potential		Bio gasification facilities: Introduced		Bio gasification facilities: Not introduced	
	Category	Number of farms (*1000)	Volume (*1000 m3/year)	Number of farms (*1000)	Volume (*1000 m3/year)	Number of farms (*1000)	Volume (*1000 m3/year)
Animal based	Pig (small size)	3,000	131,690	1,770	77,700	1,230	53,990
	Pig (medium and large)	4,140	181,670	2,190	96,100	1,950	85,570
	Cattle	8,000	822,000	N/A	N/A	N/A	N/A
	Chicken and others	N/A	125,000	N/A	N/A	N/A	N/A
	total	15,140	1,260,360	3,960	173,800	3,180	139,560
Plant based	Starch	77	377,000	36	162,740	41	214,260
	Beer	13	110,000	13	110,000	0	0
	Food	108	100,000	44	40,740	64	59,260
	Palm	44	25,300	5	2,900	39	22,400
	Paper	23	29,000	2	2,520	21	26,480
	Rubber	87	84,000	2	1,620	85	82,380
	Ethanol	24	218,400	4	36,400	20	182,000
	total	376	943,700	106	356,920	770	586,780

- Both animal Origin and Crops origin were calculated
- Single year is only available; Calculation is to be done with GDP growth

Source: JICA Report (DEDE)

Hydrogen Production Amount and possible external sales amount are given by the following equation

Hydrogen Production Amount

Forecast of Biogas Production

Hydrogen Production (mtpa) = Biogas Production(m3/yr) × Conversion Factor* (=280/200)

Calculation for hydrogen Production

	2022	2030	2040	2050
Steam Methane Reforming- Biogas	0.18 (potential)	0.24	0.31	0.39

*Source: 寒冷地土木研究所月報No661 2008年6月

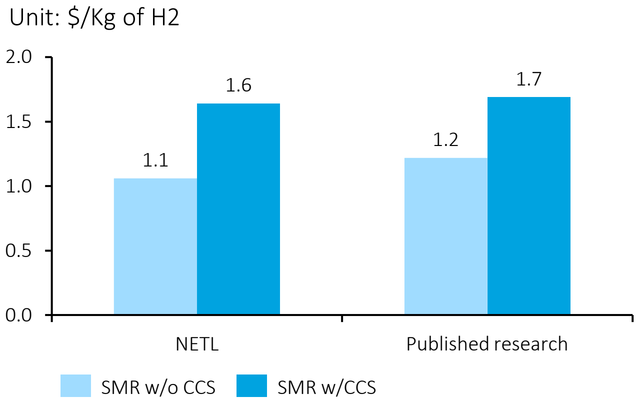
Cost Information

SMR production cost, which is highly related to price of natural gas, is between $1-$2/kg

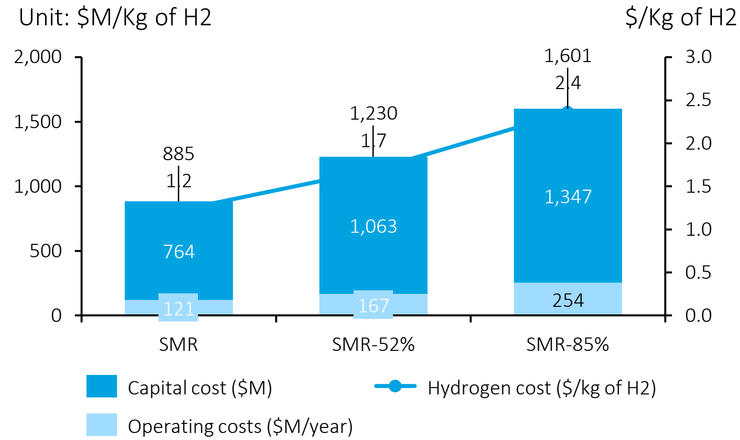
Hydrogen production cost analysis I SMR

SMR

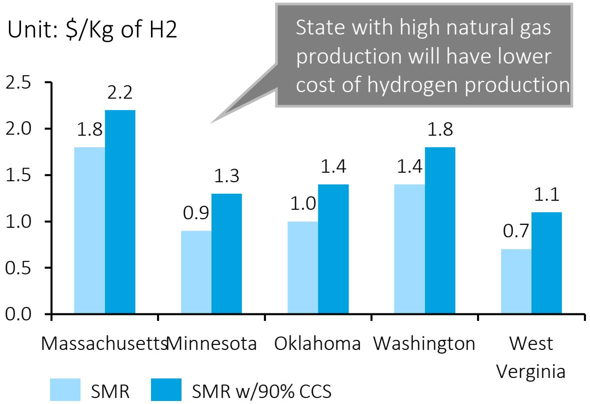
Average cost of green hydrogen by SMR



Hydrogen production cost break down



Example cost of hydrogen production by SMR I U.S.A. state



State with high natural gas production will have lower cost of hydrogen production

Key Highlight

- **Extra cost** of CCS added to the SMR process is **$0.4/kg-H2**
- The production cost by SMR is lower than electrolysis by 50-80% in 2020

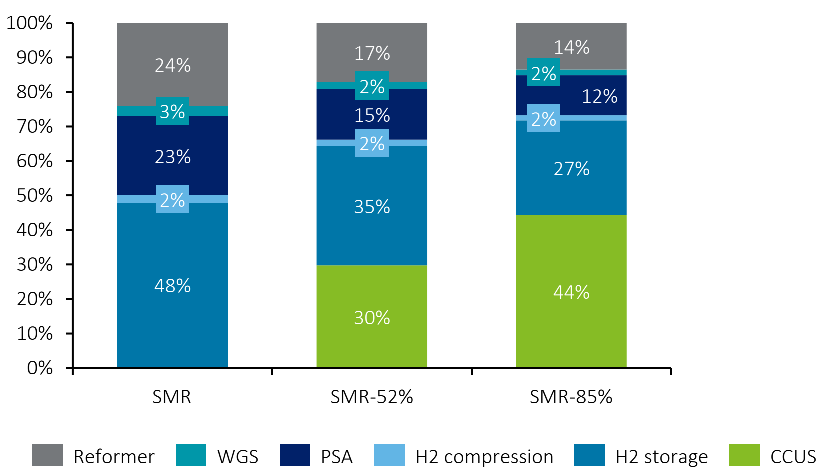
Note 1. CCS cost includes Co2 capture, compression, pipeline, storage, sequestration 2. SMR52% and 85% represent % of carbon being captured
Source: Published research, NETL

H2 storage and CCUS are the major cost component while raw materials is accounted 40% of operating cost

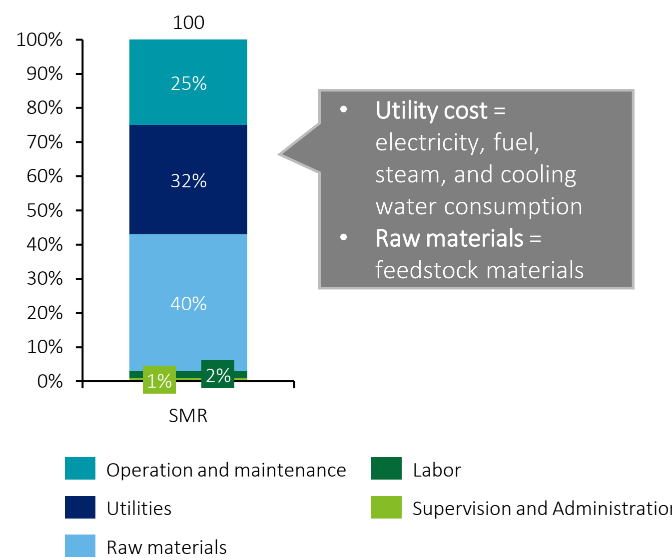
Hydrogen production cost analysis I SMR

SMR

SMR's capital cost breakdown



SMR's operating cost breakdown



Note

H2 storage
Cost on tank, safety measure, pressure control system, leak detection more.

Reformer
Facilitate chemical reaction

PSA
Technology used for separating gases

WGS
Adjust the composition of the gas mixture & increase the hydrogen content

Note 1. CCS cost includes Co2 capture, compression, pipeline, storage, sequestration 2. SMR52% and 85% represent % of carbon being captured
Source: Published research, NETL

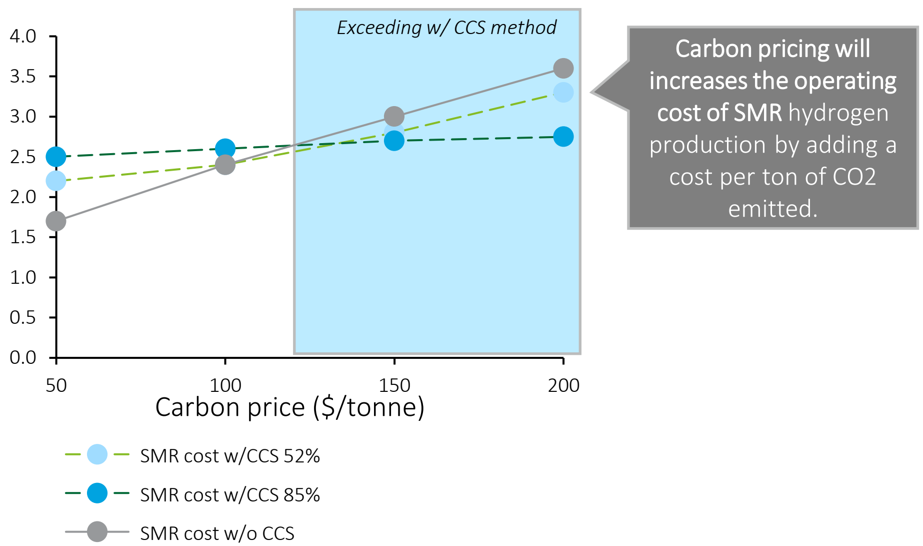
Carbon pricing could potentially shift hydrogen cost produced from SMR process to be higher in which likely to happen with the trend of carbon neutrality

Hydrogen production cost analysis I SMR

SMR

Effect of carbon pricing on hydrogen cost

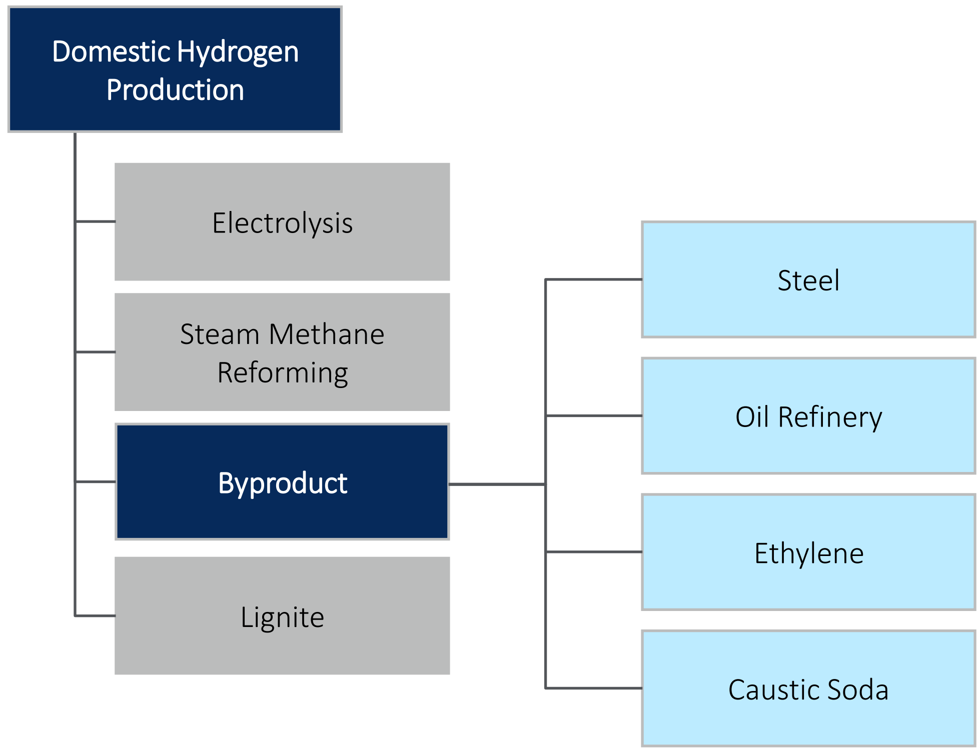
Unit: $/Kg of H2



Key Highlight

- With higher carbon price, the cost of SMR w/o CCS will exceed the one with CCS at one point

Note 1. CCS cost includes Co2 capture, compression, pipeline, storage, sequestration 2. SMR52% and 85% represent % of carbon being captured
Source: Published research, NETL


Domestic Hydrogen Production
Electrolysis
Steam Methane Reforming
Byproduct
Lignite
Steel
Oil Refinery
Ethylene
Caustic Soda

Supply Amount

Unit: mtpa

	2022	2030	2040	2050
Domestic Hydrogen Production	0.03	0.27	0.70	1.39
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Byproduct	0.03	0.03	0.03	0.03
Lignite	0	0	0.36	0.63

Trend of steel production is declining in recent year while oil refinery's production remains consistent amount overtimes

Domestic Supply- Production Source of by product hydrogen

Historical data

Type	2014	2015	2016	2017	2018	2019	2020	2021	2022
Steel (mtpa)	0.014	0.012	0.015	0.015	0.014	0.012	0.011	0.012	0.011
Oil Refinery (mtpa)	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006
Etyhlene (mtpa)	0	0	0	0	0	0	0	0	0
Caustic Soda (mtpa)	n/a	n/a	0.012	0.014	0.013	0.013	0.013	0.013	0.013
Total by product (mtpa)	n/a	n/a	0.033	0.035	0.034	0.032	0.031	0.032	0.031

Forecast

Type	2030	2035	2040	2045	2050
Steel (mtpa)	0.011	0.011	0.012	0.012	0.012
Oil Refinery (mtpa)	0.006	0.006	0.006	0.006	0.006
Ethylene (mtpa)	0	0	0	0	0
Caustic Soda (mtpa)	0.013	0.013	0.013	0.013	0.013
Total by product(mtpa)	0.031	0.031	0.031	0.031	0.031

* Scaling stage of Hydrogen reduction steelmaking is expected around 2050 in Phase 1 study

Estimation Condition of byproduct hydrogen is described as below;

Domestic Supply-Estimation Condition of Byproduct

Production Source	Byproduct Process of Hydrogen	Estimation Conditions
Steel	Coke Oven Gas (COG) BFG/LDG contain low density of hydrogen, so selling to other party is not considered	COG Production amount (m3/yr) = Crude Steel Capacity (t/yr) * 120.18 (m3/t) Hydrogen Production = COG production amount * Hydrogen content ratio(54-60% * Recovery ratio by PSA (65-70%) -> H2 ratio= 55.6%, PSA ration = 65% Steel Production Forecast calculated by elastic coefficient of GDP and steel production
Oil refinery	Contact reforming of heavy naphtha Steam Reforming	Hydrogen Production Amount (Nm3/day) = production capacity (Nm3/day, or BPSD)*Hydrogen production rate by facility*Hydrogen content ratio Hydrogen production rate by facility : approx. 63% , Content ration= 97%, Contact reforming : Hydrogen production rate: 36.24 (Nm3) for BPSD, Hydrogen content ration: approx. 85% Oil Production Forecast done by elastic coefficient of GDP and oil production
Petro chemical	Naphtha cracking in Ethylene production process Ethylene	Hydrogen Production Amount= Ethylene production amount (t/yr) * 321 (Nm3/t) * Recovery ratio by PTA (65-70%) -> PSA ratio = 65% Ethylenee production Forecast is considered stable (no increase) because new investment cannot be considered in context of carbon neutrality (need to be decarbonized)
Caustic Soda	Saline Electrolysis	Hydrogen Production Amount (Nm3/yr) = Production of Caustic Soda (t/yr) * 280 (Nm3/t)

 Source: NEDO (2020), "Estimation of byproduct hydrogen production capacity in Japan"

External sales ration vary by on-site usage of each plant

Domestic Supply- External Sales of Byproduct

Production Source	Possibility of External Sales	Rate for External Sales	Estimation Conditions
Steel	Moderate (none in the future)	40%	• By-product gases like COG are employed as fuel within the steelworks, with the remaining portion serving as fuel for power generation. The quantity fluctuates from one steel mill to another; however, in essence, by-product gases (COG, BFG, LDG) alone cannot fulfill the entire energy demand of the steel mill, necessitating the introduction of additional external fuels. • Only COG is utilized for hydrogen production, and hydrogen is generated from COG for fuel applications. Regarding the COG used for power generation, it can readily be substituted with alternative fuels, with the specific proportion varying among steel mills, typically around 40%.
Oil refinery	Possible	Surplus of Hydrogen Production Equipment	• In a previous survey of 19 refineries in Japan, it was found that nearly all by-product hydrogen (hydrogen generated as off-gas from hydrogen consumption equipment, etc.) was recovered and utilized as fuel gas within the refinery • Nonetheless, the rise in CO2 emissions and economic efficiency poses a concern, and the recovery and reuse of CO2 must be taken into account as a package of measures to enhance production
Petro chemical	none	none	• Approximately 90% of the by-product gases (methane and hydrogen) are employed as a heat source in the naphtha cracking furnace, while the remaining 10% is utilized as feedstock for modifying the characteristics of raw materials. This includes hydrogenation of acetylene, methylacetylene, propylene, and other by-products of the naphtha cracking process, as well as adjusting the molecular weight of polymer polymers, producing alcohols using CO and H from oxo-gas, and other processes such as benzene dehydration and ammonia dehydration
Caustic Soda	possible	50%	• By-product hydrogen is utilized both within the chemical industry and as a fuel source. Reports on hydrogen usage indicate that approximately 25-50% serves as a raw material in the chemical sector, being employed in processes such as hydrogenation of urethane and other chemical products, ammonia synthesis, the production of high-purity hydrochloric acid, and semiconductor reduction. Additionally, around 50% is allocated for use as fuel. Approximately 25% of the existing hydrogen demand is fulfilled through external sales.

 Source: NEDO (2020), "Estimation of byproduct hydrogen production capacity in Japan"

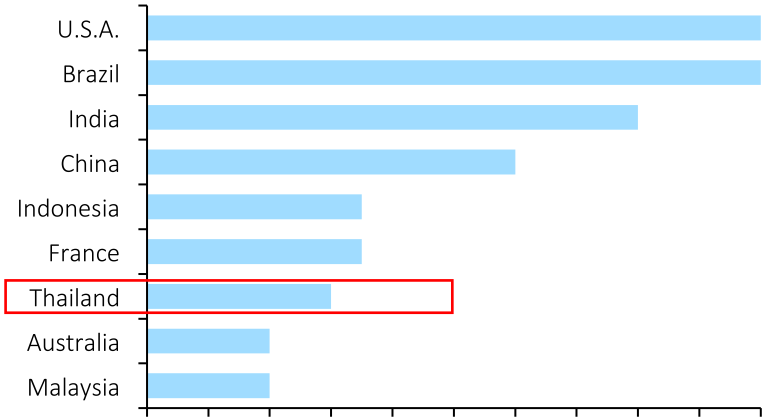
Cost Information

90% of fertilizer used in Thailand is from import as the cost of domestic production is high and the mining operation is getting banned from NGOs

Domestic Supply- Overview of fertilizer market in TH

- **In Thailand**, chemical fertilizers are classified as downstream industries that **rely almost entirely on imports** from foreign countries
- Thailand is ranked **no.7 for the top fertilizer importer** (2012-2016) which is accounted for 2.6% of global import

Top importer countries by volume I 2012-2016



- **Import growth** of chemical fertilizer is **71%** from Jan-May 2022 vs 2021.

Import and consumption (Million tonnes) I 2017-2020

(Million tonnes)	2017	2018	2019	2020
Import	6	5.8	5.7	5.8
Consumption	5.5	5.8	6	6

- **Straight fertilizer is accounted for 66.1% of the total import** volume of chemical fertilizers in Thailand
- The **production of straight chemical fertilizers in Thailand** can only be done in some types, such as **ammonia and ammonium sulfate** with **production of about 800,000 tonnes/year**

Import by type and country of origin I 2019

(Million tonnes)	% share	Major source
Nitrogen (N)	48.7	Saudi Arabia, Qatar, Malaysia
Phosphorus (P)	0.1	Egypt, China
Potassium (K)	13.4	Canada, Belarus, Israel
Compound NPK	37.9	China, Russia, Korea

 Source: IFA, Krungsri research, MOC

Caustic Soda production is approximately 1 million tonnes per year. Main player “AGC” has largely invested and established integration with other firms to increase production capacity

Domestic Supply- Overview of Caustic Soda market in TH

Key player’s production level

Company	Current capacity	Planned capacity	Key Highlight	Plant location
AGC VINYTHAI	720,000 tons/year	940,000 tons/year (by 2025)	• AGC Chemicals (Thailand) and Vinythai has **established business integration to increase efficiency in production** (July 2022) • PTTGC has ownership ratio of AGC VINYTHAI 27.32%	Map Ta Phut
AGC (Japan)	1.37 Million tons/year	1.64 Million tons/year (by 2025)	• To invest over 770 million USD to boost production of caustic soda (May 2022) • AGC's market share for caustic soda is 40% in SEA and **expect to reach 50% after this investment**	-
TTCL	173,000 tons/year	-	• Engineering company founded from the joint venture between Toyo Engineering Corporation & Italian-Thai Development • **Producing Caustic Soda for AGC Chemicals (Thailand)**	Eastern Industrial Estate

Monthly production level

Unit: Milion

Caustic Soda production level is between 74K-97K tonnes/month or **1.02 Million tonnes/year** on average

 Source: Office of Industrial Economics, AGC, AGCVINYTHAI, TTCL

Fertilizers can be made using ammonia (NH_3)as a source of nitrogen and it's the most consumed type of fertilizer in Thailand

Ammonium fertilizer type

	Ammonium Sulfate Fertilizer (21-0-0)	Ammonium Nitrate Fertilizer (34-0-0)	Urea Ammonium Nitrate
Characteristic	• **Fairly low nitrogen content** compared with other fertilizers • Help bring up the acidity of a farmer's soil more than Ammonia Nitrate type	• Dry & Solid form • **Extremely dense**, which helps farmers cover large areas quickly • **One of the highest % of nitrogen content**	• **Liquid fertilizer product** • can be mixed with herbicides, pesticides, and other nutrients
Component	• 21% nitrogen (present in the form of ammonium ions (NH_4^+)) • 24% sulfur (present in the form of sulfate ions (SO_4^{2-}) • Remaining percentage of the fertilizer consists of the associated counterions and water content.	• 34% nitrogen (present in the form of both ammonium ions (NH_4+) and nitrate ions (NO_3^-)) • Oxygen: nitrate ions (NO_3^-) contribute to the oxygen content of the compound. • Hydrogen: The ammonium ions (NH_4^+) contributes to the hydrogen content of the compound.	• Produced by combining urea, nitric acid, and ammonia • 28-32% nitrogen (typically vary based on the formulation) • Half of nitrogen comes from the urea solution and half from the ammonium nitrate solution.
Production amount	• Fertilizer Production: 800,000 tonnes/year • Nitrogen Production: 800,000 * 21% = 168,000 tonnes/year • Ammonia Production: (168,000*100%)/82.35% = 204,007 tonnes/year	• Fertilizer Production: 800,000 tonnes/year • Nitrogen Production: 800,000 * 34% = 272,000 tonnes/year • Ammonia Production: (272,000*100%)/82.35% = 330,298 tonnes/year	• Fertilizer Production: 800,000 tonnes/year • Nitrogen Production: 800,000 * 28% = 224,000 tonnes/year • Ammonia Production: (224,000*100%)/82.35% = 272,009 tonnes/year

Other type of fertilizer in Thailand

- Urea (46-0-0)
- Potassium chloride fertilizers (0-0-60)
- Diammonium phosphate fertilizer (18-46-0)
- Compound fertilizers (various formula)

Top 3 imported chemical fertilizer I 2017-2021

1.	Urea	42%
2.	Potassium chloride fertilizers	14%
3.	Diammonium phosphate fertilizer	9%

Domestic fertilizer consumption I 2016-2021

1.	Nitrogen	46.1%
2.	Other product	30.4%
3.	Potassium	23.3%
4.	Phosphorus	0.2%

Note: The numbers in the parentheses represent the N-P-K values (Nitrogen-Phosphorus-Potassium)

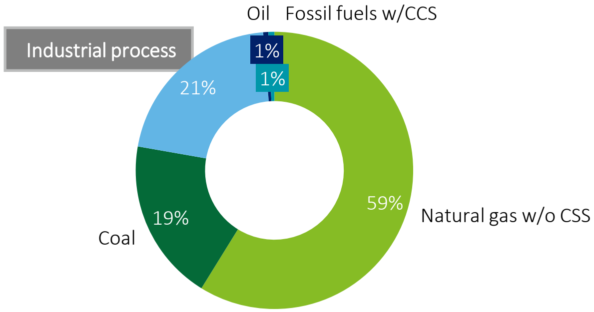
Byproduct hydrogen is relatively cheaper than other methods but it could face challenge in price increase if production volume of primary product is lower down

Hydrogen production cost analysis I Byproduct

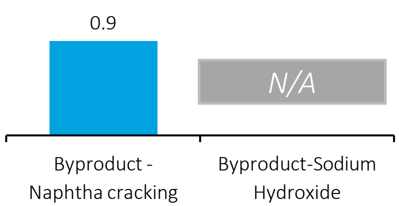
Byproduct

Hydrogen supply globally

Byproduct hydrogen derived from industrial process is accounted for 21% of total hydrogen supply



Cost of byproduct hydrogen production



Overview

- Relatively low compared to electrolysis or SMR because it is a secondary product derived from existing processes
- In China, many industrial firm **are using hydrogen byproduct to fuel to FCEV** bus/truck
  - Filling station can supply over 500 kg of H2/day worth $1.7million

Challenge

- Reducing **in steel production** (carbon neutrality's initiative by 2060), can reduce byproduct H2
- If require **the long distance delivery, using within production site is preferred** or to sell to external parties to avoid additional usage cost

Overview of Naptha cracking

- Estimate that 3.5 million tonne/year of by-product hydrogen can be produced from steam crackers
- Heavy Naphtha costs approximately **298 USD/metric ton**
- Estimate that cost of purified by-product hydrogen fuel from steam crackers is **$0.9–1.1/kg. This helps to reduce cost by 30% compared to SMR process**
- Create **less than 15-91% of GHG emission** compared to SMR

 Source : IEA, Published research, Chinadialogue

Sodium hydroxide industry’s growth, which is mainly leading by expansion project in Asia, can potentially increase byproduct hydrogen volume

Hydrogen production cost analysis I Byproduct

Byproduct

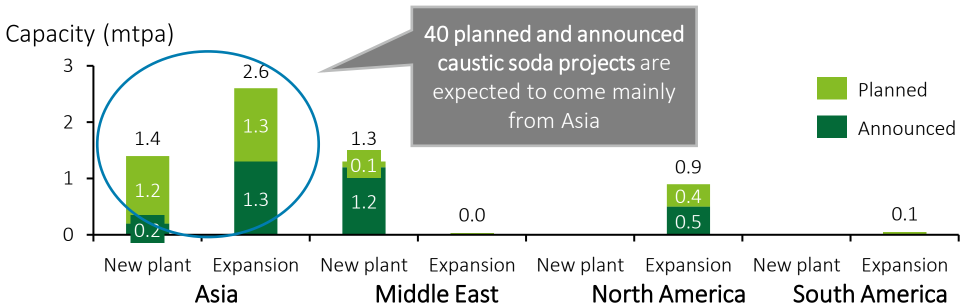
Overview of Sodium Hydroxide

Global production is expected to increase from 100 to 106 million (2022-2027) which is equivalent to **6.2% growth**

Asian countries, market leader, plans to **increase production capacity by 3.98 million ton per annum**

In 2018, **Average production price is $462/t** in China and $677/t in U.S.A.

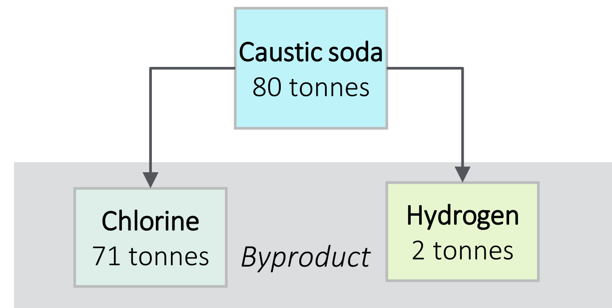
Planned production capacity by region



Production of Sodium Hydroxide

- It is generated by the electrolysis of sodium chloride solution
- Each tonnes of caustic soda requires around 1.55 tonnes of salt
- **Over 40% of production cost is energy related**
- Create hydrogen product of 2.5% for 1 ton of caustic soda production

Example



Require energy 2,200 — 2,500 kWh (9,000 MJ/t)

 Source: Globaldata, Published research

Ammonia production is estimated to be 200k tonnes/year and 36K tonnes/year for hydrogen from fertilizer industry

Calculation Ammonia & Hydrogen amount from fertilizer

Chemical component of Ammonium Sulfate

$2NH_3$ (Ammonia) + H_2SO_4 (Sulfuric acid) → $(NH_4)_2SO_4$ (Ammonium Sulfate)

Chemical content

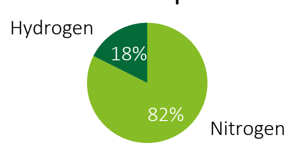
Nitrogen	21%	Sulfate	24%

To calculate amount of ammonia and hydrogen, we need the following inputs

1. Amount of fertilizer production

"Production of about 800,000 tonnes/year"

2. Ammonia mass component



N (14) + H (3) = 17

1 Calculation Ammonia amount (NH3)

- Step 1: calculate Nitrogen amount from Fertilizer
  - If Thailand produce 800,000 tonnes of Fertilizer per year
  - Total amount of Nitrogen will be 800,000*21% = **168,000 tonnes**
- Step 2: calculate amount of Ammonia from Nitrogen
  - Ammonia mass is N (14) + H (3) = 17
  - Mass % of nitrogen will be (14/17)*100 = 82.35%
  - If Nitrogen is 168,000 tonnes, amount of Ammonia will be (168,000*100%)/82.35% = 204,007 tonnes

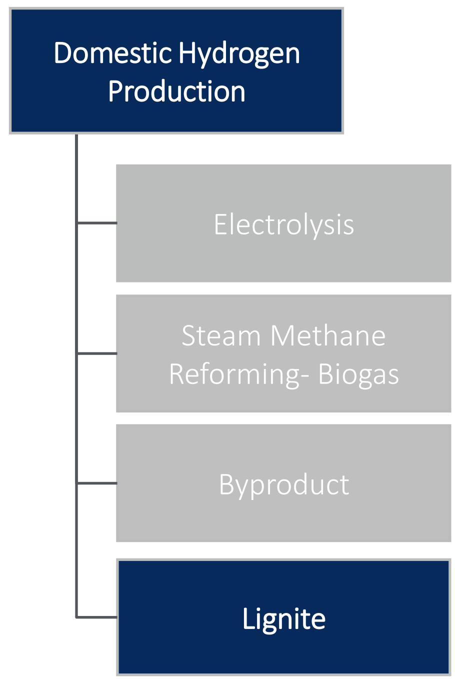
In conclusion, Thailand can produce approximately **204,007 tonnes** of Ammonia/ year

2 Calculation Hydrogen amount

- Step 1: calculate Hydrogen amount from Ammonia
  - Ammonia mass is N (14) + H (3) = 17
  - Mass % of Hydrogen will be (3/17)*100 = 17.64%
  - If Ammonia is 204,007 tonnes, amount of Hydrogen will be 204,007*17.64%= 35,986

In conclusion, Thailand can produce approximately **35,986 tonnes** of Hydrogen/ year from Ammonia Sulfate fertilizer

 Source: Published research


Domestic Hydrogen Production
Electrolysis
Steam Methane Reforming- Biogas
Byproduct
Lignite

Supply Amount

Unit: mtpa

	2022	2030	2040	2050
Domestic Hydrogen Production	0.03	0.27	0.70	1.39
Electrolysis	0	0	0	0.34
Steam Methane Reforming- Biogas	0 (0.18: potential)	0.24	0.31	0.39
Byproduct	0.03	0.03	0.03	0.03
Lignite	0	0	0.36	0.63

Hydrogen of 0.63 mtpa can be produced from Lignite in 2050, assuming to utilize Mae Moh lignite with CCS and its basin

Domestic Supply-Lignite

Blue Hydrogen Production from Lignite (mtpa) = Lignite use (mtpa) × Hydrogen Production Rate (Li / Km)

3.95% for Gaseous Hydrogen
3.09% for Liquefied Hydrogen

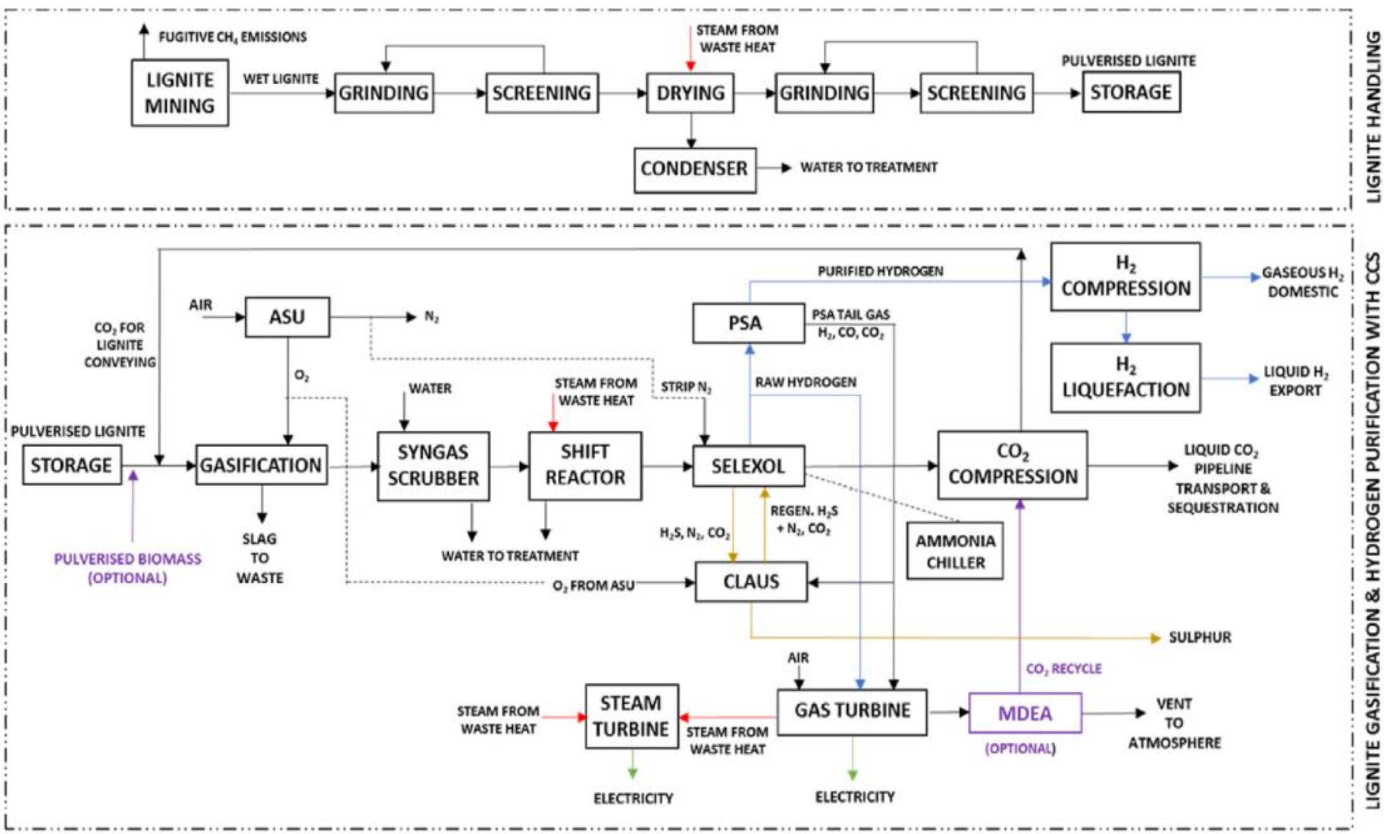
Assume to start 2040 at the earliest.
According to the Junggar Basin Project in China, turquois hydrogen will be produced by 2040.
Information about COD for others are not available as open source.

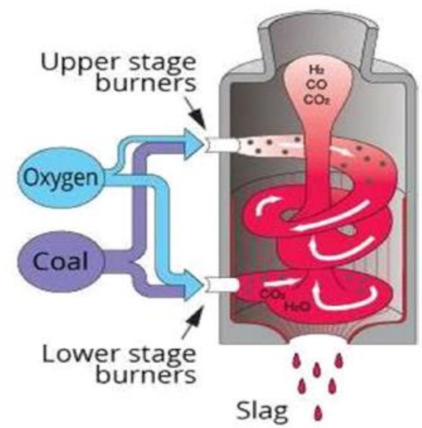
	Lignite Production and Consumption (mtpa)			H2 Production capacity (mtpa)		CO2 sequestered (mtpa)	
year	Production mtpa*	PDP2018 use @ PP mtpa	Surplus	Gaseous H2	Liquefied H2	GH2	LH2
2023	16	14.5	1.5	0.06	0.05	1.53	1.67
2024	16	14.5	1.5	0.06	0.05	1.53	1.67
2025	16	6.8	9.2	0.36	0.28	9.37	10.26
2030	16	6.8	9.2	0.36	0.28	9.37	10.26
2035	16	6.8	9.2	0.36	0.28	9.37	10.26
2040	16	6.8	9.2	0.36	0.28	9.37	10.26
2050	16	0	16	0.63	0.49	16.30	17.84
total potential in million ton 2030 to 2050	432	129.2	255.8	8.17	6.38	210.66	230.61
Reference info	Lignite Reserve: 825 million tons					Basin Capacity: 313 1,252 million tons	

 Source ：Deloitte Analysis based on Source ：Mae Moh Power Plant, EGAT

The estimation model consists of Lignite handling and gasification & purification with CCS. Hydrogen production is obtained in gaseous and liquid

Domestic Supply-system description of Lignite gasification





Source : Options for net zero emissions hydrogen from Victorian lignite. Part 1: Gaseous and liquefied Hydrogen, International Journal of Hydrogen Energy, Available online 5 May 2023

Cost Information

Cost of hydrogen from coal gasification is higher than SMR process especially when integrating CCS into the process

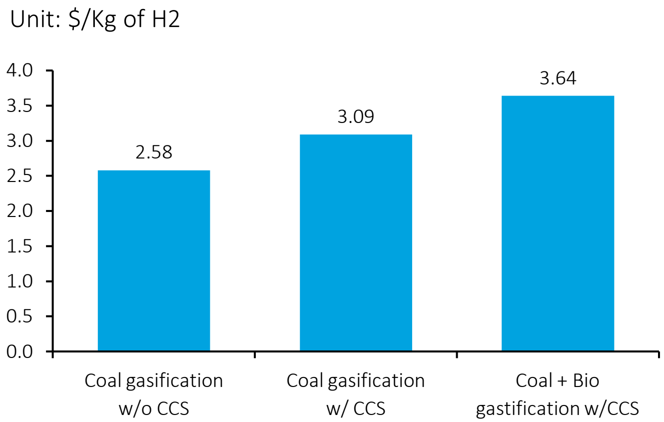
Hydrogen production cost analysis I Coal Gasification

Coal gasification

Overview of coal gasification

- The brown hydrogen market was valued at $30.4 billion in 2020, and is projected to reach $48.9 billion by 2030
- In 2022, According to U.S. Department of Energy, Hydrogen cost from coal gasification is approximately **$2.6-3.6 kg of H2.**
- **Capex costs** are usually around **$1,000/kWth** of syngas
- Cost of production depends on coal price, efficiency factor, chemical cost, labour cost and others

Average cost of hydrogen by coal gasification



Cost situation by country

China	The major producer company aims to lower down the cost of of brown hydrogen production to be **$0.90-1.46/kg**
India	Brown hydrogen produced from cheap coal in India costs approximately **$2/kg**
Australia	According to IEA, average current cost of Brown/Grey hydrogen is AUD 2.5/kg **($1.62/kg)**
Europe	In 2019, estimated European brown/grey hydrogen costs were 1.5 - 2 €/kg with CCS **($1.63-2.17/kg)**

 Source: U.S. Department of Energy, IEA, Published research, Au Government

Lignite gasification is less preferred option as the process is more expensive to produce due to high level of impurities

Hydrogen production cost analysis I Lignite Gasification

Lignite gasification

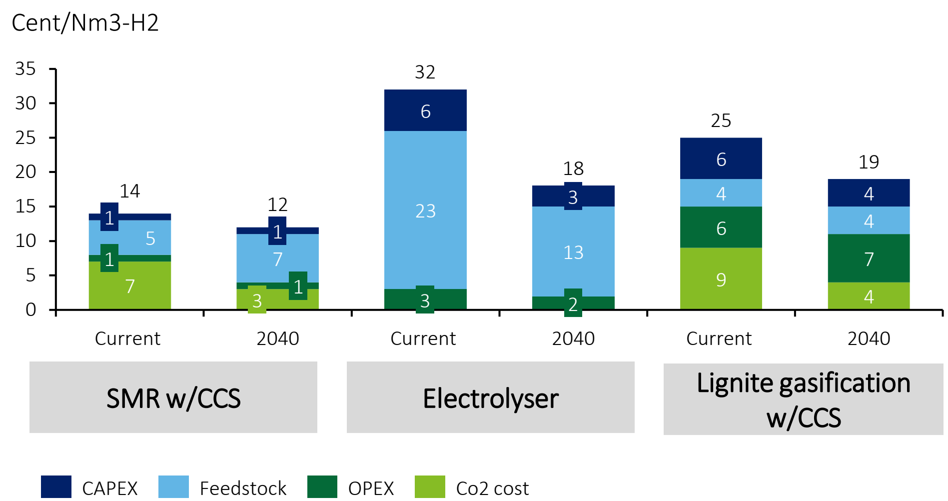
Overview of Lignite gasification

Different from coal	• Produce syngas with a **lower energy content** • Process will involve more extensive gas cleanup and purification to remove impurities • **Higher levels of impurities**, which can pose environmental challenges & require additional emissions control measures
Cost of production	• Based capex value **for Lignite Gasification with CCS is $3,851/KW** • Annual non-fuel operating expenses are assumed at 5% of capital cost)

Feedstock prices (applied to evaluate hydrogen cost)

	Unit	Current	2040
SMR w/CSS	$/mmbtu	3.4	5.7
Alkaline electrolyser	C/kwh	5.2	3.1
Lignite gasification w/CSS	$/tonne	39.8	55.7

Average cost of hydrogen production by Lignite gasification



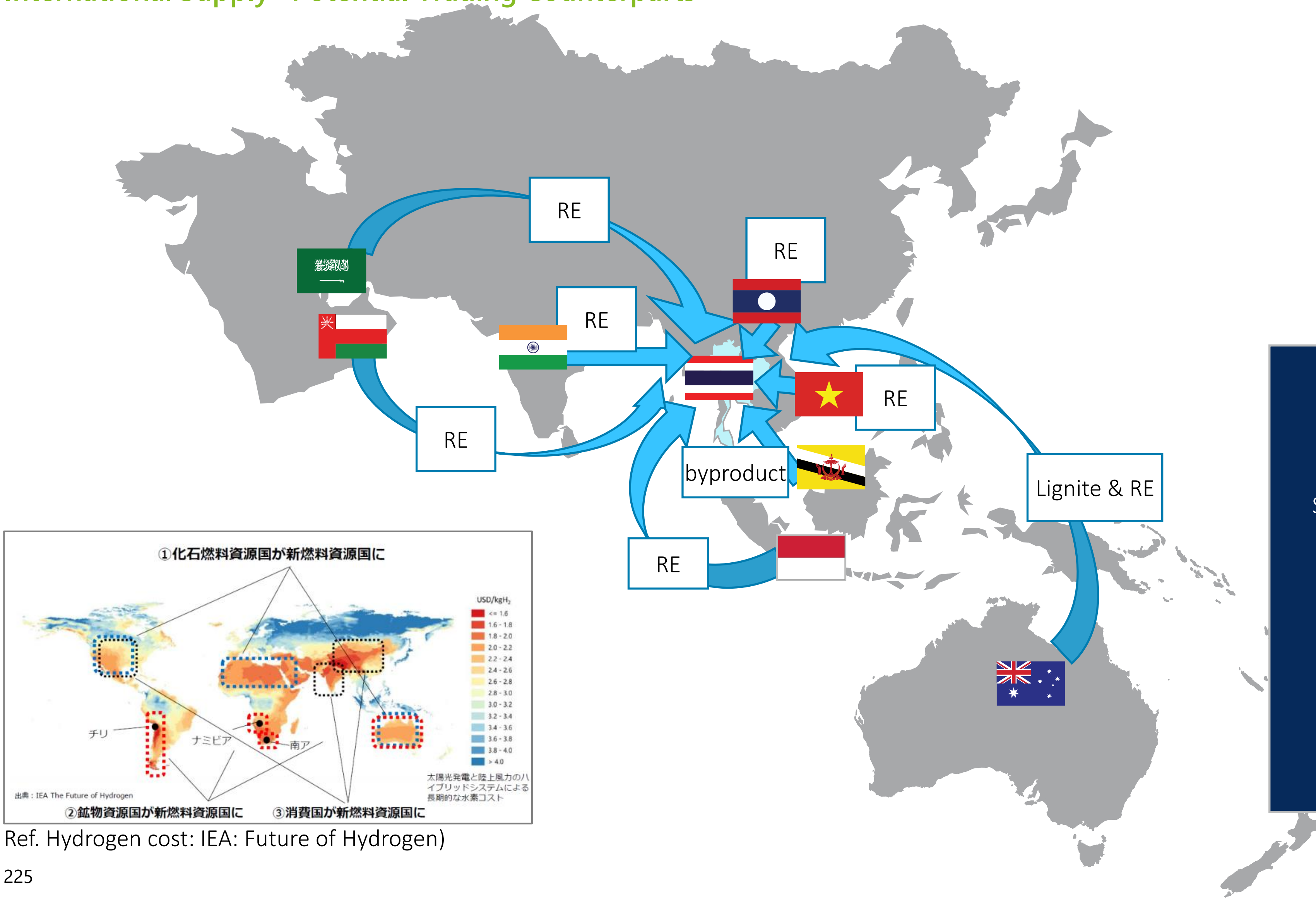
 Source: ERIA, S&P Global

Domestic Supply

International Supply

In terms of international procurement, supply is expected to come mainly from Asia and Oceania, in particular from the perspective of transport costs

International Supply –Potential Trading Counterparts

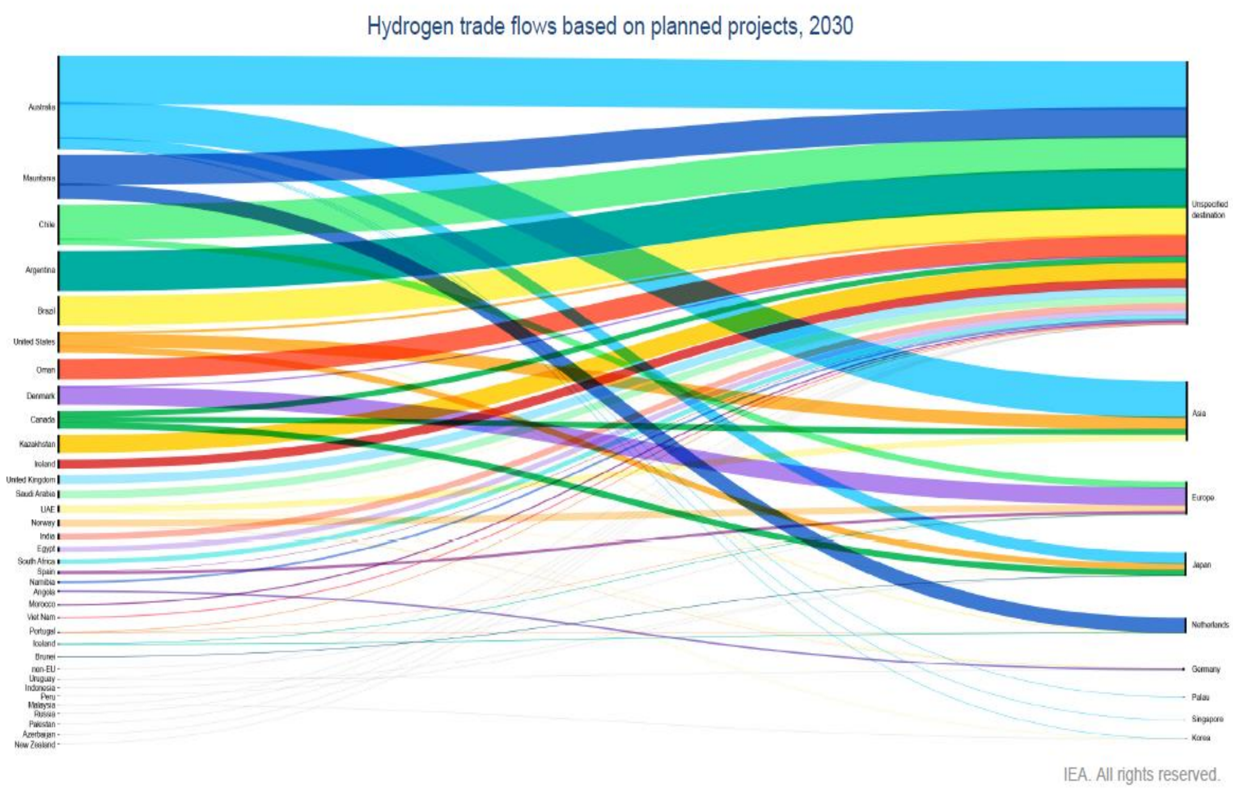


Australia
Oman
Kazafstan
Soudi Arabia
UAE
India
Vietnam
Brunei
Indonesia
Malaysia
Pakistan
New Zeland

Ref. Hydrogen cost: IEA: Future of Hydrogen)

AU, US, CA and UAE are recognized as the countries of production which trade H2 to Asia although the majority of production is with no-destination

Hydrogen Trade Forecast in 2030 (Global)



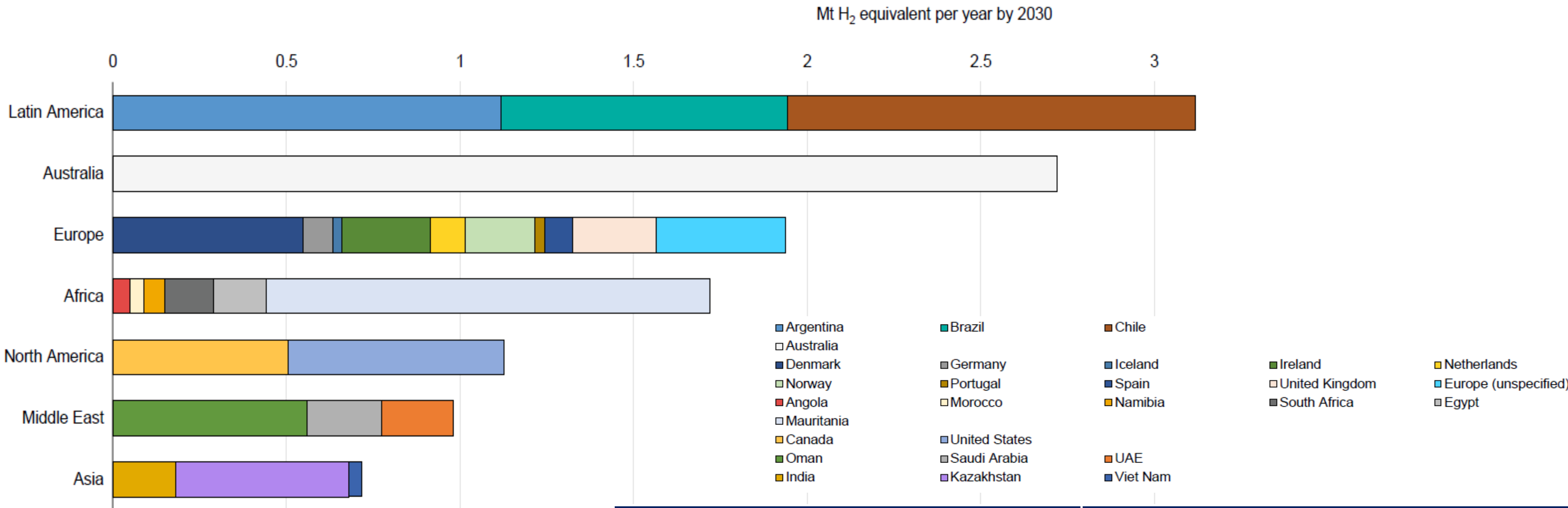
2.4 Mt H2e out of 12 Mt H2e only have off-take plan while the destination of the rest amount have not been determined yet.

Country / Region of use	Country / Region of production
Asia	Australia, United States, Canada, UAE
Europe	Chile, Denmark, Norway, Spain, Portugal, Iceland, non-EU Europe,
Japan	Australia, United States, Canada, Brunei, Indonesia, Peru
Netherland	Mauritania, Brazil, Portugal, Iceland
Germany	UAE, Norway, Angola, Uruguay
Palau	Australia
Singapore	Australia
Korea	Australia, UAE, Malaysia
Unknown	many

 Source: IEA Global Hydrogen Review 2022

4.4 Mt H2e is projected as full potential of tradable amount in 2030 within middle East, Asia and Oceania

Hydrogen Trade Forecast in 2030 (Global)



Country of Production	Trade amount forecast (2030)
Australia	2.7 Mt H2e
Middle East (Oman, Saudi Arabia, UAE)	1.0 Mt H2e
Asia (India, Kazakhstan, Vietnam)	0.7 Mt H2e <0.23 Mt H2e except Kazakh>
Total of AU, Middle East and Asia	4.4 Mt H2e <3.93 Mt H2e except KH>

 Source: IEA Global Hydrogen Review 2022

In Asian and Oceania region, 37 projects have been announced in 12 countries, which makes sum of 38.35 mtpa of H2 and 34.61 mtpa of NH3 in the future

International Supply –Total amount planned in Potential Trading Counterparts

12 Countries	38 Projects	H2 38.35 mtpa	NH3 34.61 mtpa

Unit: tpa

Country	Project number	H2 Production	NH3 Production
Australia	16	6,373,840	29,290,000
Brunei	1	100	n/a
India	6	17,545,000	1,240,000
Indonesia	3	40,037	1,000,000
Kazakhstan	1	2,000,000	n/a
Malaysia	2	107,000	1,230,000

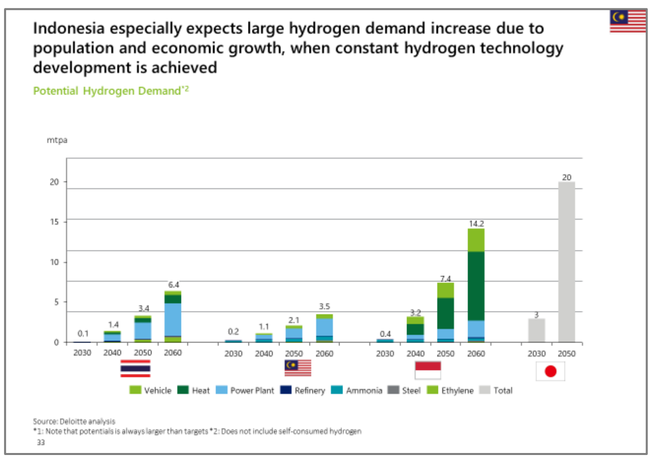
Unit: tpa

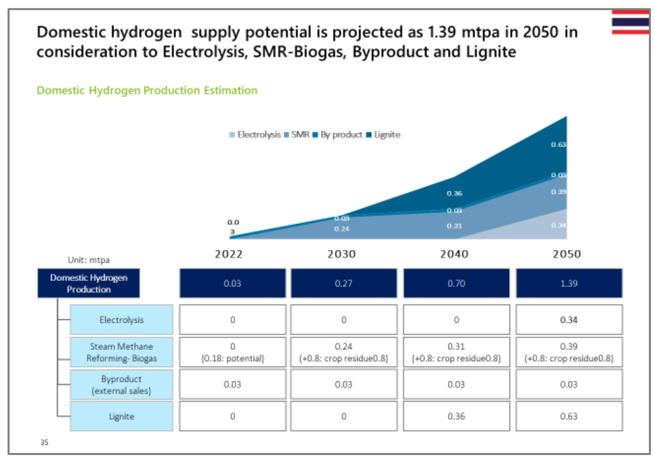
Country	Project number	H2 Production	NH3 Production
New zeland	2	180	500,000
Oman	1	500,000	n/a
Pakistan	1	55,000	n/a
Saudi Arabia	1	219,000	1,200,000
UAE	2	180	n/a
Vietnam	2	11,514,000	150,000

In 2050, Thailand shall procure 1.98 mtpa from international market to fulfill the difference between domestic supply and demand

Amount of International Procurement (estimation) 2050 (1/2)

Demand @ 2050		Domestic Supply @ 2050		Supply to be procured from international market
3.37 mtpa	−	1.39 mtpa (+ 0.8 mtpa)	=	1.98 mtpa (1.18 mtpa)





Thailand would need to procure 1.98 mtpa which is equivalent to 5% (3%) of possible international trading amount in Asia, Middle East and Oceania region

Amount of International Procurement (estimation) 2050 (2/2)

In Asian and Oceania region, 37 projects have been announced in 12 countries, which makes sum of 38.35 mtpa of H2 and 34.61 mtpa of NH3 in the future

International Supply –Total amount planned in Potential Trading Counterparts

12 Countries	38 Projects	H2 38.35 mtpa	NH3 34.61 mtpa

Unit: tpa

Country	Project number	H2 Production	NH3 Production
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Brunei	1	100	n/a
India	6	17,545,000	1,240,000
Indonesia	3	40,037	1,000,000
Kazakhstan	1	2,000,000	n/a
Malaysia	2	107,000	1,230,000

38

Unit: tpa

Country	Project number	H2 Production	NH3 Production
New zeland	2	180	500,000
Oman	1	500,000	n/a
Pakistan	1	55,000	n/a
Saudi Arabia	1	219,000	1,200,000
UAE	2	180	n/a
Vietnam	2	11,514,000	150,000

Supply to be procured from international market

1.98 mtpa
(1.18 mtpa)

Scenario A

Scenario B

Total 4 countries production is 7.02 mtpa which surpass current's need of 1.98 (1.18) mtpa

Percentage of sum of target countriesto fulfil TH demand

Scenario A: 5% (3%)

Scenario B: 28% (17%)

In Asian and Oceania region, 37 projects have been announced in 12 countries, which makes sum of 38 mtpa of H2 and 34 mtpa of NH3

International Supply –Total amount planned in Potential Trading Counterparts (Australia)

Type of project	Project	H2 amount (tonnes/year)	NH3 amount (tonnes/year)	Destination	Target year	H2 carrier	Entity	Detail
Actual	H2Perth	985,500	-	- Both local and international	-	Liquid hydrogen, Ammonia	Woodside Energy Ltd	- Developed of hydrogen and ammonia production facility - Have the potential to expand to 8,900 tonnes per day by increasing the electrolysis component. - Net zero operation: using a combination of renewable electricity, offsets and carbon capture, utilisation and storage technologies. '- Domestic demand : initial mobility uses, heavy industry uses - Export potential : ammonia production, liquid hydrogen
Actual	Bristol Springs Solar Hydrogen Project	4,900	-	- Use locally	-	-	Frontier Energy Limited	- Solar farm facility and renewables-based hydrogen production plant with an initial 36 MW electrolyser capacity - Potential use: gas networks, power generation, energy storage, industrial feedstock, and transport applications
Actual	Western Green Energy Hub	3,500,000	20,000,000	- International	2030	-	InterContinental Energy, CWP Global, Mirning Traditional Lands Aboriginal Corporation	- Large-scale hybrid wind and solar development planned to be built in phases to meet mainly export-related hydrogen/ammonia demand - Produce up to 50 gigawatts (GW) of renewable-based power over 15,000 square kilometres - Site area of 15,000 km2

In Asian and Oceania region, 37 projects have been announced in 12 countries, which makes sum of 38 mtpa of H2 and 34 mtpa of NH3

International Supply –Total amount planned in Potential Trading Counterparts (Australia)

Type of project	Project	H2 amount (tonnes/year)	NH3 amount (tonnes/year)	Destination	Target year	H2 carrier	Entity	Detail
Actual	Eyre Peninsula Gateway Project – Demonstrator Stage	10,000	40,000	- Both local and international	-	-	The Hydrogen Utility (H2U) (hydrogen infrasturecutre company)	- Plans to integrate a 75 megawatt (MW) electrolysis plant and a 120 tonnes per day ammonia production facility largely for domestic supply, export
Actual	Toyota Ecopark Hydrogen Demonstration	21,900	-	- Use locally	2021	-	Toyota	- To produce renewable hydrogen using a percent of renewable energy for use in both transport and stationary applications (Fuel cell) - Hydrogen use: Supply electricity through the use of a fuel cell to the Altona facilities, hydrogen refuelling station, fuel hydrogen powered vehicles (FECV, Forklift)
Actual	Green methanol bunkering hub at the port	15,000	-	- Use locally	-	-	HAMR Energy	- Large-scale hybrid bio/e-methanol development - Examine the transportation of green methanol from production sites in Bell Bay to Portland for storage and bunkering services - Methanol synthesis plant would be expected to produce around 200,000 tonnes of 'green' methanol/year
Actual	ABEL Energy Bell Bay Powerfuels Project	43,800	-	- Use locally	-	-	ABEL Energy Iberdrola Australia	- Potential for developing a large-scale, renewables-based hydrogen and e-methanol facility at Bell Bay

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Type of project	Project	H2 amount (tonnes/year)	NH3 amount (tonnes/year)	Destination	Target year	H2 carrier	Entity	Detail
Actual	Australia's first large scale hydrogen plant to be built in Pilbara (Yuri project)	640	-		2021 (start) - 2024 (complete)			' - Deploy a 10 MW electrolyser powered by solar PV to generate renewable hydrogen & ammonia at Yara Pilbara Fertilisers' neighbouring liquid ammonia plant in Karratha, Western Australia. - project is supported by the Australian Government with a $47.5 million grant - The renewable hydrogen produced can be used as a feedstock for chemicals such as ammonia, combusted for heat or electricity generation, vehicle's fuel - 18 MW solar PV system to power the electrolyser
Actual	H2Perth	985,500	-	- Both local and international	-	Liquid hydrogen, Ammonia	Woodside Energy Ltd	- Developed of hydrogen and ammonia production facility - Have the potential to expand to 8,900 tonnes per day by increasing the electrolysis component. - Net zero operation: using a combination of renewable electricity, offsets and carbon capture, utilisation and storage technologies. '- Domestic demand : initial mobility uses, heavy industry uses - Export potential : ammonia production, liquid hydrogen

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Actual	Toyota Ecopark Hydrogen Demonstration	21,900	-	- Use locally	2021	-	Toyota	- To produce renewable hydrogen using a percent of renewable energy for use in both transport and stationary applications (Fuel cell) - Hydrogen use: Supply electricity through the use of a fuel cell to the Altona facilities, hydrogen refuelling station, fuel hydrogen powered vehicles (FECV, Forklift)

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In Asian and Oceania region, 37 projects have been announced in 12 countries, which makes sum of 38 mtpa of H2 and 34 mtpa of NH3

International Supply –Total amount planned in Potential Trading Counterparts (India)

Type of project	Project	Hydrogen amount (tonnes/year)	Ammonia amount (tonnes/year)	Destination	Target year	Hydrogen carrier	Entity	Detail
Planned	In talk to provide green hydrogen to EU and Singapore	11,000,000	-	EU and Singapore	-	-	Potential company: (RELI.NS), Indian Oil (IOC.NS) and Adani Enterprises (ADEL.NS)	- India government will consider the billateral agreement to provide green hydrogen with the investment of EU and Singapore. India can claim carbon credit as a return
Target	Green hydrogen target : 5 million tonnes of green hydrogen by 2030	5,000,000	-	- Use locally and export	2030	-	India government	- Aim to export 70% of 5 million tonnes, the rest is for domestic consumption - No mandate to use hydrogen in certain industry as of now
Planned	Hydrogen development plant in Egypt	220,000	-	- International	-	-	ReNew Power	- Aim to develop several green hydrogen projects in India and overseas - signed a framework agreement with the government of Egypt to set up a green hydrogen plant in the Suez Canal Economic Zone - Planned capacity is 14GW (80% must come from renewable energy)
Planned	Green hydrogen and ammonia project in northern India	125,000	240000	-	-	-	Government of Rajasthan Jakson Green	- The project would be powered by "a mix of solar, wind and storage, if possible", and an electrolyser capacity of roughly 1.8GW across the three phases - Jakson Group currently generates more than 360GWh of renewable energy a year

In Asian and Oceania region, 37 projects have been announced in 12 countries, which makes sum of 38 mtpa of H2 and 34 mtpa of NH3

International Supply –Total amount planned in Potential Trading Counterparts (India)

Type of project	Project	Hydrogen amount (tonnes/year)	Ammonia amount (tonnes/year)	Destination	Target year	Hydrogen carrier	Entity	Detail
Planned	Green hydrogen project in India's Karnataka (southern India)	1,200,000	-	-	2027	-	ACME group	- Capacity to produce 1.2 million tonnes per annum - To set up a plant in 5 years
Actual	1.3GW green hydrogen project powered by 24/7 renewables	-	1,000,000	- International	2026	-	Natural Gas Corporation (ONGC) Greenko	- JV between two giant company (state owned company and private company) - Electrolyser will be built by Greenko and Belgium's John Cockerill (the world's largest electrolyser supplier)

In Asian and Oceania region, 37 projects have been announced in 12 countries, which makes sum of 38 mtpa of H2 and 34 mtpa of NH3

International Supply –Total amount planned in Potential Trading Counterparts (Indonesia)

Type of project	Project	Hydrogen amount (tonnes/year)	Ammonia amount (tonnes/year)	Destination	Target year	Hydrogen carrier	Entity	Detail
Planned	$4bn nuclear hydrogen project	-	1,000,000	-	2028	Ammonia	State-owned firms (don't disclosee name) Topsoe (Danish equiupment provider) Alfa Laval (manufacturer) Aalborg CSP (solar power specialist)	- Powered by 1GW of 25 small modular reactors - One million tonnes of pink ammonia a year — providing enough fertilser to grow food for 45 million people - Use molten-salt thorium, rather than uranium, as its energy source. (safer, cheaper, more efficient) - Ammonia from the plant can also potentially be used as CO2-free marine e-fuel
Pilot	Pertamina's green H2 pilot project	36.5	-	- Use locally	2023	-	Pertamina	- Supply hydrogen to Pertamina's polypropylene (PP) plant for petrochemical demand - The location will be in the Ulubelu geothermal working area in which it have the potential to produce 8,600 kg/d of green hydrogen
Actual	Joint Study Agreement on Green Hydrogen and Green Ammonia	40,000	-	-	-	-	Pertamina NRE, Keppel Infrastructure, and Chevron	- Explore the feasibility of developing a green hydrogen facility - Potential production capacity of at least 40,000 tonnes per year - To use at least 250 - 400 MW of geothermal energy at an early stage - Production could scale up to 80,000 and 160,000 tonnes per year,

In Asian and Oceania region, 37 projects have been announced in 12 countries, which makes sum of 38 mtpa of H2 and 34 mtpa of NH3

International Supply –Total amount planned in Potential Trading Counterparts (Brunei, Kazakhstan, Malaysia)

Type of project	Project	Hydrogen amount (tonnes/year)	Ammonia amount (tonnes/year)	Destination	Target year	Hydrogen carrier	Entity	Detail
Pilot	Brunei-Japan hydrogen supply chain for power generation in Tokyo Bay	100	-	Japan	2020	MCH	Hydrogen Energy Chain Association for Technology Development (AHEAD): Chiyoda, Mitsubishi, Mitsui and Nippon Yusen Kaisha or NYK Line	- Pilot project to bring hydrogen from Brunei to Tokyo Bay for use as a power generation fuel - Project has maximum 210 mt/year hydrogen supply capacity - Hydrogen produced from processed gas at Brunei LNG (steam reforming process) and transport it through MCH. - Expects to supply about 100 mt of hydrogen for power generation at the Mizue plant by the end of November 2020 - After hydrogen is extracted, toluene will be transported back to Brunei for repeated use as transportation medium
Actual	20 GW Green hydrogen project with the pipeline to EU	2,000,000	-	-	2032	-	Hyrasia One (EU developer), Kazakh government	- Build one of the world's five largest green hydrogen production facilities - Kazakhstan's lack of access to open seas and 2,000km distance from mainland Europe, hence pipeline could be the solution - Will use electricity generated by solar panels and wind turbines to separate hydrogen gas from water
Actual	H2biscus	7,000	1,230,000	- Use llocally, South Korea	2027	Ammonia, Hydrogen	Samsung, Posco, Lotte Chemical, SEDC Energy, Sarawak Energy Berhad	- Study the potential of supplying at least 900 megawatts of hydro-based renewable power in Sarawak - Goal is to achieve commercial production by the end of 2027.
Actual	H2ornbill	100,000		- Use locally, Japan	2030	MCH	SEDC Energy, Sumitomo Corp, ENEOS	The project aims to develop i) dehydrogenation technology for MCH(Methylcyclohexane) carrier, and ii) build green hydrogen supply chain by MCH carrier (considering export).

In Asian and Oceania region, 37 projects have been announced in 12 countries, which makes sum of 38 mtpa of H2 and 34 mtpa of NH3

International Supply –Total amount planned in Potential Trading Counterparts (New Zealand, Oman)

Type of project	Project	Hydrogen amount (tonnes/year)	Ammonia amount (tonnes/year)	Destination	Target year	Hydrogen carrier	Entity	Detail
Actual	The first green hydrogen plant powered by geothermal energy	180	-	- Use locally	2022	Ammonia	Halcyon Power (developer) Tūaropaki Trust Obayashi Corporation of Japan	- JV between Tūaropaki Trust and Obayashi Corporation of Japan - Start the operation since 2018 - To use in transportation, storage, and refueling
Actual	Southern Green Hydrogen plant	-	500,000	- Use locally and export	-	Ammonia	Woodside Energy Meridian Energy	- Expect to be the largest green hydrogen project in New Zealand - Enegy source for hydrogen production is renewable power - Proposed capacity is 600 mw - Provide up to 40% of New Zealand's dry year flexibility needs to the electricity sector
Actual	$20 billion of green hydrogen project	500,000	-	-	-	-	- Bidder company from USA, UK, Kuwait, Singapore, Oman '- Group 1: Copenhagen Infrastructure Partners, Blue Power Partners and Al Khadra Partners. - Group 3: Oman Shell, OQ, EnerTech, Intercontinental Energy and Golden Wellspring Wealth for Trading. (read more in detail)	- Aim to become a global hub for hydeogen production - There are 3 projects (sites) under this investment - Installed renewable energy capacity is more than 12 GW

In Asian and Oceania region, 37 projects have been announced in 12 countries, which makes sum of 38 mtpa of H2 and 34 mtpa of NH3

International Supply –Total amount planned in Potential Trading Counterparts (Pakistan, Saudi Arabia, UAE)

Type of project	Project	Hydrogen amount (tonnes/year)	Ammonia amount (tonnes/year)	Destination	Target year	Hydrogen carrier	Entity	Detail
Planned	The first green hydrogen project (Oracle Energy's Green Hydrogen Project)	55,000	-		2026	-	Oracle energy China Electric Power and Technology	- MOU between 2 firms to develop hydorgen production plant '- To produce 150,000 KG of green hydrogen (the nation's renewable energy landscape) - 1.2 GW hybrid power from proposed capacity 700MW solar and 500MW wind plants - Plan to allocate 7,000 acres of land for the production
Actual	NEOM's green hydrogen plant	219,000	1,200,000	-	2026	-	ACWA Power, Air Products and NEOM	- Aim to build the largest carbon free hydrogen's plant - Total of 4GW of solar and wind energy - Use 5.6 million solar panels that can produce up to 2.2GW of solar energy
Planned	Mohammed bin Rashid (MBR) solar park green hydrogen	180	-	-	2024	-	ACWA Power and Masdar (bidder), UAE government	- To produce hydrogen from solar energy, contributing to achieving competitive prices in producing green hydrogen - Solar park had been launched since 2012 - Phase 5th (2023), Production capacity is 900MW - Phase 6th (2024), Production capacity will be 1800MW

In Asian and Oceania region, 37 projects have been announced in 12 countries, which makes sum of 38 mtpa of H2 and 34 mtpa of NH3

International Supply –Total amount planned in Potential Trading Counterparts (UAE, Vietnam)

Type of project	Project	Hydrogen amount (tonnes/year)	Ammonia amount (tonnes/year)	Destination	Target year	Hydrogen carrier	Entity	Detail
Planned	Partnership between Siemens Energy & Brooge Energy to develop green hydrogen and ammonia	-	-	-	2023	Ammonia	Siemens Energy & Brooge Energy	- 650 MW solar PV plant to supply BRE's planned Phase 1 of the green ammonia project with renewable energy
Actual	The first hydrogen plant in Vietnam	24,000	150,000	-	-	liquefied gas	TGS Green Hydrogen	- The construction scheduled to begin in June 2022 and expected to be completed by 2023. - Hydrogen will be extracted from water using electrolysis powered by renewable energy - To produce green hydrogen through seawater electrolysis
Target	Target to produce 11.49 million tons of green hydrogen by 2030	11,490,000	-	-	-	-	UNDP Vietnam and the Vietnam Institute of Energy	- Current situation : Vietnam is facing challenges in energy consumption, with an increase of 10-12 per cent in demand annually - Figures were released from the joint study by the UNDP Vietnam and the Vietnam Institute of Energy on the Comprehensive Assessment of Green Hydrogen Production from Solar and Wind Power Sources

Desktop Research - ②Thailand

1. Overview of Supply Chain
2. Demand Side
3. Supply Side
4. **Public Acceptance**

People think that Thailand is not ready for hydrogen because of the high cost and lack of infrastructure

Public Acceptance of Hydrogen in Thailand (1/3)

What will be the future vehicle between EV or FCEV ?

- Most comments support on the EV and believe that problem of battery and charging time will be solved soon. For the FECV, people believe that its still expensive and Thailand don't have the readiness yet (lack of infrastructure). There are many misconceptions in how hydrogen can be produced easily at station

EV	FCEV
Battery • Expensive battery • Support EV and believe that battery issue will be improved in the future • Problem of battery and longtime charging can be solved faster than adopting hydrogen	Key barrier • Expensive and don't safe • High investment for refueling station • Its not the time for FCEV yet since the infrastructure is not established properly • Hydrogen is more expensive (150 thb/kg of H2) than using oil (5 times). This would be just a dream of car manufacturer. So EV will come first and might need to change battery for every 5 years.
Charging time • Take time to refuel electricity • Fast charging technology in the future can solve today's problem • Should have 2 batteries so can used interchangeably. However, its not practical due to the big size. Also thinking that fast charging is also not good for battery	How hydrogen is produced • To produce hydrogen, need to have nuclear power plant • Hydrogen fuel cell is definitely coming. Hydrogen production may be produced at the station right there using water and electricity or sunlight. We might be able to produce hydrogen ourselves at home (already sell it)
Other • Still have to buy electricity from Laos • Short travel distance • Electricity should win. This is because large power plants tend to be more efficient at converting various fuels.	Other • Even hydrogen car also use electricity generated converted from hydrogen (by fuel cell). Its just different way of getting electricity

Source: Thailand's online discussion forum site

While many people recognize the benefits of hydrogen in enhancing energy security, there are still concerns about high costs, energy losses, and safety issues that need to be addressed to gain people's trust

Public Acceptance of Hydrogen in Thailand (2/3)

Opinion about hydrogen in Thailand

- "There are still concerns about price and safety. If this can be solved, it will probably be the main energy of the green world in the future"
- "EV is more suitable to passenger car as it requires nearby fueling station while FCEV is better for heavy load truck for logistic and it needs specific type of fueling station"
- "Hydrogen is still not widely used in the producing country. It is expensive and have lot of compression force"
- "I want to know how far we can drive with 1 kg of H2"
- "If you are scared of car explosion from hydrogen, you should be more scared to LPG in your home. Hydrogen car in market has no explosion incident but some EV got explosion once charging"
- "EV can cause energy insecurity. There is brownout in my area even there is only 20-30% of EV on road. We might not be ready to use EV in long term yet"
- "Hydrogen usage could happen but not recently. When it comes to the end of electricity and battery era, hydrogen will be the next"
- "I want to use FCEV but now hydrogen is still expensive. I think FCEV is good in long term because if using EV, you have to change battery every 5 years. Moreover, lithium nickel for battery production will be more expensive in the future "
- "To use hydrogen, we still have to use lot of energy to produce"
- "I have heard that hydrogen can cause a big explosion. So, its very scary when there is any accident"
- "If we can solve the slow charging problem of EV, FCEV will not happen. For hydrogen, there is a lot of energy loss during conversation (from liquid hydrogen to electricity for final usage "
- "FCEV would be similar to the introduction of NGV, I think EV has better prospect as hydrogen is also expensive"

Neutral | Support hydrogen/FCEV | Don't support hydrogen/FCEV

Source: Discussion on hydrogen from online media platform

Public opinion indicates that hydrogen might be more applicable to industrial sector and we should utilize only byproduct hydrogen

Public Acceptance of Hydrogen in Thailand (3/3)

Opinion about hydrogen in Thailand

Hydrogen is more suitable to use in industrial sector. For future technology, it might take more than 15 years for technology readiness (reach economy of scale).

"Hydrogen production is not difficult as we can use Solar PV to generate it. However, the key issues are the difficulty of storage, transport"

To produce hydrogen, Electrolysis requires lot of energy, and it has the risk of explosion. Price of hydrogen has to be the same as oil or lower so people will adopt

"I have heard that the only hydrogen refueling station in Denmark is recently closed as it is not worth the investment and effective in converting energy in many steps resulting energy loss "

Electricity that is used to produce hydrogen should be used directly to charge EV instead. This is better because there is no energy loss. Then, Byproduct hydrogen from chemical industry can be used for FCEV

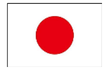
"FCEV helps to reduce reliance on one type of energy supply shortage of battery minerals. Without the high cost and safety issue, FCEV is better than EV as it cannot generate energy but rely heavily on battery. EV also has the same risk of explosion as FCEV"

Neutral | Support hydrogen/FCEV | Don't support hydrogen/FCEV

Source: Discussion on hydrogen from online media platform

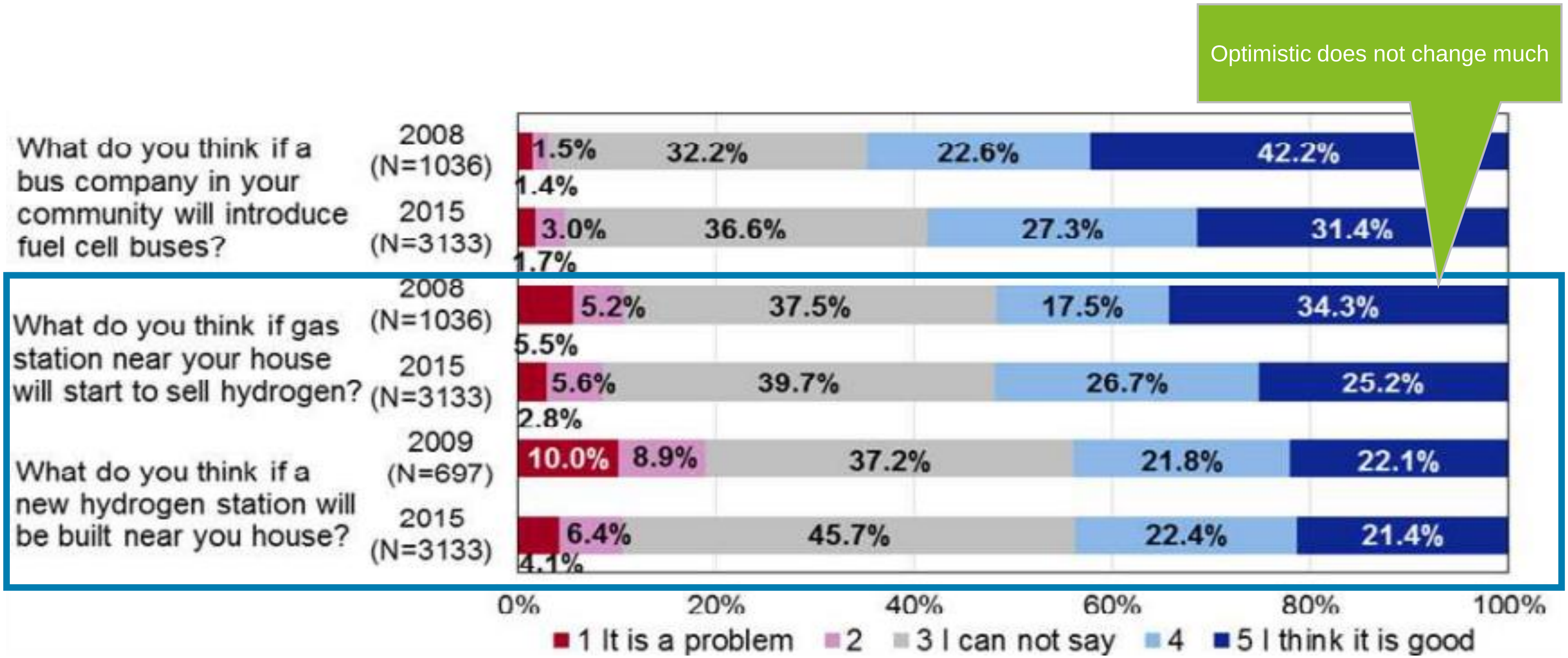
About half of respondents are still worried on having hydro station nearby their houses even in Japan

Acceptance of Hydrogen in Japan



Potential acceptance of hydrogen station and fuel cell bus operated near respondents' house

As for the fuel cell bus introduction (first question), the positive opinion decreased slightly.
For the last 2 questions, the positive opinion % does not increase from 2009



Source: Published research (Japan, 2008)

Even though Australia is advanced in Hydrogen initiatives, majority of people does not know much about hydrogen property and its application

Public perceptions of Hydrogen Energy in Australia

The following is the Public Perceptions of Hydrogen, 2021 National Survey Results by Australian government

Knowledge on hydrogen properties

- Less than 6% of respondents correctly answered all 5 questions
- Less than 20% knew that hydrogen is not available naturally in its pure form

Question	Yes	No
Is hydrogen heavier than air at room temperature?	20.2%	30.8%
Is hydrogen available naturally in its pure form?	36.8%	19.3% Answer wrong the most
Does hydrogen smell?	13.5%	45.0%
Is hydrogen flammable in air?	49.8%	12.8%
Can hydrogen be stored as a liquid?	60.1% Answer correct the most	6.9%

Knowledge on hydrogen production and uses

- The number indicated that majority of people still does not know how hydrogen is being produced and its application

How much do you know the following?	I have never heard of it	I have heard of it	I know about it and could describe it to friend
How hydrogen is produced	53.4%	37.5%	9.1%
Use of hydrogen fuel cells in vehicles	38.6%	53.1%	8.2%
Use of hydrogen fuel cell in homes	64.4%	30.7%	5.0%
Hydrogen as an energy storage medium for electricity	52.9%	40.1%	7.0%
Hydrogen refueling stations	55.3%	38.6%	6.2%
Burning hydrogen as a replacement for natural gas	47.4%	45.0%	7.6%

Source: Australian government (2022), no.of respondent is 3,020

However, Hydrogen is still ranked a top for future energy resource

Public perceptions of hydrogen energy in Australia

Perception of hydrogen production and use

- People seems to have neutral reaction when it comes to the question on hydrogen production method

Statement	2021	2018
	(mean score)	
Hydrogen should be used increasingly for energy supply in Australia	5.75	5.06
Using hydrogen will reduce greenhouse gas emissions	5.74	-
The use of hydrogen contributes to climate protection	5.55	4.76
Hydrogen should be produced using renewable energy and electrolysis only	5.31	4.94
Hydrogen should be produced using fossil fuels with CCS as an intermediate step while transitioning to renewables	4.69	4.27
Hydrogen should be produced using fossil fuels with CCS indefinitely	4.16	3.7

Note: Measured on a 7-point rating scale, where 1 = strongly disagree, 4 = neither agree nor disagree, 7 = strongly agree

Agreement with potential future energy sources

- Hydrogen is ranked No.3 after solar PV and wind as potential future energy sources

Statement	2021
	(mean score)
Solar PV	5.89
Wind	5.84
Hydrogen	5.80
Gas	4.53
Biomass	4.49
Gas or coal with CCS	4.19
Nuclear (for power)	3.95
Oil (diesel/petrol for transport)	3.80
Coal	3.58

Note: Measured on a 7-point rating scale, where 1 = strongly disagree, 4 = neither agree nor disagree, 7 = strongly agree

Source: Australian government (2022), no.of respondent is 3,020

Safety issue remains the key consideration for export while the water usage for Hydrogen production seems to be the less concerned

Public perceptions of hydrogen energy in Australia

Importance of export considerations

- Safety issues were rated the most important while "minimising the overall use of water in hydrogen production" was rated the lowest

Statement	2021	2018
If Australia was to start exporting hydrogen how important are the following considerations to you?	(mean score)	
Ensure safety in the way hydrogen is transported	4.46	3.84
Ensure safety of the production process	4.44	4.16
Create new job opportunities	4.31	3.80
Increase economic benefits to AU	4.27	3.69
Minimize the environmental impacts of the production and transport process	4.27	3.80
Support the development of a local manufacturing industry	4.23	4.09
Ensure availability of a domestic hydrogen supply	4.23	3.82
Contribute to the world's emissions reductions	4.19	3.87
Create regional opportunities through H2 production	4.13	3.77
Ensuring AU is an early mover in the export market	4.10	3.67
Retaining the rights of intellectual property for H2 production	4.03	3.66
Minimize the overall use of water in H2 production	3.80	3.88

Note: Measured on a 5-point scale where 1 = not at all important, 5 = extremely important agree

Support for domestic hydrogen facility being built near them

- About 46% of respondents agree to locate hydrogen facility near their them

Statement	2021
Strongly agree	18.3%
Agree	28.7%
Slightly agree	16.6%
Neither agree nor disagree	22.0%
Slightly disagree	5.3%
Disagree	4.8%
Strongly disagree	4.3%
Means score	5.01

Note: Measured on a 7-point rating scale, where 1 = strongly disagree, 4 = neither agree nor disagree, 7 = strongly agree

Source: Australian government (2022), no.of respondent is 3,020

Media Strategy is important for Hydrogen dissemination as the result shows; they are supportive after learning more about hydrogen

Public perceptions of hydrogen energy in Australia

Awareness of hydrogen discussions in Australia

- People have heard about H2 mostly from media and project
- National Hydrogen Strategy does not seem to be known among public

There has been discussion about using hydrogen in Australia recently	Yes	No	Unsure
I have heard about a project blending natural gas and hydrogen for domestic use	20.8%	66.5%	12.7%
I have heard about a hydrogen production project in Australia	27.1%	59.9%	13.1%
I have heard about hydrogen in the media	38.8%	50.6%	10.6%
I have heard about the National Hydrogen Strategy	14.7%	72.9%	12.4%

Support for Hydrogen

- After the benefit of hydrogen has been presented, majority of people supports the hydrogen solution for energy and environmental challenge

Overall, how do you feel about hydrogen as a possible solution for energy and environmental challenges?	Time 1	Time 2	Time 3
Very supportive	20.9%	32.2%	35.7%
Supportive	29.2%	39.0%	38.6%
Slightly Supportive	15.2%	18.4%	15.6%
Neither supportive nor unsupportive	31.9%	8.4%	7.3%
Slightly Unsupportive	1.5%	1.2%	0.9%
Unsupportive	0.8%	0.7%	0.9%
Very unsupportive	0.6%	1.1%	1.0%

Note: Time 1: Beginning of survey
Time 2 : After learn some basic knowledge about H2
Time 3 : After read H2 message from newspaper

 Source: Australian government (2022), no.of respondent is 3,020

Challenges and Implications - ②Thailand

There are multiple challenges to overcome for the successful market introduction of hydrogen, falling into three categories

Challenges

Area	Point of view	Challenges
Overall Supply Chain	Policy	Policy and Regulatory framework is yet organized
	Economy	Incentives for technology adaptor is insufficient
	Society	Hydrogen and relating technology and their benefit are not well-understood
	Technology	Detailed Supply chain is not clear for each area (information limitation)
Demand	Economy	High price of hydrogen is obstacle to secure bankability of the project
		Consideration of target regions/supply chains in global market is still unclear
	Technology	Technology have not been well-developed yet
Supply	Economy	Development/investment for production sites
		Development/investment for production sites has been insufficient
	Technology	Some of Technologies have not been well-developed yet

Category of challenges
Policy and Regulatory Framework
Supply Chain Creation
Public Acceptance

Toward hydrogen project launching, next actions shall be considered in line with three challenge categories

Implication

Further Steps toward Implementation → Hydrogen project Launch

Type	Items for Consideration	Next action	Hydrogen project Launch
Policy and Regulatory Framework	■ Clear direction and commitment by the government is essential to guide private sector ➢ Comprehensive policy and regulatory framework, and supporting implementation plans ■ Incentives in both CAPEX and OPEX for early adaptors is a key drover to create a new hydrogen and ammonia-structured society ➢ Not only for industry sector but also consumer sector	To study Policy and regulation framework and implementation plan; - Benchmarking advanced countries (i.e. EU, SG etc) - Studying examples in other industry of Thailand etc	No silver bullet; Connection and mutual collaboration among key players in public and private sectors, are a key for H2 transformation • Scheme review • Alliance study • Profitability simulation • Planning of implementation plan etc.
Supply Chain Creation	■ Coordination between Demand and Supply generate momentum of moving forward ➢ Detailed potential demand study and common understandings among stakeholders ➢ Allocating risk and introduction cost with multiple players ■ Technical development ➢ Joint-study about specific technology ➢ Focusing on specific technology areas/themes to invest to improve development efficiency	To create Collaboration In national and industrial area levels, aiming; - Information sharing - Creating leading projects - Proceeding joint technical development study etc.	
Public Acceptance	■ Fostering public acceptance of hydrogen is essential ➢ Information to be disseminated and how-to	To consider information Dissemination framework	

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