KEMENTERIAN SAINS, TEKNOLOGI DAN INOVASI
MINISTRY OF SCIENCE, TECHNOLOGY AND INNOVATION

MALAYSIA MADANI

HYDROGEN
ECONOMY & TECHNOLOGY
ROADMAP

HYDROGEN

ECONOMY & TECHNOLOGY

ROADMAP

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Cetakan Pertama, 2023

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"The future starts with the present. Today, we live in a rapidly changing climate that also presents us with promising times to correct our path. As Malaysia embarks on another chapter in her long-term commitment to achieve decarbonisation targets including via energy transition, extraordinary and inclusive efforts are required.

Such systematic and comprehensive efforts must also significantly improve Malaysia's technological prowess within a dynamic local ecosystem, generate new income streams, develop high-skilled workforce, contribute to environmental sustainability and creating a progressive, inclusive society as envisioned under Malaysia MADANI.

Progressive long-term planning and policies are crucial, and Malaysia has always emphasised the importance of the energy sector's critical role in the national economy. The 12th Malaysia Plan recognises the importance of emerging renewables and low carbon energy that can play a pivotal role in energy transition, decarbonising the energy sector and industry, and fuelling a sustainable future towards a carbon-neutral economy.

Hydrogen has a huge potential to be the cornerstone for new energy and economic driver for Malaysia. Developing this potential requires investment in hydrogen technologies to promote domestic consumption, ensure generation stability, provide security of affordable energy, sustain international energy trading, and decarbonise emissions.

I am delighted that the Ministry of Science, Technology and Innovation (MOSTI) created the Hydrogen Economy and Technology Roadmap (HETR) to guide the development of Malaysia's hydrogen economy. This roadmap is a supporting document to the National Energy Policy 2022-2040 (NEP). Both the NEP and the HETR are living documents, which shall pave the way to achieving environmentally sustainable, long term energy security for Malaysia, driven by technological innovation.

HETR provides a clear deployment pathway to scale up hydrogen economy and technology to drive both supply and demand, simultaneously. Hence, we need to invest in new infrastructure to develop and distribute hydrogen to expand its economy of scale, as well as in new technologies and cultivating talents. We also need to establish a comprehensive regulatory framework to facilitate growth along the whole hydrogen value chain and finally, we must strengthen collaboration and cooperation to further advance the uptake of hydrogen as we move towards a low-carbon socio-economic development for decades to come.

By the year 2030, HETR projected that between 0.4%-1.3% reduction in Greenhouse Gases (GHG) emission can be achieved depending on the implementation model proposed in the HETR. Projected revenue of up to RM12.1 billion in 2030, contributing between RM49 billion and RM61 billion to the country's Gross Domestic Product (GDP). Additionally, HETR is also expected to create between 8,000 to almost 45,000 job opportunities in the clean energy sector by the year 2030. By the year 2050, these projected figures will increase significantly, driven by technology effectiveness and maturity, increased hydrogen production and the consumption of hydrogen and its derivatives expanding to new sectors. Malaysia can be positioned as a major hydrogen exporter in Asia Pacific, generating more than RM400 billion in revenue, creating more than 200,000 potential job opportunities for the Rakyat while achieving up to 15% GHG emissions reduction.

I wish to congratulate MOSTI for taking the initiative to develop HETR. This holistic approach and collaboration involving various ministries, agencies, research institutions and industry stakeholders are needed to create a robust and competitive hydrogen ecosystem in Malaysia, being part of the global hydrogen economy value chain. I wish my very best for our future endeavours in hydrogen.

Thank you.

ANWAR IBRAHIM
5 October 2023

Preface By
Minister of Science, Technology and Innovation

Hydrogen has long been regarded as the fuel of the future. At the Ministry of Science, Technology and Innovation (MOSTI), we believe that hydrogen could become a fuel of the present before the next decade, delivered by technological innovation and driven by systematic planning. The Hydrogen Economy and Technology Roadmap (HETR) is MOSTI's answer to addressing the three energy challenges namely reliability, affordability and sustainability, while achieving decarbonisation targets.

As a supporting document to the National Energy Policy 2022-2040, HETR is also not merely a roadmap for decarbonisation through energy transition but also a living document for new industrial development propelled by technologies and innovation. Many countries possess strategic interests in being innovators and technology producers, rather than just technology users, especially in critical areas such as transition to clean energy. Malaysia is no exception, and my ministry has no intention to be mere spectators in the globally developing hydrogen economy. Via the HETR, we aim for Malaysia to be a leading hydrogen economy country by the year 2050 while achieving the world's decarbonisation targets. In terms of the revenue generation, the economic benefits increase significantly along the short to medium and finally to the long-term with the adoption of hydrogen into more domestic sectors and progressive export operation to finally positioning Malaysia to be a major exporter in the Asia Pacific with projected revenue of more than RM400 billion by the year 2050. All these revenues reflect the benefit on the development of infrastructure for export, utilisation in domestic sectors and open new avenues for job creation.

Furthermore, hydrogen has a bright future in Malaysia as the country possess several advantageous qualities which will allow us to be one of the important players in the Asia Pacific region by the year 2050, if not sooner. We have the necessary basic elements in the country upon which we can develop further and enhance systematically via the HETR. These include diverse Renewable Energy (RE) sources to generate green hydrogen such as solar, bioenergy and sustainable hydropower, innovative local technologies and reliable expertise, as well as the expanding potential of Malaysia's innovation ecosystem.

There are numerous challenges ahead of us but if we remain steadfast and committed to the energy transition process towards decarbonisation, we shall reap many benefits through hydrogen, namely sustainably inclusive socio-economic growth, energy security and global climate stability as inspired by the Malaysia MADANI aspirations. Finally, to achieve these goals, my ministry and I welcome constructive feedback, collaboration and participation in this exciting technological endeavour.

Thank you.

CHANG LIH KANG
5 October 2023

Preface By
Secretary General, Ministry of Science, Technology and Innovation

The Hydrogen Economy and Technology Roadmap (HETR) is in line with Ministry of Science, Technology and Innovation's (MOSTI) aspirations as outlined in the National Science, Technology and Innovation Policy 2021-2030 and serves as a supporting document to the National Energy Policy 2022-2040.

HETR focuses on developing a robust and competitive hydrogen ecosystem across the value chain in Malaysia via accelerated technological advancement. Innovation in hydrogen-related technologies is imperative to drive both demand and supply for successful deployment of hydrogen at scale for a developing Hydrogen Economy such as Malaysia's.

The long-term strategic approach outlined in HETR is to facilitate transition to green hydrogen use by focusing on new technologies and increasing the targeted conversion efficiency of hydrogen-related technologies across the hydrogen value chain. In the mid-term, the improvements would effectively allow hydrogen generation and utilisation to be price competitive, both for domestic consumption and export. Hence, technology is a primary driver and enabler in HETR apart from other factors as outlined in its five strategic thrusts. MOSTI has always been the champion of technology and innovation deployment in Malaysia, as well as the talents critical to sustain this cause. Hydrogen shall be no exception as the ministry has charted its target for the Hydrogen Economy via the HETR.

Keys to success are innovation, collaboration, and perseverance. There are challenges to rebuild a world powered by clean energy and those challenges need to be addressed and must be addressed collectively. Embarking into hydrogen within the primary energy sectors demands navigating through economically feasible production of hydrogen, storage, transportation, and end-use, all of which should be driven by technological advancements and enhancements.

We at MOSTI are always committed to continuously drive innovation for the benefit of the Rakyat, in line with Malaysia MADANI's aspirations.

Thank you.

AMINUDDIN BIN HASSIM
5 October 2023

“Keys to success are innovation, collaboration, and perseverance”

CHAPTER I

ASPIRATION OF HYDROGEN ECONOMY TOWARDS NET ZERO BY 2050

Hydrogen, a colourless, odourless, tasteless, flammable gaseous substance that is the simplest member of the family of chemical elements is an energy carrier that can be used to store, move, and deliver energy produced from non-renewable and renewable sources. Being the most abundant element, hydrogen can be generated from domestic waste, non-renewable and renewable feedstocks.

1.1 Introduction

The Intergovernmental Panel on Climate Change (IPCC) Special Report on Global Warming of 1.5 °C highlighted the importance of reaching net-zero carbon dioxide (CO_2) emissions globally by mid-century or sooner to avoid the worst impacts of climate change (IPCC, 2018). As of 23 April 2021, 44 countries and the European Union have pledged to meet a net-zero emissions target: in total they account for around 70% of global CO_2 emissions and Gross Domestic Product (GDP).

At present, majority of the energy sources release Greenhouse Gases (GHG) emissions, particularly CO_2 contributing to climate change and environmental impact. The U.S. Energy Information Administration (EIA) projects that world energy consumption will grow by nearly 50% between 2018 and 2050. With the rapid growth of electricity generation, renewables—including solar, wind, and hydroelectric power—are the fastest-growing energy sources between 2018 and 2050, surpassing petroleum and other liquids to become the most utilised energy sources. Staying within the Paris Agreement of 1.5˚C temperature limit requires rapid, large-scale systemic transformations to decarbonise the global energy system by the year 2050.

Sectoral energy consumption covers three major energy consumers in Malaysia: the residential and commercial, industrial, and transportation sectors respectively. Among these sectors, the bulk of the energy consumption is by the industry and transport sectors, constituting almost two-third of the total energy consumption in 2019. Reduction in grid carbon intensity, adoption of renewable energy (RE), carbon capture and storage (CCS), electrification, and energy efficiency (EE) is estimated to reduce CO_2 emission by up to 70%. In advanced countries, clean hydrogen is expected to first be utilised as industrial feedstock in the existing industries (e.g.: steel, ammonia, methanol, refining) as a replacement to grey hydrogen. As such, focus need to be shifted on developing renewable and clean energy from solar, wind, nuclear, hydropower and biofuels as replacement to fossil fuels.

Therefore, Hydrogen Economy envisions utilising hydrogen as a clean, low-carbon energy resource to meet the world's energy needs, replacing fossil fuels and forming a substantial part of a clean energy portfolio. Just as all other RE sources, hydrogen also falls under the category of carbon neutral energy, but the specialty of hydrogen that makes it inclusive can be attributed to its potential in the Circular Economy model which industry players from different sectors and economic landscapes can benefit from. Malaysia's GDP, which is based on the open economy was adversely affected the world were containing the spread of the COVID-19 pandemic and practising the new norm. Hydrogen Economy has the potential to create a new industry that will expand the country's economic growth. Hydrogen is also an environmentally friendly resource which produces only pure water and heat when combusted.

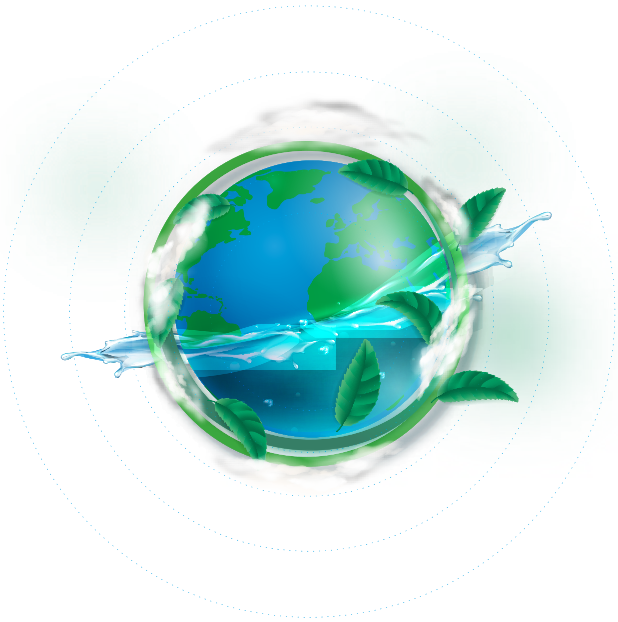
Furthermore, creation of employment opportunities through technology penetration across the Hydrogen Economy value chain will create positive impact on socio-economy by ensuring job security, supply of power in remote regions and rural areas, and ensuring cleaner environment with less pollution for citizens to live. Undoubtedly, the aspiration of Hydrogen Economy has the inclusivity to empower economic, environment, social well-being as envisaged by the Malaysia MADANI targets and core values, aligning sustainable socio-economic growth according to the 12th Malaysia Plan (RMK-12) and the big agenda of Net Zero by 2050

According to the Hydrogen Council, the International Hydrogen market could be worth up to US$ 2.5 trillion by 2050, meeting 18 % of global energy demand, providing 30 million jobs around the world, and reducing CO_2 emissions by 6 gigatons per year. The Ministry of Science, Technology and Innovation (MOSTI) via this Hydrogen Economy and Technology Roadmap (HETR) aims to achieve decarbonisation targets by strategically position Malaysia in the highly lucrative global hydrogen ecosystem, where the global green hydrogen market has been projected to reach USD 189.19 billion in 2050. From this projected figure, Asia Pacific accounts for USD 81.12 billion (43 %), followed by ASEAN with market opportunities of USD 25.81 billion (13 %) and Malaysia at USD 3.10 billion (2 %).

Countries such as Japan, South Korea, China, Australia, and other developing countries in ASEAN has begun to venture in adopting hydrogen into mobility and energy-intensive sectors to meet the environmentally driven regulations and standards adopted by different sectors.

Despite hydrogen being an environmentally friendly alternative to fossil fuels which can be used to provide flexible and high-density power and propulsion for a wide range of industrial plants and modes of transportation via hydrogen fuel cell technology, the challenges lie on transporting and storing hydrogen, cost to generate hydrogen from renewable sources and for end-use application due to low maturity of technology across the hydrogen value chain in Malaysia. Grey hydrogen produced with natural gas costs US$2 per kg in the US, while in Europe, Australia and Asia it costs US$5-6 per kg due to higher natural gas prices. Blue hydrogen produced from natural gas paired with carbon capture and storage (CCS) costs between US$5 to 7 per kg in the US, and $7 to 11 in Europe and Australia respectively. Green hydrogen produced through electrolysis using renewable power costs US$10-15 per kg, depending on availability. With the economy of scale and maturity of the nascent technology across the hydrogen value chain, certain countries have developed the infrastructure to reduce the Levelised Cost of Hydrogen (LCOH) in the range of USD 1.5 – 2/kg. Hence, it is the intention of this roadmap to analyse the current findings and estimate investment required for adoption of Hydrogen Economy in Malaysia.

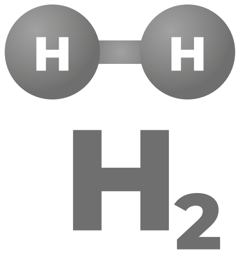
Hydrogen has the highest density content compared to any common fuel by weight (about three times more than gasoline). It takes more energy to produce hydrogen (by separating it from other elements in molecules) than hydrogen provides when it is converted to useful energy. However, hydrogen is useful as an energy source or fuel because it has a high energy content per unit of weight, which is why it is used as a rocket fuel. The higher the energy density, the higher the fuel quality, which is inversely proportional to its chemical complexity. Hence comparison on energy density shows that cost parity is achieved when Levelised Cost of Hydrogen (LCOH) is three times compared to fossil fuel. Hydrogen also offers significantly more cost-effective and stable long term energy storage alternative, approximately at USD 8/kWh to expensive battery-based system circa USD137/kWh for Variable Renewable Energy (VRE). Besides the economic aspect, the technology component across the value chain will balance the roadmap aspirations. The technology trajectory looks at solutions to improve the hydrogen generation (electrolysers, gasification reactors, plasmolysis and others), storage and conversion efficiencies (solid-state chemicals, LOHC, and others) which will directly impact the economic aspect in terms of LCOH (USD/kg) broken down into generation, storage, transportation, and conversion costs. Thus, this makes Hydrogen Economy a viable path for a carbon neutral nation by the year 2050.



1.1.2 Different Shades of Hydrogen

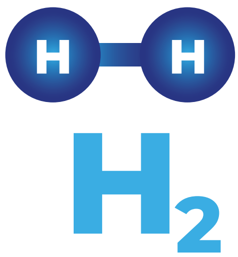
Hydrogen can be produced via multiple processes and energy sources such as natural gas, biomass, and renewable energy (RE) like solar, wind, hydro and has been traditionally used as a feedstock in several industrial processes (such as ammonia synthesis and the refining of crude oil). The four types of hydrogen as identified by the International Renewable Energy Agency (IRENA) that is included in this roadmap include grey, blue, turquoise, and green hydrogen. Industry players are also contemplating to move away from hydrogen taxonomy based on colours to carbon-intensity based alternative.

IRENA (2020), Green Hydrogen: A guide to policy making has defined the difference of the four types of hydrogen as follows:



Grey Hydrogen

Grey Hydrogen is produced with fossil fuels (i.e., hydrogen produced from methane using Steam Methane Reforming (SMR) or coal gasification). The use of grey hydrogen entails substantial CO_2 emissions, which makes these hydrogen technologies unsuitable for a route toward net-zero emissions. Whereas, grey hydrogen, being the cheapest mean of hydrogen, might be a crucial stepping stone before embarking on more expensive type of hydrogen.



Blue Hydrogen

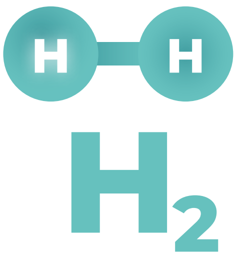
Blue Hydrogen is defined as hydrogen produced from natural gas through a reforming process (e.g.: Steam Methane Reforming) that produces both hydrogen and CO_2, where the CO_2 is being captured and stored. There are also certain certification body which considers low-carbon hydrogen produced from petrochemical processes as a co-product and defined this as blue hydrogen if it meets certain threshold of CO_2 emission based on its life cycle assessment of carbon footprint. Around three-quarters of hydrogen is currently produced from natural gas. Retrofitting with Carbon Capture and Storage (CCS) would allow the continued use of existing assets while still achieving lower Greenhouse Gases (GHG) emissions. Presently, there are two options for CO_2 capture and sequestrations in the production of blue hydrogen in Malaysia which is CCS hub for onshore capture-offshore storage (in the early conceptual stage) and offshore capture-offshore storage for natural gas production from reservoirs with high CO_2 contents. This is an option is to produce hydrogen with lower GHG emissions while reducing pressure on the renewable energy capacity installation rate to produce green hydrogen.

Blue hydrogen is expected to play a significant role in the overall global portfolio of hydrogen supply and demand as global demand cannot be met only by green hydrogen as this relies on geographical location and current cost is still expensive given that production has yet to be scaled-up.

On that note, Malaysia has abundant natural gas, already have mature processes and infrastructure in place, that should be monetised and utilised through CCS technology as it will unlock the capability to produce blue hydrogen to supplement the limitation of green hydrogen due to currently limited RE sources.

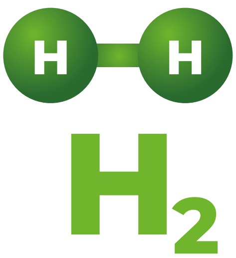
However, CCS capture efficiencies are expected to reach 85-95% at best, which means that 5-15% of the CO_2 will still be emitted and these high capture rates have yet to be achieved. In sum, the carbon emissions from hydrogen generation could be reduced by CCS but not totally eliminated. This means that while blue hydrogen could reduce CO_2 emissions, it does not meet the requirements of a net-zero future. Notwithstanding, blue hydrogen should be recognised as one of the means to meet the projected demand of hydrogen and decarbonisation efforts, as both as a transition (due to cost competitiveness) and long-term hydrogen source (to meet demand volume). Notably, industrial processes such steel production may require a continuous flow of hydrogen; blue hydrogen could be an initial solution while green hydrogen ramps up production and storage capacity to meet the continuous flow requirement.

Turqoise Hydrogen



Turquoise Hydrogen combines the use of natural gas as feedstock with no CO_2 production. Through the process of pyrolysis, the carbon in the methane becomes solid carbon black. A market for carbon black already exists, which provides an additional revenue stream. Carbon black can be more easily stored than gaseous CO_2. At the moment, turquoise hydrogen is still at the pilot stage (Philibert, 2020; Monolith, 2020).

Green Hydrogen



Among the different shades of hydrogen, Green Hydrogen – hydrogen produced from renewable energy sources – is the most suitable one for a fully sustainable energy transition. The most established technology options for producing green hydrogen are water electrolysis fuelled by renewable electricity. Electrolysis is a developed and commercialised process, with various technologies available, each with benefits and barriers to uptake. Water electrolysis to produce green hydrogen is limited to about 200 MW of electrolyser capacity in few hundreds' demonstration projects. Green hydrogen production through electrolysis is consistent with the net-zero route, allows the exploitation of synergies from sector coupling, thus decreasing technology costs and providing flexibility to the power system. Other renewables-based solutions to produce hydrogen exist. However, except for SMR with biogases, these are not mature technologies at commercial scale yet (IRENA, 2018). Low RE costs and technological improvements will reduce the cost of production of green hydrogen.

1.2 Global Drivers of Change

The rapid development of the global trends significantly impacts the social, economic, political, environmental, and technological landscape. Mega trends such as the rise in the economic power, paradigm shift in automotive industry, rapid urbanisation, demographic, and social change as well as a sustainable environment for climate change are triggering far-reaching impacts on individuals, society, industries and nations. The global drivers of change as shown in Figure 1 that was brought by Hydrogen Economy are interlinked with the Sustainable Development Goals (SDG) targets that was set up in 2015 by the United Nations General Assembly and intended to be achieved by the year 2030.

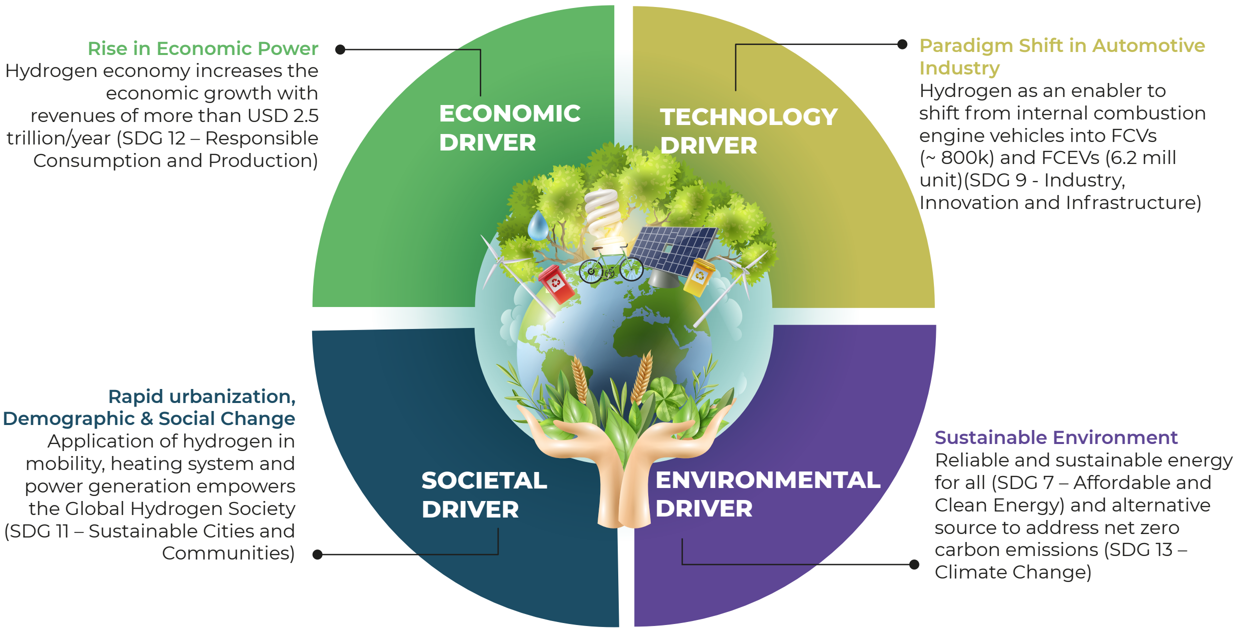


Figure 1: Global Drivers of Change from Hydrogen Economy

1.2.1 Rise in Economic Power

Given its numerous uses and decarbonising potential, countries and corporations around the world are intensifying their investment in hydrogen. The industrial use of hydrogen is already a major global business, with a total demand of around 115 million metric tons in 2018 (60% for 'pure' hydrogen and 40% for hydrogen-based fuels). Today, industrial applications for hydrogen are dominated by hydrogen use as a chemical agent in oil refining and fertiliser production.

According to the International Energy Agency (IEA), the current top four industrial uses are oil refining (33%), ammonia production (27%), methanol production (11%) and steel production via the direct reduction of iron ore (3%). By the year 2023, industrial demand for hydrogen is expected to grow to USD 199.1 billion.

In the United States, the funding provided by the U.S. Department of Energy for hydrogen and hydrogen fuel cells has ranged from approximately USD 100 million to USD 280 million per year over the last decade, with approximately USD 150 million per year being invested in hydrogen by the U.S. Department of Energy since 2017. The US Department of Energy invested USD 276.8 million for hydrogen and fuel cell technologies, 0.0013% of United States GDP in 2020.

Japan's Ministry of Economy, Trade and Industry has also budgeted hydrogen funding of 11% of Japan's GDP, approximately USD 560 million for 2019, while China has also announced hydrogen transport industry investments of more than USD 17 billion through to the year 2023 (0.12% of China's GDP in 2023).

In line with this investment, Hydrogen Economy increases the economic growth with revenues of more than USD 2.5 trillion/year for US, Japan, and China. This aligns with SDG 12: Responsible Consumption and Production in achieving economic growth and sustainable development that requires reduction of ecological footprint by changing the way of production and consumption of goods and resources.

1.2.2 Paradigm Shift in Automotive Industry

The development of new and diversified technologies is creating exciting opportunities within the automotive industry. Along with long-range Battery Electric Vehicles (BEVs), governments and Original Equipment Manufacturers (OEMs) are also looking at Fuel Cell Electric Vehicles (FCEVs) as a viable solution especially for light and heavy commercial vehicles (CVs), Sports Utility Vehicles (SUVs) and passenger cars. Fuel cells are a promising technology that could assist the automotive industry to massively reduce fossil fuel usage by converting hydrogen into electricity. Hydrogen fuel cells vehicles could be the key to cutting out energy-related CO_2 emissions by 60% by 2050, an agreement reached by 195 countries at the COP21 meeting held in Paris in 2015.

The agreement for the first time brought all nations into a common cause to undertake ambitious efforts to combat climate change. A new positive step in this direction comes from car-manufacturer Hyundai, which has announced the launch of a new brand called HTWO that will be dedicated to hydrogen fuel cells. HTWO stands for ‘H2’, the hydrogen molecule, whilst also representing ‘Hydrogen’ and ‘Humanity’, the two main pillars of Hyundai’s fuel cell business.

Other car manufacturers such as Toyota, Honda, Foton, Mercedes-Benz, Volkswagen, BMW, SAIC, FeiChi Bus, and Dongfeng have shown a strong commitment to these alternatives to electric batteries. As of December 2020, 31,225 passenger FCEVS powered with hydrogen had been sold worldwide (Global EV Outlook 2021, IEA). South Korea is the country with the most passenger FCEVs (10,041 units), followed by the United States (9,135), China (5,546) and Japan (4,100).

This brings us to meeting the SDG 9 – Industry, Innovation, and Infrastructure. Inclusive and sustainable industrialisation, together with innovation and infrastructure, can unleash dynamic and competitive economic forces generating employment opportunities and new income streams. They play a key role in introducing and promoting new technologies, facilitating international trade, and enabling the efficient use of resources.

1.2.3 Rapid Urbanisation, Demographic and Social Change

Japan, one of the leading countries in hydrogen development, has set a goal of becoming the world's first 'Hydrogen Society,' which includes plans to build 900 hydrogen-refuelling stations in the country by 2030. Japan's Ministry of Economy, Trade and Industry (METI) has set ambitious goals in the lead up to the Olympic Games 2022 and deployed 100 hydrogen fuel cell buses for the games (which is part of a longer-term goal of deploying 200,000 such vehicles in the next six years) and powered the Athlete's Village with hydrogen.

In addition to the number of Japanese automobile companies that have been developing FCEVs (such as Toyota, Honda, and Lexus), several other Japanese companies have also invested heavily in hydrogen. This transformation goes with the target set for SDG 11 – Sustainable cities and communities. The target is to have investment in public transport, creating green public spaces, and improving urban planning and management in participatory and inclusive ways to make cities and human settlements inclusive, safe, resilient, and sustainable.

1.2.4 Sustainable Environment

The role of hydrogen in creating a sustainable environment is through decarbonisation, in which hydrogen can replace the use of fossil-fuel -based energy sources in many sectors, while not emitting CO_2. Hence, this global driver of change addresses, SDG 7 – Affordable and Clean Energy by having a reliable and sustainable energy and SDG 13 – Climate Change by means of hydrogen as an alternative source to address net zero carbon emissions.

1.3 Global Benchmarking

1.3.1 Global Initiatives of Hydrogen Economy

Globally, many countries are pursuing the transition to decarbonisation of various sectors particularly transport, energy and industrial sectors with hydrogen playing a significant role. It is observed that the government in leading economies, for example Japan, Australia, Germany, South Korea, and China are releasing national strategic roadmaps and announcing several stimulus packages including incentives and funding to support hydrogen technology development, feasibility studies, demonstration, and pilot projects as to increase industry competitiveness as well as hydrogen uptake for domestic use and exports to global markets. Currently, the share of green hydrogen production is still insignificant. Therefore, strategies are being emphasised to increase production of hydrogen from renewable energy sources or other methods that could contribute to low carbon emissions.

Benchmarking of initiatives in the advanced countries include global and regional statements on Hydrogen Economy, is concluded as the following:

1. International Energy Agency Energy Technology RD&D Budgets (2020 first edition) estimates 150 publicly funded hydrogen demo projects in Europe alone and about $700 million in public research funds flows to hydrogen globally every year;

2. IRENA's Renewable Energy Roadmap (RE map) analysis indicates an 6% hydrogen share of total final energy consumption by 2050;

3. Hydrogen Council in its publication of the Hydrogen for Net Zero, suggested that investment cycle away from hydrogen delivering 18% of global energy demand, abating 6 Gt (gigatons) of CO_2 annually, and creating 30 million jobs by mid-century;

4. European Union Green Deal Recovery the EU adopted on July 8, 2021 strategies for energy system integration and hydrogen, aiming to become climate-neutral by 2050. The new hydrogen economy can be a growth engine to help overcome the economic disruption caused by COVID-19;

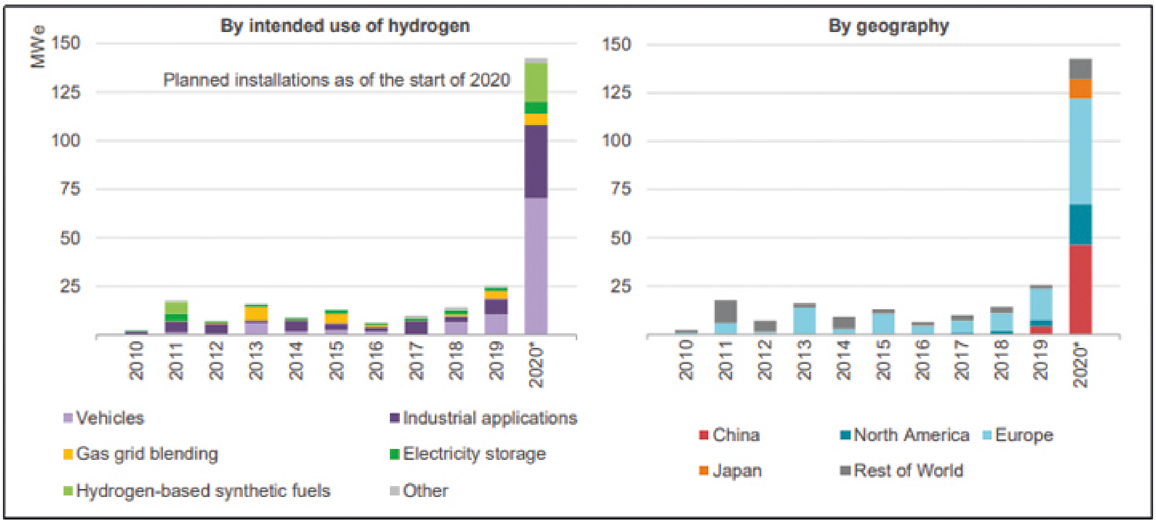
5. Germany Economic Stimulus Package stated that out of the €130 billion economic stimulus package, €7 billion to promote hydrogen and create a demand-driven market. Energy and Climate Fund (310 million euros) between 2020 and 2023, for basic research on green hydrogen;

6. Australia National Hydrogen Strategy announced the allocation of $13.4 million to implement and coordinate the National Hydrogen Strategy. $370 million from Clean Energy Finance Corporation (CEFC) and Australian Renewable Energy Agency (ARENA) funding for Advanced Hydrogen and Electrolysers project.

A global hydrogen revolution is upon us with the EU Clean Hydrogen Strategy, the French Hydrogen Strategy, United States' 'Road Map to a Hydrogen Economy', Japan's Hydrogen Nation, Korea's Hydrogen Economy Road Map and Australia's 3.6 GW green hydrogen project in Queensland. As shown in Figure 2, the capacity of electrolysers for hydrogen production by geography and for intended use are increasing mainly for mobility application with China having the highest capacity. The details on Hydrogen Economy landscape in a global level are tabulated in Table 1.

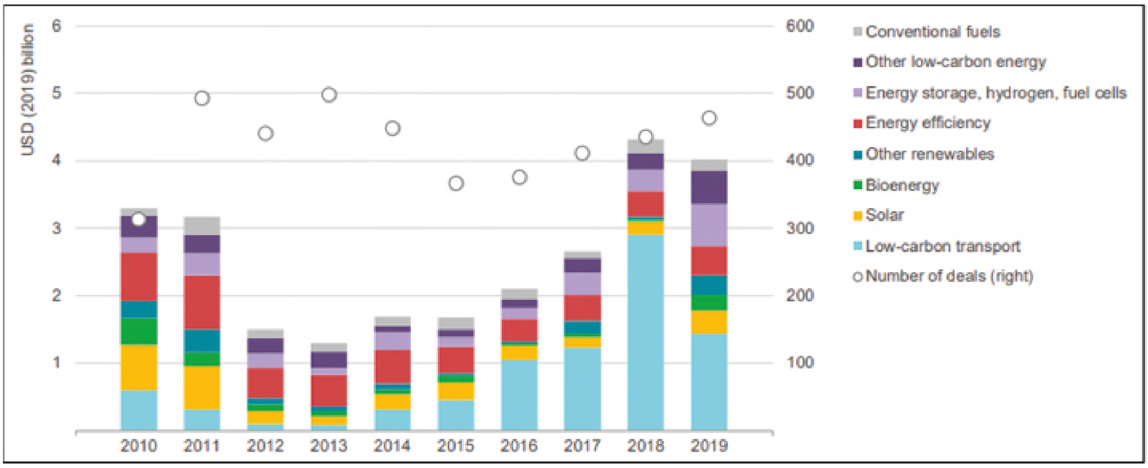
Meanwhile, Hydrogen Initiatives in the ASEAN countries are summarised as below:

- **Malaysia:**
  Integrated Hydrogen Production Plant and Refuelling Station, H2 Fuel Cell buses and cars May 2019
- **Thailand:**
  Demonstration of Hydrogen Microgrid, Nov 2019
- **Indonesia:**
  Formalised collaboration with Toyota to implement H2One™ off-grid system as a fuel for power generation, Oct 2018
- **The Philippines:**
  Formalised collaboration with Toyota to implement H2One™ off-grid system as a fuel for power generation, Oct 2018
- **Singapore:**
  Low emission building powered by Hydrogen. Local companies' partnership with Japanese energy firms to develop innovative ways to use hydrogen fuel, March 2020
- **Brunei Darussalam:**
  Hydrogen production from liquefied natural gas and export to Japan, June 2020



Source: World Energy Investment, 2020

Figure 2: Capacity of electrolysers for hydrogen production by commissioning year, by intended use of hydrogen (left) and geography (right)



Source: World Energy Investment, 2020

Figure 3: Early-Stage Venture Capital Investment in Energy Technology Companies

While still in its infancy for many countries in the ASEAN region, some initial steps have been taken to promote the development of the hydrogen industry and early-stage venture capital investment in Energy Technology Companies in Figure 3 shows the rise in investment in 2018 after a significant drop from 2012 - 2017 Increasingly, there is a growing recognition that hydrogen has significant potential to reduce the region's dependence on fossil fuels. In 2020, the Singapore Government announced a $49 million (approximately USD 36 million) Low-Carbon Energy Research Funding Initiative, which will support the research and development of low carbon technologies such as hydrogen.

In the same year, several agreements were executed between Singaporean and Japanese companies to explore the importation and usage of hydrogen as a green energy source. In Brunei Darussalam, preliminary steps have also been taken to explore the production and transportation of hydrogen in 2021, as part of a hydrogen supply chain demonstration project, a total of 4.7 metric tonnes of hydrogen was shipped to Japan from Brunei Darussalam's first pilot hydrogenation plant, which is operated by the Advanced Hydrogen Energy Chain Association for Technology Development. Benchmark of Malaysia Hydrogen Economy development against the ASEAN countries are tabulated in Table 2.

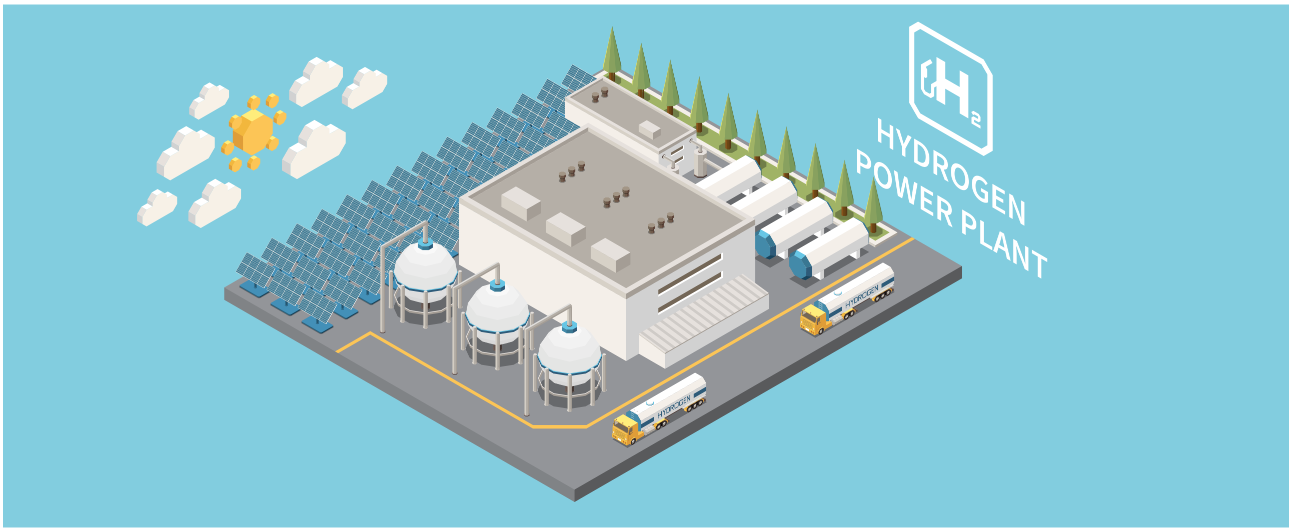


Table 1: Global Benchmarking of Hydrogen Economy

Aspect/ Country	Japan	Australia	United Kingdom
Policy/Roadmap /Strategy	• Third Strategic Roadmap for Hydrogen and Fuel Cells (2019)	• Australia's National Hydrogen Strategy	• Industrial Decarbonisation Strategy, APPG on Hydrogen & Hydrogen Advisory Council
Economic Instruments	• Funding demonstration projects • 70 billion yen support	• $263.7 mil -CCS/CCUS • $275.5 mil – clean H2 hubs	• 240 mil Net Zero Hydrogen Fund • £ 1 bil Net Zero Innovation Portfolio
National Target	• 200k FCVs (2025) • 800k FCVs (2030) • 320 refueling stations in 2025, 900 in 2030 • 1,200 fuel cell buses in 2030	• To achieve more than 26-28% of 2030 Paris Target	• Net zero Co2 emissions in 2050 • Phasing out fossil fuels 2050 • 80GW green H2 in 2050 • 250k job creation • Cost reduction of 20%

South Korea	China	United States
• Hydrogen Economy Roadmap 2040	• 14th Five Year Plan (2021-2025) • Blue Book on China's Hydrogen Energy Industry • Infrastructure Development (2016) • China White Paper on Hydrogen Energy and Fuel Cell Industry	• US Hydrogen Energy Leadership
• $34 million Hydrogen Economy Fund	• R&D Funds via National Programmes • FCEVs – exemption from vehicle, ship, and purchase tax • Four million yuan for each new FCEV refuelling station that meets national technical standards.	• Annual funding for hydrogen and fuel cells ranged from USD 100 million- USD 280 million.

• 6.2 million FCEVs in 2040
• Refuelling stations – 310 (2022), 1200 (2040)
• 40k FC buses, 80k taxis and 30k trucks in 2040
• 15GW of power
	• H2 Production – H2 production from renewable energy. Coal-based H2 + CCS
	• H2 Storage – Long distance pipeline (long-term)
	• FCEVs 50k (Near term), 130 million (Mid-term), 500 million (Long-term)
	• H2 energy ratio 4% (short-term), 5.9% (mid-term), 10% (long-term)
	• H2 fueling stations – 200 (short-term), 1500 (mid-term), 10,000 (long-term)
		• Near-term (2020-2022)
		  • 12 million metric tons of Hydrogen
		  • 30,000 FCEVs, 50,000 material handling FCEVs
		• Short -term (2023-2025)
		  • 13 million metric tons for hydrogen demand, 150,000 light-, medium- and heavy – duty FCEVs, 125,000 material handling FCEVs.
		• Medium-term (2026-2030)
		  • 17 million tons of hydrogen demand, 1.2 million FCEVs, 300,000 material handling FCEVs, 4,300 fueling stations.
		• Long –term (2030 onwards)
		  • $750 billion revenue by 2050, 63 million metric tons of hydrogen demand and all equipment including FCEVs.
		• 14% of US final energy demand

Aspect/ Country	Japan	Australia	United Kingdom
Industry Value Chain	• Ammonia as a potential fuel to maritime industry, transport, and storage • Woven City, Hydrogen-powered city by Toyota and ENEOS (Est. completion in 2024)	• Formation of H2 cluster through SMEs	• Zero Carbon Humber – industrial cluster • HyNet Northwest – natural gas production • Hydrogen to Humber (H2H)
Achievements/ Progress	• 3,800 FCEVs • 135 refueling stations. • 91 FC buses • 250 FC forklifts	• Legal frameworks, Infrastructure Assessment, pilot projects, State of Hydrogen report	• Demonstrations, market acceleration, frameworks

South Korea	China	United States
• Hydrogen Fuel Supply Facilities • Hydrogen Convergence Alliance	• Inner Mongolia: Power-to-Gas for Energy Storage • Zhejiang: Hydrogen Integrating with Offshore Energy and Aquaculture • Jilin: Gas Blending Technology & Wind Power-to-Gas • Hebei: Green Hydrogen and FCV Demonstrations for Winter Olympic • Shandong: Hydrogen Transportation Corridor • Shanghai: FCV Infrastructure Construction	• Second-generation FCEVs and fueling stations for light-duty vehicles, buses, and material handling vehicles • First-generation FCEVs and fueling stations for heavy-duty vehicles • Fuel cells scaled up to 30+ MW for data centers and facility backup power • Initial pilots for energy storage, enabling intermittent renewables, nuclear, data centres, and industrial applications
• Largest H2 fuel cell production • 200MW facility under construction • Hyundai to develop FCEVs.	• 11 provinces have listed H2 as a key economic priority.	• 7,600 FCEVs deployed, 25,000 fuel cell material handling vehicles, more than 8,000 small scale fuel systems in 40 states, more than 550 MW of large-scale fuel cell power installed or planned.

Table 2: Benchmark of Malaysia Hydrogen Economy Against ASEAN Countries

Aspect/ Country	Malaysia	Indonesia	Brunei	Philippines
Policy/ Roadmap /Strategy	None	None	None	None
Economic Instruments	None	None	• Incentives for energy efficient appliances and vehicles which may include FCV	• Zero-rate import duty on components, parts and accessories for the assembly of hybrid, electric, flexible fuel and CNG motor vehicles.
National Target	None	None	None	None
Industry Value Chain	• Production of green hydrogen in Sarawak: 130kg per day • Production of grey hydrogen - 1 MTPA	• Production of hydrogen from biohydrogen reactor - 720L of H2 gas per hour	• A total of 4.7 metric tonnes of hydrogen have been shipped to Japan and is expected to supply 210 metric tonnes in 2020	• Pilipinas Shell Petroleum Corp is constructing an integrated hydrogen manufacturing facility at its Tabangao refinery

Singapore	Thailand	Vietnam	Cambodia	Myanmar	Laos
None	None	None	None	None	None
• Energy Market Authority of Singapore has introduced R&D grants to support the industry in hydrogen innovation for sandbox trials	None	None	None	None	None
None	None	None	None	None	None
• Linde Gas Singapore Pte Ltd joined with Keppel Data Centres Holdings Pte Ltd, Kawasaki Heavy Industries Ltd, Mitsui O.S.K. Lines Ltd and Vopak LNG Holding B.V to explore the development of infrastructure to supply hydrogen to power data centres owned by Keppel Corp's unit in the city state. • Brown hydrogen is produced though SMR and partial oxidation on Jurong Island and it is a feedstock for industry processes	• Bangkok Industrial Gas Company Limited (BIG), announced they are the first and biggest hydrogen producer of Thailand with the capability to produce hydrogen at a rate of 17,000 cubic meters per hour	None	None	None	None

Aspect/ Country	Malaysia	Indonesia	Brunei	Philippines
Achievements/ Progress	• Launch of Sarawak Energy's Integrated Hydrogen Production Plant and Refueling Station in Kuching, Sarawak in May 2019 with a production capacity of 130kg of Hydrogen per day. • Production of hydrogen buses in Sarawak • Gentari to venture into green hydrogen production • SEDC Energy has inked MoUs with Japanese consortium (Sumitomo Corp & ENEOS) and Korean consortium (Samsung Engineering, POSCO & Lotte Chemical) for hydrogen production and export in MCH and Korean for hydrogen export in ammonia form.	• (Toshiba ESS) announced on August 2018 that it has concluded a memorandum of understanding (MOU) with state-owned Badan Pengkajian dan Penerapan Teknologi (BPPT) on the implementation of the renewables-based H2One™ autonomous off-grid hydrogen energy system. • An Australian-based oil and gas company, Lion Energy is conducting a study for a potential hydrogen production facility in Seram Island, Indonesia, a location where Indonesia is producing its oil and gas activities	• Collaboration with Japan's Advanced Hydrogen Energy Chain Association for Technology Development (AHEAD) – supply of hydrogen produced from processed gas at Brunei LNG from Brunei to Tokyo Bay	• MOU with Toshiba Energy Systems & Solutions Corporation on the implementation of the renewables-based H2One™ autonomous off-grid hydrogen energy system

Singapore	Thailand	Vietnam	Cambodia	Myanmar	Laos
• In March 2020, five Singaporean and two Japanese companies signed a MoU to develop ways to use hydrogen as a low-carbon energy source comprising of PSA Corporation, Jurong Port, City Gas, Sembcorp Industries, Singapore LNG Corporation, Chiyoda Corporation and Mitsubishi Corporation	• Phi Suea House is powered entirely by a solar-hydrogen system, the world's first for energy storage of its size. The solar-powered hydrogen storage system provides 24-hour, year-round access to clean energy (Phi Suea House, 2019).	• A support programme for the Ministry of Industry and Trade sponsored by the German Corporation for International Cooperation indicates that the country has a solar power potential of 130 GW and a wind power potential of 27 GW (MOIT, 2016).	None	None	None

1.3.2 Hydrogen Market Opportunities

China, Japan, South Korea, and Singapore are expected to be primary export markets as these countries have a mature hydrogen ecosystem. China, being the largest hydrogen consumer, is expected to require 35 MTPA of hydrogen in 2030 and up to 60 MTPA of hydrogen in 2050. Most of the consumption comes from electricity generation, followed by industry applications and transportation, both of which have similar energy requirements. The hydrogen demand from China stands at USD 19.48 billion in 2040 and USD 38.55 billion in 2050. China, being the most demand-intensive country is also expected to be a supply-intensive country. However, China's production of hydrogen is expected to fall short of the demands for domestic use.

Japan and South Korea albeit demanding lesser hydrogen, are limited in terms of resources to produce their own hydrogen. They are looking for opportunities to import hydrogen especially from Southeast Asia due to its proximity and well-established supply lines between these two countries. Japan's hydrogen demand stands at 3 MTPA of hydrogen in 2030 and is expected to increase to 20 MTPA of hydrogen in 2050 across a 20-year horizon. South Korea on the other hand is expected to require 2 MTPA of hydrogen in 2030 and is expected to increase approximately over 5-fold to 11 MTPA of hydrogen in 2050. The market potential for both countries stands at USD 4.9 billion in 2040 and USD 10.14 billion in 2050 respectively based on 10% penetration.

In February 2020, Singapore announced its Long-Term Low Emissions Development Strategy (LT-LEDS) to halve its peak emissions from 65 MtCO_2e to 33 MtCO_2e by 2050 with a view to achieve net zero emissions. The hydrogen required by Singapore in 2030 is 0.3 MTPA of hydrogen and expected to reach 1 MTPA of hydrogen by 2050. According to a report by National Climate Change Secretariat, Singapore is hard-pressed for options when it comes to alternative forms of renewable energy. It has rather flat land, no geothermal resources, and low wind speeds. Plans to build a commercially viable carbon capture system in Singapore are underway, but there are two main challenges. First, the location to store the carbon dioxide once it has been captured is tricky to be answered. Other countries typically store it underground in oil and gas wells, which are now redundant, but Singapore does not have such wells. Second, most of Singapore's electricity is generated through burning natural gas in Combined Cycle Gas Turbines (CCGTs), which produce a low concentration of CO_2 in its emissions compared to coal. This makes it more expensive and difficult to separate the CO_2.

Due to these challenges, importing hydrogen seems to be the best option with lower cost and barrier for Singapore to halve its peak GHG emissions by 2050. Study of Hydrogen Imports and Downstream Applications for Singapore has targeted Sarawak as one of the strategic locations with competitive price below USD 4/kg by 2050 for hydrogen import to Singapore. With regards to the export market, the targets for hydrogen demand (MTPA) in different countries in 2030 and 2050 is included in appendices for further reading.

At the time of writing this HETR document, PETRONAS through Gentari has been spearheading the initiatives to export hydrogen to Japan by developing projects in Malaysia and Canada for hydrogen export in ammonia or methylcyclohexane (MCH). Besides that, SEDC Energy has inked MoUs with Japanese consortium (Sumitomo Corp & ENEOS) and Korean consortium (Samsung Engineering, POSCO & Lotte Chemical) for hydrogen production. The MoU with Japanese consortium focuses on the hydrogen export in the form of MCH and MoU with Korean focuses on the hydrogen export in ammonia form.

Malaysia is well-positioned to become one of Asia Pacific's key hydrogen trading hub between hydrogen exporters in Australia and the Middle East, and large emerging consumer hubs of Asia (China, Japan, South Korea, and Singapore). Apart from industry initiatives, the Government of Malaysia's role in building strategic partnerships with hydrogen demand-intensive countries by way of Government-to-Government (G2G) initiatives focusing hydrogen export is important.

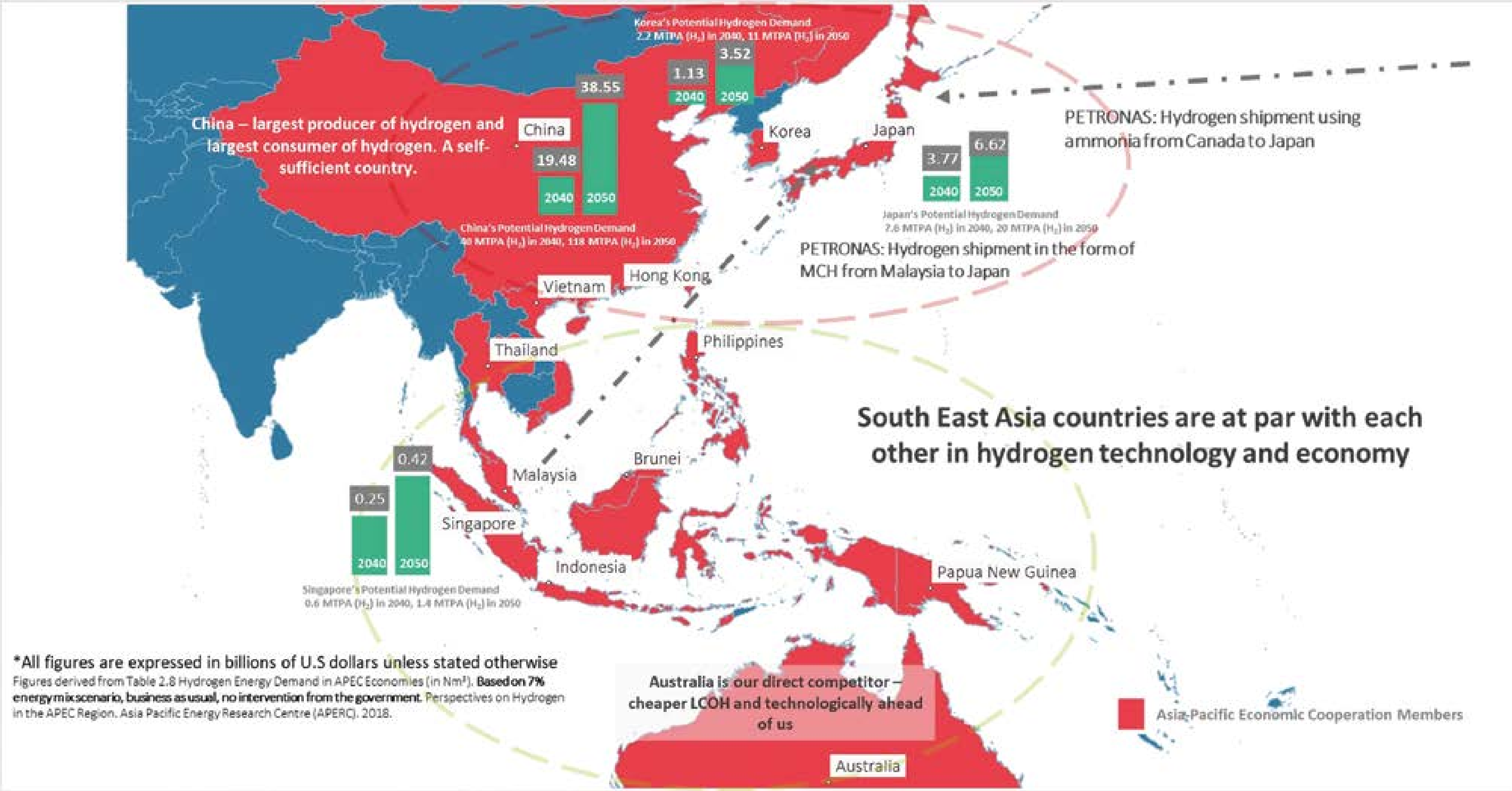


Figure 4: Hydrogen market opportunity for export

1.4 Hydrogen Economy for Malaysia

Many countries around the world have begun to reap the benefits from the adoption of hydrogen in meeting future energy needs, be it for industrial application, mobility, or domestic use. Based on Malaysia Renewable Energy Roadmap, as of December 2020, the installed capacity is 8,450MW. To achieve these same goals, Malaysia has set several targets and embarked on efforts to shift towards green growth in implementing the 2030 SDG Agenda.

Through implementation of the Green City Action Plan (GCAP), the installation of more renewable energy equipment such as photovoltaic solar panels to accelerate the green growth initiatives has flourished among the industrial sectors to support sustainable urban development.

There are several cases for change as shown in Figure 5 that the hydrogen economy presents to push Malaysia towards becoming a prosperous and high-tech nation by 2050, as addressed in the following sections.

1.4.1 Case for Change in Malaysia

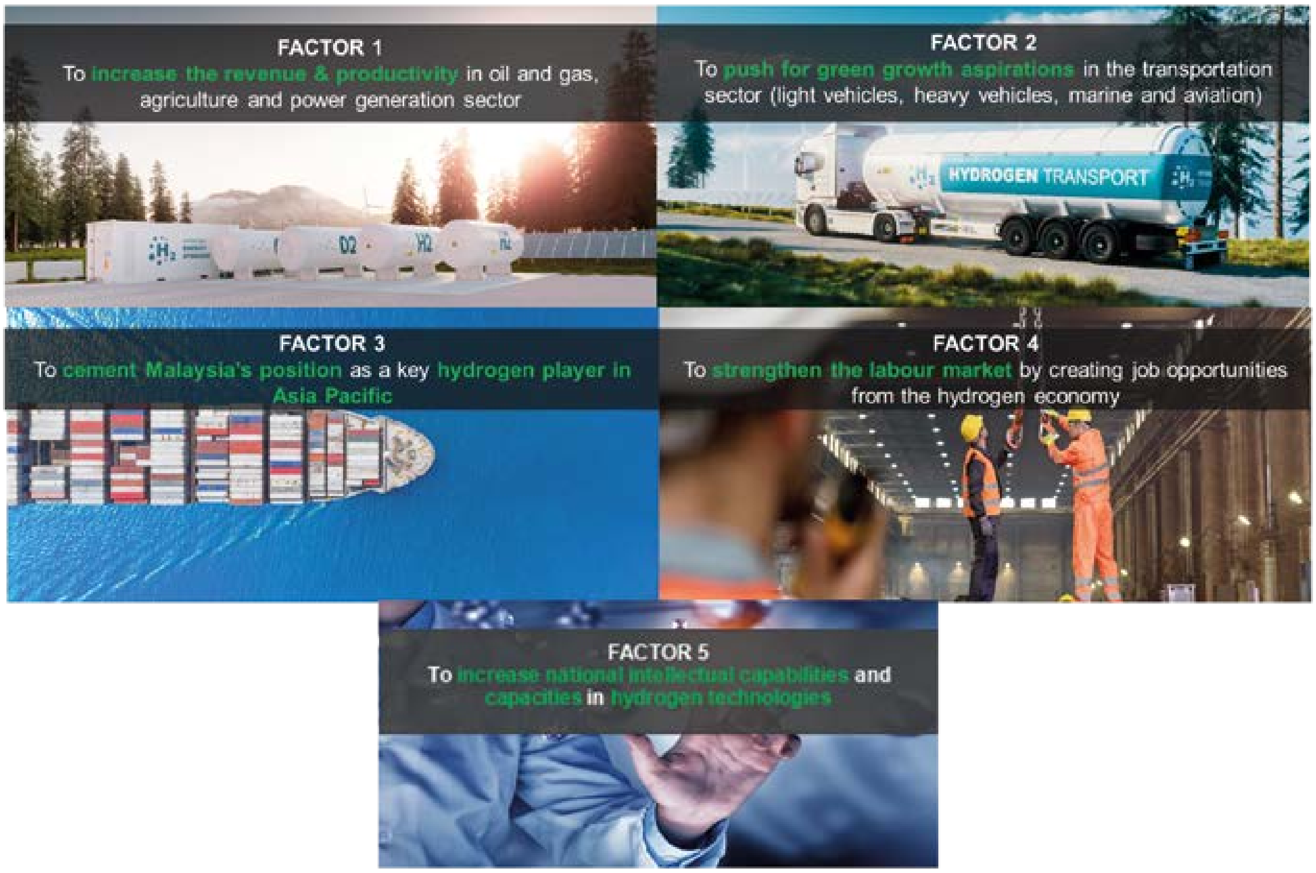


Figure 5: Case for Change in Malaysia

The transition from fossil fuels to renewable energy sources provides significant challenges and opportunities for various energy sectors. Incorporation of hydrogen in the primary energy mix introduces a degree of complexity in relation to its production, transportation, and end-use. Nevertheless, considering the benefits that our international counterparts have gained from the Hydrogen Economy, it is timely for Malaysia to invest and venture into hydrogen.

1.4.1.1 Revenue and Productivity of Economic Sectors

The first case of change addresses the economic aspect, looking at increasing the revenue and productivity in oil and gas, agriculture, and power generation sectors. Carbon-free hydrogen production, transmission, and distribution are now widely recognised as central components to the oil and gas industry's decarbonisation efforts in the upstream, midstream, and downstream operations. Oil and gas companies have begun to explore the feasibility of CCUS for onshore and offshore hydrogen production from petrochemical plants, natural gas, and offshore storage of CO_2 to produce blue hydrogen.

Annually a minimum of 168 million tonnes of biomass waste is generated in Malaysia. In general, palm oil waste accounts for 94% of biomass feedstock while the remaining contributors are agricultural and forestry by-products, such as wood residues (4%), rice (1%), and sugarcane industry wastes (1%). According to data from the Malaysia Palm Oil Board for 2020, the amount of solid biomass waste generated from palm oil industry in Malaysia accounts for a total of 98.1 million tonnes. Palm Oil Mill Effluent (POME) and Empty Fruit Bunch (EFB) generated from mills in Malaysia amount to 58 million tonnes per year and 20 million tonnes per year respectively (MPOB 2020). Biohydrogen production from POME and EFB through dark fermentation, gasification process and various treatment methods has shown a promising route for green hydrogen production at pilot-scale.

The development of major hydropower projects in Malaysia is generally undertaken by utility companies such as Tenaga Nasional Berhad (TNB) in Peninsular Malaysia, Sarawak Energy Berhad (SEB) in Sarawak while in Sabah by the Sabah Electricity Sdn. Bhd. (SESB). Overall, the total gross hydropower potential documented is about 414,000 GWh per year of which about 123,000 GWh per year is the technical potential for development. About 87,000 GWh (70%) of this energy potential is in Sarawak, 20,000 GWh in Sabah and 16,000 GWh in Peninsular Malaysia. Malaysia is blessed with the geography to accommodate hydropower dams which in turn provides electricity to produce green hydrogen. This will potentially unlock a revenue of RM7.7 billion coming from hydrogen demand through the power generation sector in 2050. The potential economic benefits from hydrogen under a Business-as-Usual (BAU) and Emission-Driven Scenario (EDS) will be able to generate a revenue of RM 560.63 billion and RM 776.63 billion, in 2050 respectively.

1.4.1.2 Green Growth Aspiration in Mobility Sector

The second case for change looks at the adoption of emerging technologies to penetrate the Malaysian market. Existing and emerging hydrogen technologies acts as enablers to produce, store, transport and use hydrogen in mobility sectors, power generation, application in non-energy sectors and for heating. Malaysia hydrogen demand from the prioritised end-use segment is listed below in accordance with the economics feasibility, practicality and executability of hydrogen end-use in the order of probability of success:

a. Replacement feedstock for existing industries that are already using grey hydrogen as feedstock,
b. Marine fuel and marine bunkering,
c. Development of specific hydrogen industrial and demand hubs,
d. Aviation fuel (long term),
e. Coal or gas co-firing power plants,
f. Large or heavy land vehicles,
g. Back-up power generation, and
h. Small land vehicles

The backbone of social growth and economic expansion of any country relies on the transportation system. Rapid urbanisation, accompanied by a rise in the number of vehicles on the road has contributed to the increase in energy consumption and carbon emissions. Transport sector emits the most greenhouse gases and consumes the most energy. According to the Energy Commission's National Energy Balance 2013, the transport sector consumed the highest amount of energy at 43.3% (about 22,357 ktoe) in 2013 compared to 37.0 % (about 17,728 ktoe) in 1993. RMK-11 has outlined the strategies to encourage low carbon mobility through the utilisation of Energy Efficient Vehicles (EEV) and public transportation. Following that, the adoption of EEVs has slightly reduced the amount of energy required for transportation to 36.4 % (Energy Commission's National Energy Balance 2018). As a follow-up to this initiative, National Transport Policy (2019 – 2030) and 12th Malaysia Plan (RMK-12) has explicitly positioned transition of the NextGeneration Vehicles (NxGV) for aviation, marine and land transportation through the adoption of the hydrogen fuel cell.

National Automotive Policy 2020 (NAP 2020) encourages new growth areas through integration of technology such as NxGV, Mobility as a Service (MaaS), and Industrial Revolution 4.0 (IR4.0) which are in line with the development of future technologies. Considering the more dynamic development in the automotive industry, there is a need to expand the EEV technology and engineering of the automotive sector to NxGV. As part of the technology thrust under NAP 2020, feasibility study on Hydrogen Fuel Cell technology has been outlined as a specific measure under electric vehicles development. For land transportation, electric vehicles are expected to dominate the small-sized vehicles segments (e.g., for city driving).

Meanwhile for the large-sized land vehicles (e.g., buses, trucks, lorries), fuel-cell (FC) technology may have the advantage. It is worthwhile to note that, the adoption of hydrogen in air and maritime transportation segment may not be depending on fuel cell alone, but rather hydrogen in other forms, for example ammonia fuel for marine vessels (with ammonia-driven engine), and eFuels for air transportation (e.g. synthetic kerosene) Therefore, it is imperative to consider the required infrastructure overhaul and its ensuing investments for this to take-off. It is forecasted that the hydrogen demand from the transportation sector will reach RM 3.7 billion in 2050, primarily arising from light passenger vehicles and public transport. Pragmatically, it is envisaged that this major transformation will be challenging for Malaysia and would require immense government push, a major investment, and complete establishment of the hydrogen ecosystem.

1.4.1.3 Cement Malaysia's Position in Asia Pacific

The third case for change explores the strategies to reap economic benefits by cementing Malaysia's position as a key hydrogen player in Asia Pacific through export of hydrogen as an energy carrier. This is driven by demands from Japan, China, South Korea, and other hydrogen economies with clear hydrogen targets. This demand, coupled with Malaysia's geographical location, provides the competitive advantage in providing hydrogen solutions and capturing the growing hydrogen demand in the Northeast Asian market.

The revenue from hydrogen export is forecasted to stand at USD 81.12 billion in 2050, which is equivalent to 249 MTPA of hydrogen. China, Japan, and South Korea have set ambitious targets to put millions of hydrogen-powered vehicles on their roads by the end of the next decade at a cost of billions of dollars. The APAC economic powerhouses also see hydrogen to confront environmental issues while developing local industries to fuel their industry and power generation. Following this target, the demand of hydrogen in Japan, South Korea and China is close to 3 MTPA, 2 MTPA and 35 MTPA respectively by 2030 (APEC Energy Demand and Supply Outlook 7th Edition, Hydrogen in ASEAN – Economic Prospects, Development and Applications).

According to the conclusion of the pre-feasibility study done in 2021 for the development of green hydrogen and ammonia project that SEDC Energy Sdn. Bhd. has joined forces with other players shows that the project is expected to produce 7000 ton/year of green hydrogen for Sarawak's local use, 600,000 ton/year of blue ammonia, 630,000 ton/year of green ammonia and 460,000 ton/year of green methanol. The H2biscus Project will serve as an exemplary project of international standing for renewable energy trading and hydrogen transportation between South Korea and Malaysia.

In addition to that, ENEOS has also signed an MoU with SEDC Energy Sdn. Bhd. and Sumitomo Corporation to come up with a CO_2-free hydrogen supply chain which involves the conversion of hydrogen into methylcyclohexane (MCH) as an efficient means of transportation to Japan. The feasibility study projected 3,000 ton-H2/yr. for local consumption and 50,000 or

100,000 ton-H2/yr. for export in the form of MCH. Another recent joint feasibility study between PETRONAS/Gentari and ENEOS of Japan, for a commercial hydrogen production and conversion project in Kerteh, Terengganu, are expected to have a total hydrogen production and conversion capacity of up to 50,000 ton-H2/yr. by 2027 for export in MCH form to Japan. The supply and demand will be able to provide economic stimulus to Malaysia, whilst providing the necessary investments required to establish the hydrogen infrastructure in Malaysia.

1.4.1.4 Strengthen the Local Labour Market

The fourth case for change is towards empowering the socio-economic landscape from the aspect of economic security, which creates job opportunities. The COVID-19 pandemic has resulted in a shrinkage of Malaysia's GDP by 5.5% and increased unemployment to 711,000 in 2020 compared to 508,200 in 2019 (DOSM, 2020). Recovery from the pandemic remains slow in 2021 with an increase in GDP of only 3.1%. Despite this growth, unemployment increased up to 733,000 in 2021 compared to 711,000 in 2020. Currently, around 95% of global hydrogen production comes from fossil fuel feedstocks.

The development of Hydrogen Economy through deployment of technology across the value chain and adoption of hydrogen by the end-use sectors initiates green job revolution. As hydrogen is expected to be operational from 2025 onwards, the socio-economic development via Hydrogen Economy will bring in revenue through export and creation of low, semi and high skilled job opportunities along the hydrogen value chain. Hydrogen economy provides opportunities to rejuvenate Malaysia's economy, achieve decarbonisation targets, creating new employment potentials in the future.

1.4.1.5 National Intellectual Capabilities and Capacities

The fifth and last case for change looks at increasing national intellectual capabilities and capacities in hydrogen innovation. The use of emerging technology sources to diversify Malaysia's fuel mix is as one the pathways to meet the decarbonisation agenda by 2050. Given the growing desire to reduce dependence on fossil fuels and carbon emissions, researchers are looking into developing less carbon-intensive technologies to be deployed for a large-scale hydrogen production using renewable energy sources. Since 2000, 1,561 hydrogen related publications were published, while research funding related to hydrogen stands at 121 projects since 2006.

The trends shows that Malaysia is actively building its national intellectual capabilities and capacities in hydrogen technologies, creating talents and intellectual property rights (IPRs). Development of the local capacity and regaining cutting-edge capabilities is the solid foundation and essential step that will bring forward the domestic hydrogen technology into commercialisation scale.

1.4.2 Development of Hydrogen Economy

Malaysia's national vision is to build a prosperous, inclusive, and sustainable country through economic empowerment, environmental sustainability, and social re-engineering. The success of this national vision will be reflected through the people's well-being, economic security, and growth sustainability.

Besides that, to comply with the Paris Agreement on climate change, a growing number of countries are setting ambitious Greenhouse Gases (GHG) emissions reduction targets for the coming decades to achieve carbon neutrality. At present, the Malaysian Government has emphasised several technology-driven efforts in driving the country forward towards the goal to become a developed, prosperous, and high-tech nation by 2030. While mid- and long-term climate commitments have become more ambitious in many parts of the world, policymakers are searching for policies and technologies to deliver on announced pledges.

Hence, it is timely for this roadmap to realise the inclusion of technology in advancing hydrogen economy. At an industrial scale, Sarawak Energy Berhad (SEB) has begun exploration into hydrogen business through electrolysis demonstration project for FCEV vehicles.

PETRONAS through Gentari has committed into a joint feasibility study with few counterparts in realising the technology at mass production scale to meet the GHG emission reduction target. Numerous pilot projects examining various applications for hydrogen use and feasibility studies for its transportation are currently underway. SEDC (through SEDC Energy) has signed MoU with Japanese and South Korean companies for hydrogen export and the hydrogen local production caters for local market through Sarawak Metro public transport as a start and Sarawak's own multifuel station that caters for ICE vehicles, BEV and FCEVs. SEDC Sarawak, through SEDC Energy, plans to build six multi-fuel refuelling stations that will offer conventional fuels, electric charging and hydrogen refuelling in Sarawak. The versatility of hydrogen as chemical storage, energy carrier, and feedstock for industrial production has its significant role in supporting the Paris Agreement's targets for the year 2030.

The Malaysian strategy makers and energy planners showed remarkable enthusiasm in developing timely and visionary energy plans and policies after the 1973 and 1979 oil crises. Initially, the two main energy sources (1) oil and (2) natural gas have been exploited to provide the country with its primary energy requirements. Realising this, the introduction of the Four Fuel Diversification Strategies in 1981, followed by the Five Fuel Diversification Strategies in 2001 were formulated to include other energy resources in the primary energy mix. A summary of policies, roadmap and strategy related to the Renewable Energy ecosystem were analysed by looking at economic instruments, national target, industry value chain, and the impact to Hydrogen Economy.

1.4.3 Supporting Policies on Hydrogen Economy

1.4.3.1 Study of Existing Plans/Policies/Blueprints

The Economic Planning Unit (now known as the Ministry of Economy) and the Ministry of Energy and Natural Resources (now known as the Ministry of Natural Resources, Environment and Climate Change; NRECC) are the federal ministries responsible for energy direction in Malaysia.

The chronology of Malaysia's energy policy transition is as depicted in Table 3 below:

Table 3: Chronology of Malaysia energy policies

No	Policy	Year	Description
1	Petroleum Development Act	1974	The Act which vested PETRONAS the exclusive rights to explore, develop and produce petroleum resources in Malaysia
2	National Petroleum Policy	1975	The first National Energy Policy introduced to regulate downstream oil & gas industry via the PDA 1974
3	National Energy Policy	1979	The policy was formulated with a 3-pronged objectives as listed below: i. To ensure adequacy, security, and cost-effectiveness of energy supply ii. To promote efficient utilisation of energy, and iii. To minimise negative environmental impacts in the energy supply chain

No	Policy	Year	Description
4	National Depletion Policy	1980	The policy was formulated to prolong the lifespan of Malaysia's oil reserves for future security and stability of oil supply
5	Four Fuel Policy	1981	The national Four-Fuel Diversification Policy was introduced to ensure that the nation pursues balanced utilisation of oil, gas, hydro and coal. The objective of the policy is to prevent over-dependence on oil as the main energy resource especially for electricity generation. The aim was to ensure reliability and security of energy supply by focusing on four (4) primary energy sources namely oil, gas, hydro, and coal in the energy mix. In line with the policy, utilisation of gas in electricity generation increased from 67.80% in 1995 to 78.70% in 2000. On the other hand, the contribution of oil in generation mix declined from 11% in 1995 to 5.3% in 2000.
6	Electricity Act 1949 (Repealed by Act 447 in 1990)	1990	An Act to provide for the regulation of the electricity supply industry, the supply of electricity at reasonable prices, the licensing of any electrical installation, the control of any electrical installation, plant, and equipment with respect to matters relating to the safety of persons and the efficient use of electricity and for purposes connected therewith.
7	Five Fuel Policy	2001	The policy emphasised on Renewable Energy to be included as fifth fuel in the energy mix. Renewable energy to complement the existing four fuel sources listed in the Four Fuel Policy. Average Oil production level is maintained at 600,000 barrels per day as to ensure reserves are prolonged.
8	National Renewable Energy Policy and Action Plan	2010	A policy for Renewable Energy development in Malaysia towards enhancing the utilisation of indigenous renewable energy resources to contribute towards national energy supply security and sustainable socio-economic development. The specific actions for RE Action Plan are establishment of the necessary institutional arrangements and supporting measures to encourage and nurture the growth and development of the RE businesses.
9	Renewable Energy Act	2011	An Act to provide for the establishment and implementation of a special tariff system to catalyse the generation of renewable energy.

No	Policy	Year	Description
10	Sustainable Energy Development Authority Act	2011	An Act to provide for the establishment of the Sustainable Energy Development Authority Malaysia and to provide for its functions and powers
11	Feed-in Tariff	2011	The Feed in Tariff is a mechanism under Renewable Energy and Action Plan to catalyse generation of RE up to 30MW. This mechanism allows electricity produced from indigenous renewable energy resources to be sold to power utilities at a fixed premium price for a specific duration
12	National Energy Policy 2022 – 2040	2022	The National Energy Policy, 2022-2040 (DTN) strategically charts the way forward and outlines key priorities for the energy sector in the coming years. The DTN is spearheading a pragmatic move towards a cleaner energy mix by promoting enhanced demand side management and encouraging the development, commercialisation, and adoption of green technologies – as well as the upskilling of the energy sector workforce in meeting future industry needs. Hydrogen was also included in the DTN official document.

Other policies, national strategic documents, and programmes in the form of action plans, economic instruments, standards, and development are considered in line with the above. These initiatives address the vision and strategies, alternative energy diversification, environmental conservation and enabling environments that also compliments the actions stipulated in the National Energy Policy 2022 – 2040. The existing policies/roadmap/strategy in Malaysia are tabulated in Table 4.

a. National Biofuel Policy (2006)

The National Biofuel Policy envisions that biofuel will be one of the five energy sources for Malaysia, enhancing the nation's prosperity and well-being. The policy is primarily aimed at reducing the country's dependence on depleting fossil fuels, promoting the demand for palm oil as well as stabilising its prices at a remunerative level;

b. Malaysian Biofuel Industry Act (2007)

The Act was introduced in 2007 to streamline the licensing and regulation of the country's biofuels industry as well as facilitating sector development;

c. National Green Technology Policy (2009)

The policy states that Green Technology shall be a driver to accelerate the national economy and promote sustainable development. Energy, Economy, Environment and Society are the four main pillars of the policy, with the aim of attaining energy independence and promoting efficient utilisation, conserving, and minimising impact to the environment, with technology enhancing the economic development as well as improving the quality for life for all. Energy, Building, Transport and Water and Waste Management are the four main sectors under the National Green Technology Policy (NGTP);

d. National Climate Change Policy (2010)

The policy is aimed at promoting effective management of resources and enhanced environmental conservation to strengthen economic competitiveness and improve quality of life, integrate climate change considerations into national policies, and strengthen institutional and implementation capacity to address challenges and opportunities from climate change;

e. National Energy Efficiency Action Plan (2016)

NEEAP is developed to enhance energy efficiency with a target of 8% reduction in electricity demand in 2025 with energy efficiency initiatives. This is enabled by the implementation of the energy efficiency plan, strengthening of institutional framework and capability development, sustainable funding mechanism, and promotion of private sector investment into energy efficiency initiatives;

f. Demand-Side Management Study 2017

The study was conducted as a preliminary assessment to enhance energy demand-side management with a holistic approach which is cross-sectoral and encompasses various energy sources. This was done to promote energy security and sustainable energy, social development, low carbon economy, human capital development and to meet global climate change commitments;

g. Large Scale Solar

Large Scale Solar (LSS) is a competitive bidding programme to drive down the Levelised Cost of Energy (LCOE) for the development of LSS photovoltaic plants, with the Energy Commission as the implementing agency for this scheme. Malaysia has opened a bidding exercise for one gigawatt (GW) solar plant worth about RM4 billion, the largest capacity offered under its LSS scheme. The previous three cycles of LSS boasted capacities of between 370 megawatts (MW) to 500MW. The Ministry of Energy and Natural Resources (now known as the Ministry of Natural Resources, Environment and Climate Change; NRECC), via the Energy Commission, is requesting proposals through competitive bidding process for the development of the fourth cycle of LSS (LSS4) projects;

h. New Net Energy Metering (2019)

The concept of New Net Energy Metering announced in 2019 relies on consumption of Solar PV System energy, prior to export of any excess energy to TNB on a 'one on one' offset basis. This scheme is applicable to all domestic, commercial, industrial and agriculture sectors as they are customers of TNB.

i. Peninsular Malaysia Generation Development Plan 2020 (2021 – 2039)

Provide projection of electricity demand growth with the consideration of the economic parameters, considering the COVID-19 pandemic impact, emerging trends, and disruptive technologies. In achieving the 31% RE capacity mix target for Malaysia by 2025, a total of 1,178MW1 of new RE capacities will be developed in Peninsular Malaysia from 2021 onwards. The additional RE capacities consist of 1,098MW of solar and 80MW of non-solar. The RE capacity mix for Malaysia is projected to increase to the 40% level by 2035. Malaysia's commitment on sustainable energy pathway will continue with new RE and CCGT plants coming into the system post-2030. An additional 2,414MW of RE capacity would be developed in Peninsular Malaysia from 2026 to 2035 to support the country's long-term national commitment;

j. 12th Malaysia Plan (RMK-12)

The Twelfth Malaysia Plan (RMK-12) is aligned with the shared prosperity initiative encompassing three dimensions, namely economic empowerment, environmental sustainability, and social re-engineering;

k. Shared Prosperity Vision 2030

i. **Economic Empowerment**
The economic empowerment dimension will include new sources of growth, including Industrial Revolution 4.0, digital economy, aerospace industry, integrated regional development as well as growth enablers such as sustainable energy sources and infrastructure connectivity;

ii. **Environmental Sustainability**
The environmental sustainability dimension, among others include the blue economy, green technology, renewable energy as well as adaptation and mitigation of climate change;

iii. **Social Re-Engineering**
The social re-engineering dimension comprises enhancing societal values, improving purchasing power of the people, building a resilient Bumiputera community, strengthening social security networks and improving the wellbeing of the people;

l. National Automotive Policy (2020)

The NAP 2020 envisions Malaysia's automotive industry in the era of digital industrial transformation from 2020 to 2030, thus enabling Malaysia to realise Connected Mobility. Moving beyond Energy Efficient Vehicles (EEV), the concept of mobility will now shift the direction and product development from what used to be powertrain-based, into incorporation of intelligence and connectivity features in vehicles;

m. National Transport Policy (2020)

Government will focus on streamlining initiatives through the National Transport Policy, enhancing connectivity across regions, integrating different modes of transport, upgrading airport infrastructure, improving port accessibility and capacity, as well as optimising transport infrastructure. Towards this end, efforts will be undertaken to facilitate modal shift for transportation of cargo, especially hazardous and dangerous goods, from road to rail;

n. Low Carbon Mobility Blueprint (2021)

Low Carbon Mobility Blueprint (LCMB) has identified hydrogen as a fuel for Low Carbon Mobility under Focus Area No.3 (Alternative Fuel Adoption), and to be implemented under Strategy No.5: Creating an Ecosystem for Growth of Alternative Fuel and Energy Industry. The strategy suggests potential cumulative reduction of 18.3 million tonnes of CO_2 by 2030;

o. National Energy Policy (2022-2040)

The Economic Planning Unit (Now known as the Ministry of Economy) launched the National Energy Policy in September 2022. Hydrogen was mentioned in NEP 2022-

2040 as a section in the official document. The phases for hydrogen implementation, hydrogen technologies and the role of hydrogen in Low Carbon Nation Aspiration 2040 have been outlined. There are two action plans dedicated to hydrogen in the NEP 2022-2040;

p. Low Carbon Cities Master Plan

Malaysia has introduced the Low Carbon Cities Framework and launched the Low Carbon Cities Challenge 2030, with the aim to accelerate the transformation towards designated low carbon zones in state capitals and major cities within Malaysia. They will be guided by the necessary systems and tools to develop strategic low carbon action plans in reducing GHG emissions via energy and water efficiency, low carbon mobility, reduction in waste to landfills and increase green spaces. Its target is to realise 200 Low Carbon Zones and 1,000 Low Carbon Partners by 2030. The currently drafted National Low Carbon Cities Masterplan intends to transform Malaysian Cities into low carbon cities whilst pushing the low carbon development in Malaysia to the next level. A total of 33 local and regional government has been selected as Target Cities;

q. Green Technology Financing Scheme

The Green Technology Financing Scheme (GTFS) offers financial support (subject to the green technology/component cost by Participating Financial Institutions (PFIs)) for Producers, Users and Energy Services Companies (ESCOs) by offering a rebate of 2% on interest/profit (limited to the first seven (7) years only) for each loan/financing and 60% government guarantee on Green Technology Cost, with a total funding pool of up to RM2.0 billion.

The financing offers RM100 million for producers, RM50 million for users and RM25 million for Energy Service Companies with financing tenure of 15, 10 and 5 years respectively. The eligible sectors for GTFS are Energy, Building, Transport, Water and Waste, Building and Township and Manufacturing;

r. Green Technology Incentives

In the Budget 2014 the Government has announced an investment tax allowance for the purchase of green technology equipment and income tax exemption on the use of green technology services. In the Budget 2019, the Malaysian Government has announced the expansion of the list of green assets which qualifies for the Green Technology Investment Allowance (from 9 assets to 40 assets which will be listed in the MyHIJAU directory. In 2020, MGTC approved 243 applications which are expected to reduce GHG emissions by 575,564 tCO2eq emissions. The approved applications have a potential value of green investment amounting to RM965.6 million and is expected to create a total of 471 green jobs. List of qualifying assets include energy storage (battery) and electric vehicles (EV) which are eligible for hydrogen and fuel cells technologies;

s. MyHijau Mark

MyHIJAU Mark & Directory is a government initiative to promote the sourcing and purchasing of green products and services in Malaysia. The programme started on 23 October 2012 and brought together certified green products and services under a single mark. Registered green products and services will be listed in the MyHIJAU Directory, which is a reference for green procurement (including Government Green Procurement; GGP and Green Private Purchasing; GPP), green incentives (including Green Investment Tax Allowance; GITA and Green Income Tax Exemption; GITE) and related green technology initiatives. As of 2019, MyHIJAU Mark & Directory registered 7,498 products and services from 470 participating companies. The relevant sub-categories for MyHijau registration in relation to hydrogen and fuel cell technology products and services are – alternative fuel, automotive products, product, equipment, and system. Presently, hydrogen and fuel cell technology products and services are not yet registered under the MyHijau directory;

t. Hydrogen EcoNanoMY

The Hydrogen EcoNanoMY programme under the facilitation of NanoMalaysia Berhad aims to develop and produce local game-changer technologies that can generate hydrogen on-demand and on-site, which is cost effective while also looking into the ecosystem surrounding the value chain and addressing market interest in hydrogen economy including technology, both locally and internationally;

u. National Transport Policy (2019-2030)

4 Main Sectors, 5 policy thrusts and 23 strategies.

Policy Thrust 4:

Advance Towards Green Transport Ecosystem

a. Enforced compliance to acts/ regulations & shift towards international environment standards;
b. Prioritise public transport network as a fundamental structure in urbanised areas;
c. Accelerate implementation of low carbon mobility initiatives;
d. Institute measures to control pollution, noise, and waste from the transport sector;
e. Develop effective Communication, Education & Public Awareness (CEPA) to create behavioral change.

Key Action Items:

- Adopt international sustainable indicators for all levels of transport planning;
- Institutionalise green standards for ports, airport, transport terminals and logistics;
- Limit development of new highways in urban centres;
- Align the planning of urban centres and public transport network across national policy;
- Impose TOD requirements in urban areas and around public transportation nodes;
- Encourage Work-Play-Shop-Stay development concept;
- Review Act 333 to support the growth and the use of EEV/ EV in Malaysia;
- Encourage use of different models of EEV;
- Formulate & implement fuel economy policy;
- Develop green index and incentives to go green;
- Develop procedure for vehicles' end of life;
- Establish guidelines for scrap waste, refurbishment, recycling;
- Minimise noise pollution from transportation infrastructure;
- Increase awareness on benefits to use public transport;
- Understand travel behaviour to identify right intervention;
- Implement program to promote behavioural change;

v. National Policy on Science, Technology and Innovation (NPSTI) 2013-2020

5 Key Policy Foundations and 6 Strategic Thrusts.

The NPSTI is grounded on the following 5 fundamental foundations namely:

i. STI for Policy;
ii. Policy for STI;
iii. Industry Commitment to STI;
iv. STI Governance; and
v. STI for a stable, peaceful, prosperous, cohesive and resilient society.

To ensure its success and future achievements, the above five foundations should embody the following six strategic thrusts:

i. Advancing scientific and social research, development and innovation;
ii. Developing, harnessing and intensifying talent;
iii. Energising industries;
iv. Transforming STI governance;
v. Promoting and sensitising STI; and
vi. Enhancing strategic international alliances

w. Advancing scientific and social research, development and commercialisation

To achieve a more innovative economy, the National Science Research Council (NSRC) has established nine priority areas in R&D

efforts, apart from enhancing innovation infrastructure and strengthening partnership and collaboration among all the key players of the economy for mutual benefits:

i. Biodiversity;
ii. Cyber Security;
iii. Energy Security;
iv. Environment and Climate Change;
v. Food Security;
vi. Medical & Healthcare;
vii. Plantation Crops & Commodities;
viii. Transportation & Urbanisation; and
ix. Water Security.

x. Malaysian Intended Nationally Determined Contribution (INDC) 2021-2030

Since the Ninth Malaysia Plan (RMK-9:2006-2010), Malaysia has started initiatives to increase the share of use for non-fossil fuel energy. The National Biofuel Policy 2006 has already laid the groundwork for the development and use of biofuels. The National Biofuel Industry Act 2007 was put in place to regulate the biofuel industry and to promote the mandatory use of the B5 domestic blend of 5% palm biodiesel and 95% fossil fuel diesel. By the end of 2014, Malaysia has also introduced the bio-diesel B7 Programme.

The Tenth Malaysia Plan (RMK-10:2011-2015) focused on sustainable growth and introducing mitigation strategies to reduce emissions of GHG. Three significant financial tools were introduced to promote sustainability measures. These consist of the introduction of a Feed-in Tariff (FiT) mechanism in conjunction with the Renewable Energy Policy and Action Plan (2010) to help finance renewable energy investment, providing fiscal incentives and funding for green technology investments and promoting projects eligible for carbon credits. In the forestry sector, two major initiatives were launched, the Central Forest Spine (CFS) and Heart of Borneo (HOB) to ensure sustainable forest management and use of natural resources.

The Government of Malaysia has continued to pursue the green growth goal under the Eleventh Malaysia Plan (2016-2020) with further focus on pursuing green growth for sustainability and resilience. These include strengthening the enabling environment for green growth, adoption of sustainable consumption and production, conserving natural resources and strengthening resilience against climate change and natural disasters. These actions will further reduce Malaysia's carbon footprint.

Table 4: Study on existing policies/roadmap/strategy in Malaysia

Policy/ Roadmap / Strategy	National Biofuel Policy (2006)	Malaysian Biofuel Industry Act (2007)	National Green Technology Policy (2009)	National Climate Change Policy (2010)	National Energy Efficiency Action Plan (2016)	Demand-Side Management Study (2017)
Economic Instruments	N/A	N/A	Green Technology Financing Scheme (GTFS)	N/A	N/A	N/A
National Target	Promotional awareness programme to educate the public on the use of B5 diesel	Regulatory regime for the licensing of blending, storage, transportation, and export of biodiesel from palm oil.	Reduction 40% GHG emission intensity by 2020	GHG emission intensity per unit GDP had improved by 32% in 2011 compared with 2005 level	52,233 GWh of energy savings (8.0%) by 2025	40% reduction in GHG emission intensity of GDP
Industry Value Chain	Voluntary trials on B5 diesel by MPOB FOR selected users in the industrial sectors	i. Production of biofuel ii. Trading of biofuel iii. Biofuel services	i. Initiative Greening the Building Sector ii. Initiative Greening the Transport Sector iii. Initiative Towards Sustainability Consumption and Production	i. Emission reduction through sustainable management of forest ii. Urban rail-based public transport	i. Promotion of 5-star rated appliances ii. Minimum Energy Performance Standards (MEPS) – on EE lighting and motors	Registered Electrical Energy Managers, and promoting the implementation of Energy Performance Contracting for government buildings
Impact to Hydrogen Economy	No direct impact to hydrogen economy	No direct impact to hydrogen economy	No direct impact to hydrogen economy	No direct impact to hydrogen economy	No direct impact to hydrogen economy	No direct impact to hydrogen economy

Policy/ Roadmap / Strategy	Large Scale Solar	New Net Energy Metering 2.0 (2019)	New Net Energy Metering 3.0 (2021)	12th Malaysian Plan	Shared Prosperity Vision 2030	National Automotive Policy (2020)	National Transport Policy (2019-2030)
Economic Instruments	N/A	N/A	N/A	N/A	N/A	Funding from other agencies for the development of EEV (FCEV included)	Provision of incentives for EEV/ EV manufacturers and users
National Target	Drive down the Levelised Cost of Energy (LCOE) 1MW- 30 MW	500MW energy produced from the solar PV installation	Initially allocated capacity of 500MW, and 300MW additional was offered in November 2021	N/A	N/A	Malaysia as a Regional Hub for the production of Next-generation Vehicle (FCEV included)	45% reduction of greenhouse gas emission intensity of GDP by 2030 and adoption of cleaner fuel.
Industry Value Chain	LSS connected to Transmission Network in Peninsular Malaysia	i. NEM Rakyat Programme (100MW) ii. NEM GoMEn Programme (Government Ministries and Entities) (100MW) iii. NOVA Programme (Net Offset Virtual Aggregation) 300MW	Effect from 2021 to 2023 and assigned through three different sub-schemes: i. 1. NEM Rakyat program for residential systems (100 MW) ii. 2. NEM GoMEn Programme (Government Ministries and Entities) (100MW) iii. 3. NEM Nova scheme, or Net Offset Virtual Aggregation (600 MW)	N/A	N/A	N/A	N/A
Impact to Hydrogen Economy	H2 Electricity Grid	No direct impact to hydrogen economy	No direct impact to hydrogen economy	Indirectly mentioned – Hydrogen as the means for economic empowerment	Indirect impact to hydrogen, in the form of future economy	FCEV considered as critical components and systems to be developed	Support the growth and the use of EEV/EV

Policy/ Roadmap / Strategy	Low Carbon Mobility Blueprint (2021-2030)	National Energy Policy (2022)	Low Carbon Cities Master Plan	Green Technology Financing Scheme 2.0	National Graphene Action Plan 2020	National Policy on Science, Technology & Innovation (NPSTI) 2021-2030
Economic Instruments	Specific to BEVs	N/A	Incentives for low carbon vehicles	Funds from financial institutions approved by BNM and MOF for green products production, adoption of green technology	Facilitation of funds for product development and scale-up	N/A
National Target	N/A	To reduce coal dependence in the energy consumption mix	GHG emission reduction target in cities from 2021-2050	N/A	i. RM 10 billion to Malaysia's GDP ii. Creation of 9,000 jobs	Increasing GERD to 3.5% of GDP in 2030
Industry Value Chain	N/A	Increased commitment in the gas and LNG industry	Smart grid system at city level	N/A	Focusing on downstream graphene applications	N/A
Impact to Hydrogen Economy	Creating an Ecosystem for growth of alternative fuel and energy industry	Direct impact to the Hydrogen economy	Impact to the transportation sector	Green hydrogen producers/users may benefit from GTFS 2.0	Indirect impact Technology developed can be applied	Provides integrated and holistic approach to the rapidly evolving STI ecosystem.

Policy/ Roadmap / Strategy	10-10 MySTIE Framework	ASM Science and Technology Foresight 2050	National Green Technology Masterplan Malaysia (2017-2030)	National Physical Plan (NPP)	Natural Gas Roadmap (2021-2040)	National Energy Policy (2022 – 2040)
Economic Instruments	N/A	N/A	Emphasise on R&D&C funding, combined with private sector as well as community sourced financing	N/A	N/A	i. Total investment of RM9.2 billion/yr ii. Contribution to GDP RM13 billion/year
National Target	N/A	N/A	i. Renewable Energy • 23% in 2025 • 30% in 2030 ii. Transport • 40% EEV Public Transport in 2025 iii. 10% EEV Private Transport in 2025	Reduction in CO_2 emission by 45% (2030) and 50% (2040) as well as promoting low carbon economy	Green hydrogen expected to reach 53% of grey hydrogen cost in 2030	i. Shared mode of public transport of 50%. ii. Use of electric vehicles (Evs) of 38%. iii. B30 mixed fuel for heavy vehicles as an alternative fuel iv. Energy savings of 11% for industry and commercial use and 10% for residential use v. 18,431 MW total installed capacity of RE vi. 17.0% of renewable penetration in primary energy mix
Industry Value Chain	N/A	N/A	Executing green initiatives across the value chain by shifting towards green energy, green products, and green processes	N/A	i. Production of hydrogen from reforming methane, albeit at small scale ii. Explore the low-cost electrolysis process in hydrogen production	i. 207,000 added jobs, majority in green economy sectors ii. Enhance country value capture by developing local capabilities and industries across the RE value chain and in enablers such as smart grid, smart energy management systems and other innovations associated with the modernisation of the electricity sector.

Policy/ Roadmap / Strategy	10-10 MySTIE Framework	ASM Science and Technology Foresight 2050	National Green Technology Masterplan Malaysia (2017-2030)	National Physical Plan (NPP)	Natural Gas Roadmap (2021-2040)	National Energy Policy (2022 – 2040)
Impact to Hydrogen Economy	A framework to map hydrogen towards socio-economic drivers and science & technology drivers	FCEVs as potential product/service categorised 2021-2035	Emphasis on EEV (including FCEV) and land transport	N/A	Expressed the need to lower down the levelised cost of green hydrogen through exploration on low-cost electrolysis process.	i. Action plan emphasis in unlocking opportunities and long-term competitive advantage in the emerging hydrogen economy ii. Technology that focuses on optimal conversion for long-range transport such as ammonia, liquid hydrogen, liquid organic hydrogen, or metal hydride will be considered for export and hydrogen as fuel for future in mobility iii. Implementation of hydrogen as part of the Low Carbon Nation Aspiration 2040 in the 14th and 15th Malaysia Plan: i. Implement pilot and market entry programmes of hydrogen as well as next generation bioenergy i. Establish globally competitive hydrogen export hub in Sarawak

1.4.3.2 Role of Hydrogen Economy in 12th Malaysia Plan

The recently tabled 12th Malaysia Plan 2021-2025 (RMK-12) sets an ambitious goal for the country to achieve Net Zero by 'as early as' 2050. This calls for incentivising clean energy adoption, encourage better energy efficiency, and ultimately reduce GHG emissions. The role of Hydrogen Economy has been explicitly stated in Advancing Green Growth by achieving the Low-Carbon Nation status in the transportation sector. Advancing green growth in mobility is imperative for achieving shared prosperity, not only in terms of economic growth, but also for environmental sustainability and social inclusivity.

Nevertheless, adoption of hydrogen in mobility sectors presents challenges in terms of infrastructure, connectivity, fuel subsidies, cost of ownerships, tax structures, regulations and others. Towards the end of this roadmap development, the price subsidies for the current petrol or diesel prices and incentives for consumers to own hydrogen vehicles will be analysed. The diffusion of hydrogen into energy mix, addresses the economic empowerment, environmental sustainability and social re-engineering initiatives are as illustrated in Figure 6.

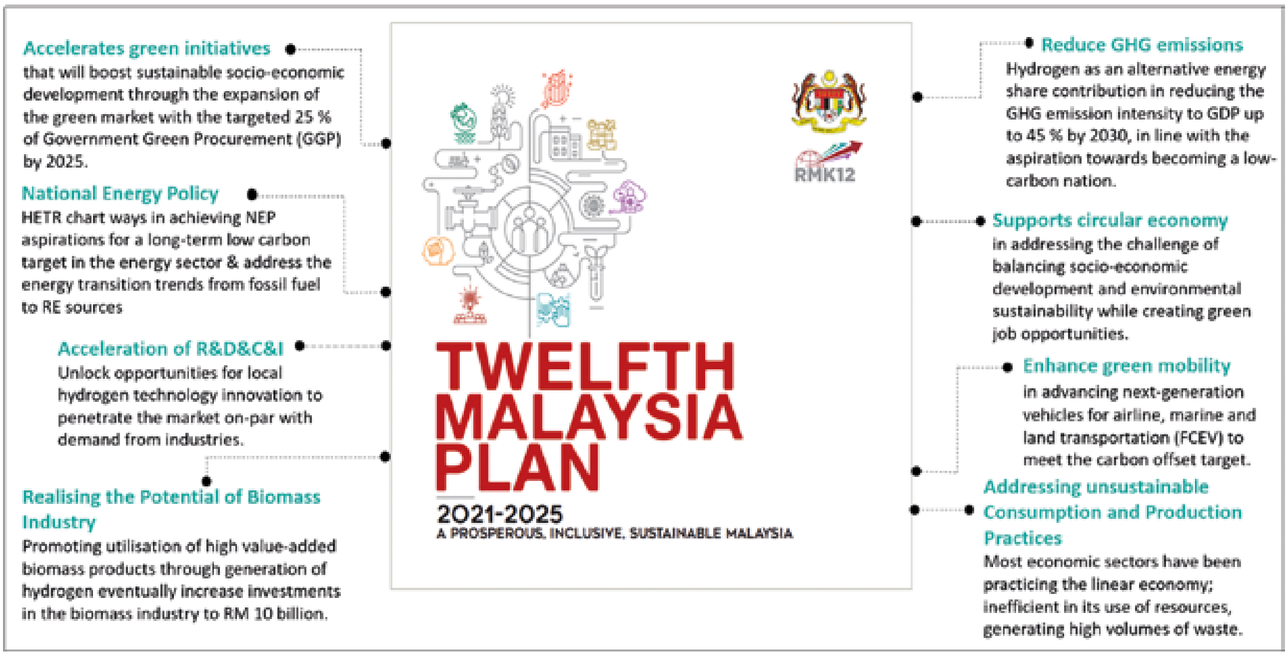


Figure 6: Role of Hydrogen Economy in Advancing Green Growth in 12th Malaysia Plan

Planning the timeline and strategies for the establishment of Hydrogen Economy is of the utmost importance, as it adds value to existing economic sectors as traditional business models which is now increasingly challenged by market liberalisation, decarbonisation, decentralisation, and digitalisation. Hydrogen offers ways to decarbonise a range of sectors such as iron and steel, long-haul transport, and chemicals. The 12th Malaysia Plan (RMK-12) has placed targets in the expansion of the green market through Government Green Procurement (GGP), and reduction in Greenhouse Gases (GHG) emissions.

This will be implemented through investment in advancing next generation vehicles, technologies and supporting infrastructure, such as energy-efficient, hydrogen-powered, and electric vehicles, and their charging stations. The push for hydrogen-powered vehicles creates the demand for Malaysia to venture into the path of creating a hydrogen ecosystem that requires both top-down and bottom-up approaches. In the meantime, the adoption of green technology by industries are driven through Circular Economy model to create more sustainable and responsible businesses and investments.

The Hydrogen Economy and Technology Roadmap fits in 5 game changers as outlined in the 12th Malaysia Plan (RMK-12) as follows:

a. **Game Changer II:** Catalysing Strategic and High Impact Industries to Boost Economic Growth;
b. **Game Changer III:** Transforming Micro, Small and Medium Enterprises as the New Driver of Growth;
c. **Game Changer IV:** Embracing the Circular Economy;
d. **Game Changer X:** Improving TVET Ecosystem to Produce Future-ready Talent;
e. **Game Changer XII:** Aligning Research and Development towards Commercialisation, Wealth Generation and Economic Growth

1.5 Snapshot of Hydrogen Economy & Technology Roadmap (HETR)

An overview of the targets in the Hydrogen Economy and Technology Roadmap (HETR) is as presented in Figure 7. It shows the different colours for hydrogen classification that are related to Malaysia, represented as grey, blue, and green hydrogen respectively. These colours represent the source and route of hydrogen production.

There is plenty of grey hydrogen produced in Malaysia through different processes in the oil and gas hydrogen supplied from fossil fuels, at the expense of GHG emissions which will not be a sustainable option for the future. Hence, the need for a cleaner hydrogen is pivotal, where grey hydrogen can be classified as blue hydrogen by means of capturing the carbon released using Carbon Capture, Utilisation, and Storage (CCUS) technology. The global production cost of blue hydrogen is between US$ 1.5/kg H_2 and US$ 4/kg H_2, while the production cost for green hydrogen is between US$ 4/kg H_2 and US$ 6/kg H_2.

Blue hydrogen should remain our prime target in the short to long-term, pivoting our sizeable Oil and Gas sector into the Hydrogen Economy. CCUS are yet to be commercially available due to high capital expenditure. Strategic investment through foreign and domestic direct investments can be realised when there is involvement of other fossil-based sector players. There are many other CO_2 capture technology available (membrane, absorption and others) in addressing effective CO_2 capture (<1kgCO2/kg H_2). Besides focusing on natural gas + CCUS, the co-product hydrogen from existing processing plants that meets certain certification standard or low carbon based on life cycle assessment of carbon footprint may be regarded as blue hydrogen. According to IEA's New Zero scenario, blue hydrogen will supply almost 40 % of total global hydrogen by 2050. This agrees with Hydrogen Council's findings as stated in the Hydrogen Decarbonization Pathways that green hydrogen will serve 60 % of the market, and 40 % will be served by blue hydrogen.

Green hydrogen, generated from renewable sources such as solar, hydropower, and wave energy remains as Malaysia's strategic goal in the long-term. Hence, to retain Malaysia's position as a key energy exporter as highlighted in this document, we should start looking into transitioning to green hydrogen as soon as possible. Malaysian green hydrogen production price stands at USD 6/kg, being the second most expensive next to turquoise hydrogen. Regarding the cost competitiveness, the supply of both blue and green hydrogen is needed for us to meet the projected demand for clean hydrogen to achieve decarbonisation targets by 2050.

Turquoise hydrogen, produced from a process called methane pyrolysis produces hydrogen and solid carbon. This process has yet to be proven at industrial scale and is the most expensive method to produce hydrogen at USD 10/kg. However, as this process produces solid carbon, which can be further refined into graphene, the production cost can be shared between relevant industries. Since the technology are yet to be proven on a commercial scale, the technology development is expected to take place once green technology has attain its maturity. On that note, turquoise hydrogen can be considered for long-term solution due to carbon neutral process.

At the current state of hydrogen prices, it is important to bring down the production cost of hydrogen to a target price of USD 1/kg for green hydrogen by 2050, as forecasted by IRENA. This is crucial for Malaysia to feed its domestic use in the long term as hydrogen will be used in various sectors particularly mobility, energy generation, agriculture, industry uses and domestic use. Apart from that, the price of blue hydrogen should be lower for us to remain competitive in the export market as it serves our short to mid-term target primarily by exporting to high hydrogen demand countries such as South Korea and Japan.

In terms of transportation, Malaysia should focus on the potential of Fuel Cell Energy Vehicles (FCEVs), further developing new technologies across the FCEV supply chain. Competition with Battery Electric Vehicles (BEVs) will be inevitable in the future as global automotive manufacturers are phasing out internal combustion engines due to policies set by many developed countries to ban fossil-fuel powered vehicles in major cities by 2030. To realise this effort, both the government and industry players should investigate the feasibility of FCEVs. Major investments are needed in developing FCEVs infrastructure particularly refuelling stations and supply network. Subsidies shall be required for hydrogen, replacing fossil-fuel subsidies to achieve cheaper alternative fuel source. Awareness campaigns are required both for industry and consumers to increase adoption of FCEVs.

To achieve the targets mentioned above, interventions are required for Malaysia to achieve RM 82 billion hydrogen revenue as identified in the earlier business case. Malaysia should adopt the “Buy-some and Build-some” strategy to identify the technologies we need to develop and what kind of technologies needed to be procured and technologies to be developed to reduce the technology cost, and to increase the reliability of hydrogen technologies across the hydrogen value chain in Malaysia.

Although hydrogen has higher energy density than gasoline, there are technical drawbacks exhibited across the cluster of the hydrogen economy value chain (Production, Conversion and Storage, Transportation and End-Use) such as the case where gaseous form of hydrogen creates storage difficulties, synthesis that is an energy intensive process leading to loss in efficiency. This is where technology innovation comes into play to improve the existing and emerging technologies. As such, some of the technological solutions to address the drawbacks impacting the cost, efficiency and as baseline for the roadmap are as follows:

a. Improvements on the electrolyser for green hydrogen production. Despite the high input energy supplied to electrolyser for hydrogen generation lies in the range of 50 – 55 kWh/kg-H2, the energy contained in 1kg of H2 is 33.33 kWh. The substantial amount of energy loss that is accounted during the process around 20 – 22 kWh/kg-H2 need to be tackled, justifying more investment required to develop conversion technologies to lower the conversion cost.
b. Improve fuel cell efficiency beyond the current range of 50–60 %.
c. Reduce the amount of energy required for hydrogen storage by analysing the capacity and energy requirement between different method or state of hydrogen such as solid state vs. compressed gas.
d. Studies to explore on CO_2 capture technology for production of blue hydrogen such as membrane, absorption and others. At present, the CCUS technology are focused primarily on the deep well storage technology (stored in depleted oil and natural gas reservoirs deep underground).

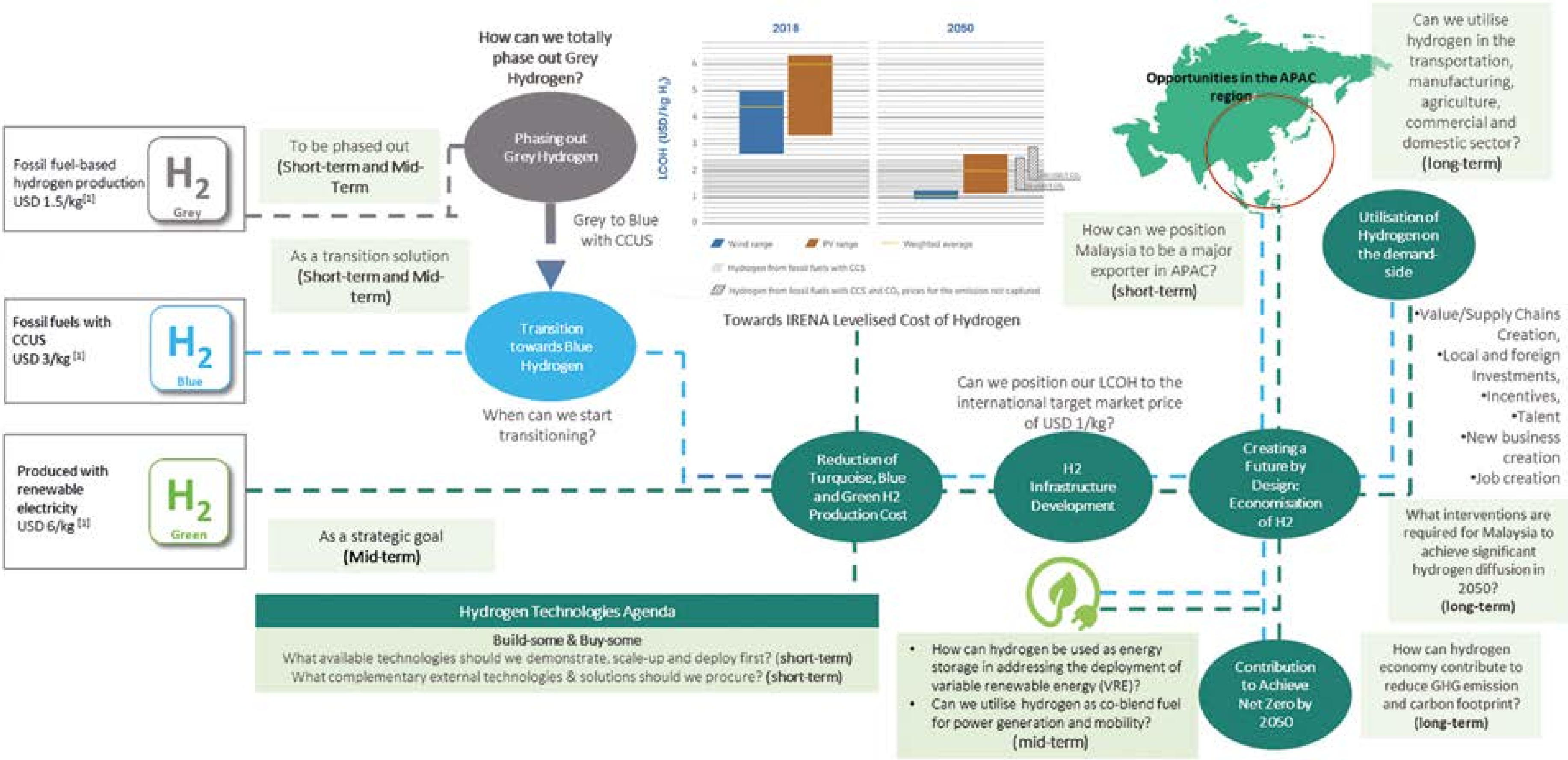


Figure 7: An overview of the roadmap presenting the current, short-term, mid-term and long-term target


HYDROGEN H2


H2
HYDROGEN
ENERGY
STORAGE

CHAPTER 2

HYDROGEN ECONOMY IN MALAYSIA

2.1 Development of Hydrogen Economy in Malaysia

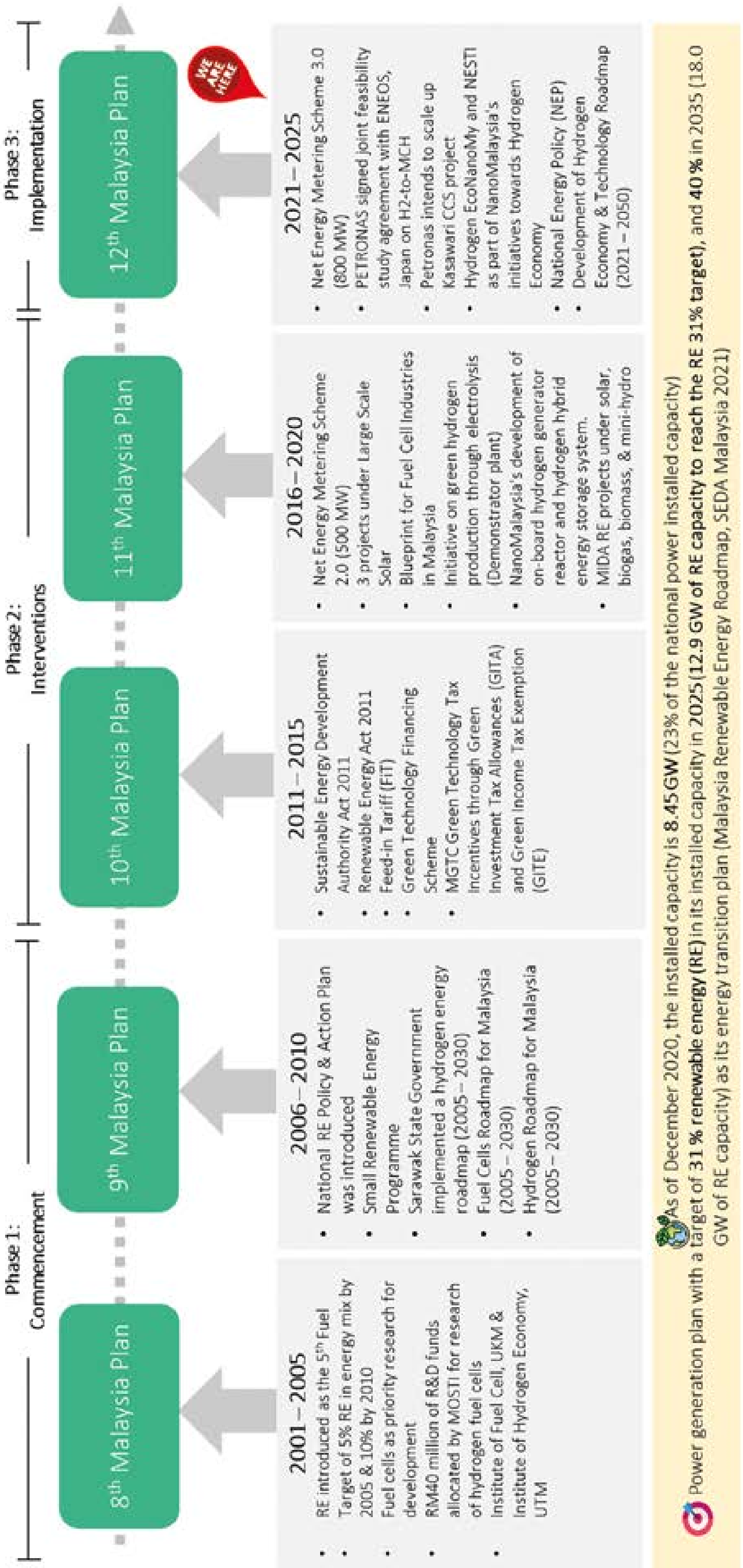


Figure 8: Policies and Initiatives towards Hydrogen Economy and Technology Roadmap development in Malaysia from 8th Malaysia Plan to 12th Malaysia Plan

2.1.1 Milestone towards Hydrogen Economy in Malaysia

Globally, we have witnessed a wave of hydrogen strategies and roadmaps published with significant national targets coupled with the support of economic instruments to decarbonise the energy value chain. With almost an equal momentum, Malaysia introduces various initiatives and interventions in adopting renewable energy for different end-use sectors. The journey of Hydrogen Economy development in Malaysia was captured based on the renewable energy milestone and strategies from 8th Malaysia Plan and was divided into three phases. Phase 1 (8th – 9th Malaysia Plan) was the period where hydrogen begin to commence through the introduction of renewable energy as the 5th fuel strategy in the energy-mix, fuel-cell research, and hydrogen technology adoption by Sarawak State government which push for crafting a hydrogen roadmap up to 2030.

Aligned with the hydrogen development around the world, Malaysia's journey in hydrogen began around the year 2000s. Renewable Energy (RE) was introduced as the 5th fuel strategy in the energy-mix under the National Energy Policy in 2001 as Malaysia has huge potential in RE resources in the form of biomass, biogas, municipal waste, solar and hydro. RE was accepted as the fifth fuel in the Five-Fuel Diversification Strategy and targeted to contribute between 5 % and 10 % by 2005 and 2010 respectively. To meet this goal, the Small Renewable Energy Programme (SREP) was launched under the initiative of the Special Committee on the Renewable Energy (SCORE) aimed at supporting the government's strategy to intensify the development of RE as the fifth fuel. The government has identified hydrogen fuel cells as priority research for development since the Eighth Malaysia Plan (2001–2005) which align R&D with the RE target. Ministry of Science, Technology, and Innovation (MOSTI) has allocated RM 40 million of R&D funds for research on hydrogen fuel cells from 1997 to 2013.

The Fuel Cell Institute (Institut Sel Fuel), re-named as Institute of Fuel Cell (IFC-UKM) was established in July 2006 as the first research institute in Universiti Kebangsaan Malaysia (UKM), to conduct research on fuel cell and hydrogen energy. Research in fuel cell and hydrogen energy in UKM started with the construction of the first proton exchange membrane fuel cell in Malaysia. This path was then followed by the formation of Institute of Hydrogen Economy (IHE) in Universiti Teknologi Malaysia in 2009. IHE started as Fuel Cell Research Group in 1996 with funding of RM 2 million and was later supported with RM 15 million Intensification of Research in Priority Areas (IRPA) grant from MOSTI.

Following to the commissioning of the state-of-the-art laboratory scale technologies and human capital development through various R&D programmes, the 9th Malaysia Plan began to intensify the development of hydrogen through policies, programmes, and roadmap. Facilitation on the RE industry growth are realised through National RE Policy & Action Plan which leads to implementation of Fuel Cells Roadmap and Hydrogen Roadmap for Malaysia (2005 – 2030) for generation of hydrogen using RE resource, development of hydrogen network for hydrogen fuel cell vehicles. As Sarawak is blessed with hydropower source, the Sarawak State Government implemented a hydrogen energy roadmap to harness energy from hydropower.

Phase 2 (10th – 11th Malaysia Plan) was the period of interventions in the form of positioning the initiative through legislation and financial support which facilitates development of projects at commercial scale. As a start, SEDA Malaysia was established in September 2011 to administer and manage the implementation of the Feed-in Tariff (FiT) mechanism mandated under the Renewable Energy Act 2011. The RE Act implements a special tariff system to catalyse the generation of renewable energy whereby FiT encourages the industrial sector and the public to generate electricity from RE sources via technology such as solar panels or wind turbines and sell the surplus energy to the National Grid. With the new RE Act 2011, the target is revised to 985MW or 5.5% share of the energy mix by 2015.

By 2020, the target is for RE to comprise 11% or 2,080MW of overall electricity generation. Green Technology Financing Scheme (GTFS) was introduced in 2010 to promote green investments by providing easier access to financing and at a lower financing cost. As of December 2017, GTFS attracted the attention of 28 Participating Financial Institutes (PFIs) to invest for 319 projects amounting to RM 3.638 billion. The socio-economic impacts gained through this scheme; 4,909 job opportunities were created and GHG reduction of 3,784 Mil TCO_2/yr. In tandem with the Malaysian Government's agenda to drive the growth of Malaysia's green economy, an announcement of green technology tax incentives in the Budget 2014 was introduced where Malaysian Green Technology and Climate Change Centre (MGTC) has been mandated to commence and verify the Green Technology Incentives through Green Investment Tax Allowances (GITA) for the purchase of green technology equipment or assets, and Green Income Tax Exemption (GITE) for green technology service providers.

As the framework for the accomplishment of a hydrogen economy has been proposed in the roadmap to penetrate the Malaysian market, moving forward industry players has begun to venture into renewable energy commercialisation. As a start, Sarawak Energy Berhad (SEB) built Southeast Asia first integrated hydrogen production plant through electrolysis, refuelling station and introduced the state's first hydrogen-powered vehicles as demonstrator project. Under the focus area of Energy and Environment, NanoMalaysia Berhad (NMB) has embarked on the development of *In-Situ* hydrogen production and hydrogen hybrid energy storage system. Based on MIDA's database on approved renewable energy projects in 2020, there are 1,178 renewable projects out of which 1,162 are solar projects. Solar energy projects are the most widespread RE projects due to the lower production cost of photovoltaic (PV) equipment and easier financing under green projects. It is timely for hydrogen to be generated from the abundant renewable sources and attain maturity to be cost competitive.

While the 3rd phase (12th Malaysia Plan and onwards), marked the aggressive efforts by Malaysia aligned with the acceleration of green agenda where hydrogen has been adopted as clean fuel source for mobility. PETRONAS through Gentari has teamed up with Japanese and South Korean energy and industrial players to develop a clean hydrogen supply chain between exporting countries like Malaysia and importing countries like Japan and South Korea. As such joint feasibility studies to develop this hydrogen supply chain are currently being undertaken. PETRONAS through Gentari is also working to produce and export co-product low carbon hydrogen, and continuously assessing the technical and economic feasibility of blue hydrogen production with CCS in Malaysia. SEB has also been in discussion with Japan to chart potential collaboration on hydrogen energy, which is deemed to be the future of green and renewable energy (RE). Besides that, NMB has launched the Hydrogen EcoNanoMy and NanoMalaysia Energy Storage Technology Initiative (NESTI) as part of their initiatives towards Hydrogen Economy. With the aim to create a holistic ecosystem for the government, industries and research community, the development of Hydrogen Economy and Technology Roadmap (HETR) by MOSTI provides facilitation platform and synergy among players.

2.2 Hydrogen Potential in Malaysia

As of 2018, the three largest primary energy sources in Malaysia were natural gas (41%), crude oil, petroleum and others (30%), and coal and coke (22%). On the other hand, hydropower and renewables contributed 7% of primary energy supply in 2018 (National Energy Balance, 2018). Though most of Malaysia's current electricity generation capacity comes from natural gas and coal sources, the Government of Malaysia is seeking to achieve a more balanced portfolio of electricity generation over the coming years to meet its growing demand and reduce its dependency on fossil fuels.

This has benefited industry players in Malaysia to explore the possibility of adopting various technology to harness energy from renewable sources. Besides relying on renewable sources as feedstock for hydrogen production, there are other ways to produce low-carbon hydrogen such as blue hydrogen which comes from natural gas and is combined with CCS or turquoise hydrogen from pyrolysis of natural gas.

Malaysia is focusing intently on the sustainable use of energy with prudent and efficient management of resources under the 11th

Malaysia Plan (2016–2020) through the introduction of the National Energy Efficiency Action Plan (NEEAP) (2016–2025). In NEEAP, the production route to produce different type of hydrogen from non-renewable and renewable sources are as follows: natural gas to produce blue hydrogen, solid biomass from palm oil mills (empty fruit bunch, palm kernel shell, mesocarp fibre, oil palm fronds and trunk) and Palm Oil Mill Effluent (POME) as biogas feedstock, and energy from solar, large, and small hydropower, and Ocean Thermal Energy Conversion (OTEC) to produce green hydrogen.

Despite OTEC technology is not commercially available in Malaysia, research is underway to study the feasibility of technical parameters at strategic locations in the country. The difference in heat energy between warm surface water and cold deep-sea water of the ocean, i.e., approximately 20°C temperature difference, is utilised in the OTEC process. Malaysia is not yet on any global map showing the areas with the potential of generating ocean-thermal energy. However, with the completion of a recent marine survey in the South China Sea during the period 2006-08 (MyMRS), it has been confirmed that indeed the temperature at the bottom of the North-Borneo Trough (known as "Sabah Trough") at a water depth of 2,900 metres (m) is about 3°C, compared to that of the surface at about 29° C. *(Ocean Thermal Energy Development in Malaysia, UTM)*

The techno-economic model will select technology options with the least cost to reach the targeted production volume. The production and usage of hydrogen is recognised as a mean for decarbonisation, by being a complementary alternative energy when other energy sources are not available. The following section will present on fossil fuels and renewable sources in Malaysia for different type of hydrogen production.

2.2.1 Fossil Fuel

Malaysia is the second-largest oil and natural gas producer in Southeast Asia and is the fifth largest exporter of Liquefied Natural Gas (LNG) in the world, as of 2019 (U.S. Energy Information Administration, January 2021). According to the Oil & Gas Journal (OGJ), Malaysia held proved oil reserves of 3.6 billion barrels as of January 2020, the fourth-largest reserves in Asia Pacific after China, India, and Vietnam.

2.2.2 Renewable Sources

Overview of RE in Malaysia

Malaysia has abundance of resources readily exploitable for renewable energy generation:

a. Solar irradiation for solar generation
b. Agricultural, domestic, and industrial waste for bioenergy combustion or gasification
c. Rivers for small hydroelectric power

As of 2020, RE installed capacity in Malaysia amounted to 8,450 MW. Large hydro is the largest contributor to RE capacity with 5,692 MW, followed by solar PV and biomass with 1,534 MW and 594 MW respectively. Small hydro capacity amounts to 507 MW and biogas to 123 MW. In 2021, the Government of Malaysia increased the RE target to 31 % by 2025 and 40 % by 2035, from the previous target of 20 % by 2025, with the new target includes large hydropower as its energy transition plan (Malaysia Renewable Energy Roadmap, SEDA Malaysia 2021). The government agencies under the purview of the Ministry of Energy and Natural Resources (now known as the Ministry of Natural Resources, Environment and Climate Change; NRECC), namely the Sustainable Energy Development Authority (SEDA) Malaysia and Energy Commission (EC) are committed to this target, evidenced by RE programmes such as the; Feed-in Tariff scheme (FiT), Large Scale Solar auction (LSS), Net Energy Metering (NEM) and Self-Consumption (SELCO). The RE installed capacity as of 2020 and the potential RE resource are tabulated in Table 5(a) and Table 5(b), respectively. Solar PV has by far, the largest resource availability at 269 GW. Large hydropower comes in second at 13.6 GW (13,619 MW), followed by bioenergy (biomass from agriculture waste, biogas, and solid waste) at 3.6 GW, small hydropower (up to 100 MW) close to 2.5 GW, and lastly geothermal resource availability has been estimated at 0.23 GW.

Solar PV

Located near the equator, Malaysia has a substantial amount of solar resources. Presently, the installation of solar has covered the following geographical areas:

a. Ground mounted solar installation on unused land (flat land, not classified for any specific use) that does not include water bodies, forest, agricultural land, and mountainous area. This configuration has the highest solar potential in Malaysia at 210 GW, driven by the availability of unused suitable land.
b. An estimated 16.6 GW of floating solar PV resource potential is available in Malaysia. Which includes floating installation on water bodies on 17 large hydroelectric power plants and 62 reservoir dams covering 2,944 km^2 surface area.
c. Peninsular Malaysia has by far the highest rooftop solar PV resource at 37.4 GW as it is highly urbanised. Sarawak and Sabah possess 2.6 GW and 2.2 GW of rooftop solar PV resource respectively through installation on residential, commercial, industrial, and building rooftops.

Large Hydropower

Large hydropower accounts for most of the installed of the capacity with 5,692 MW; 2,240 MW of large hydro is installed in Peninsular Malaysia and 3,452 MW in Sarawak. Around 73% of the identified resource potential (10 GW) comes from central and northern Sarawak, followed by 23% potential of 3.1 GW in Peninsular Malaysia, and the last 4% (493 MW) is identified in Sabah (MyRER, 2021).

Sarawak Corridor of Renewable Energy (SCORE) is a major project that plans to build 12 new dams in Sarawak by 2030. In recent years, the 2,400 MW Bakun plant developed by Sarawak Hydro was opened in 2011, becoming Malaysia's largest hydropower plant, and this was followed in 2015 by Sarawak Energy's 944 MW Murum plant beginning full operations. Sarawak Energy Berhad (SEB) also received the Sarawak state government approval for its 1,285 MW Baleh project in 2016, and there are several other hydro projects in the pipeline which could represent a further 4 GW of new capacity.

With the abundant hydropower resources, the hydroelectric power stations in Sarawak currently operate at a total capacity of 3.5 GW, with plans for an additional 1.3 GW by 2025. Tenaga Nasional Berhad (TNB), the country's largest utility company, also recently completed the construction of two plants in Peninsular Malaysia – the 250 MW Hulu Terengganu project and the 382 MW Ulu Jelai project in the state of Pahang. The distribution of installed capacity of hydropower stations in Malaysia as of December 2016 are tabulated in the Appendix.

Small Hydropower

Peninsular Malaysia has the highest resource potential at 1,736 MW, followed by Sabah with 591MW, and Sarawak with 188MW. The potential sites that can be exploited for small hydropower development may exceed the existing resource potential identified (2.5 GW) given the abundance of 189 river basins in Malaysia.

Bioenergy

On average, 95.5 million tons of Fresh Fruit Bunch (FFB) are processed by approximately 450 palm oil mills each year in Malaysia (MPOB, March 2019). Of the 19.6 million tons (dry weight) of Empty Fruit Bunch (EFB), Mesocarp Fibre (MF) and Palm Kernel Shell (PKS) that are produced each year, 12.3 million tons could be available for biomass combustion, which is equivalent to 2.3 GW of biomass resource. An average of 64 million m^3 of POME is generated each year, translating to approximately 550 MW of power generation from biogas resource in Malaysia (MyRER, 2021). Based on findings from the engagement with industry and academia experts, approximately 30 to 40 kg EFB is required to produce 1kg hydrogen and 4 to 5 tonne POME is needed to produce 1kg hydrogen. Hence, Malaysia has the capacity to produce green hydrogen by biomass gasification and Steam Methane Reforming (SMR) of syngas using POME.

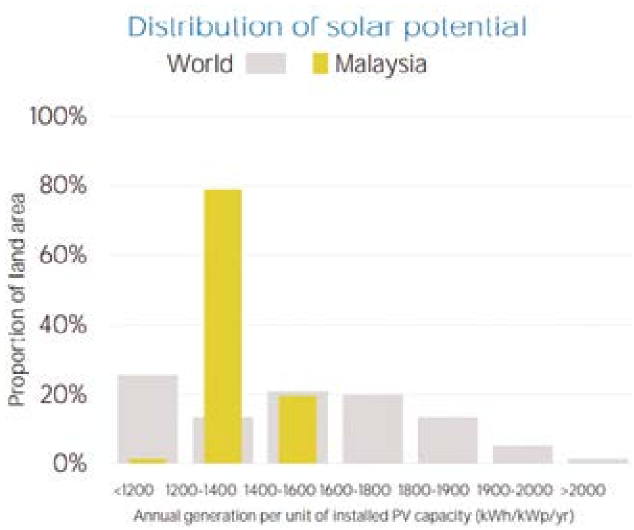
Table 5(a): Renewable Energy Installed Capacity in Malaysia as of 2020
(Source: Malaysia Renewable Energy Roadmap: Pathway Towards Low Carbon Energy System, 2021)

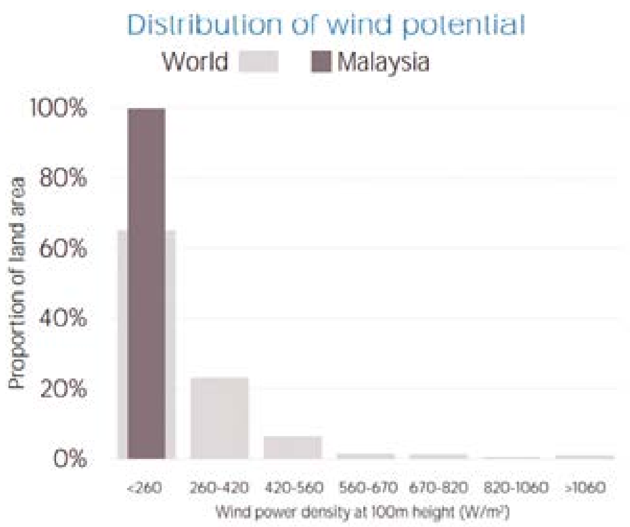
Renewable	8450 MW (23 %)	
Non-Renewable	**28,307 MW (77%)**	
Breakdown of RE Sources	**RE Installed Capacity as of 2020 (MW)**	
	MW	**%**
Solar PV	1534	18
Bioenergy	594	7
Small Hydro (Up to 30MW)	507	6
Large Hydro (Above 30MW)	5692	67

Table 5(b): Renewable Energy Resource Availability in Malaysia quantified in equivalent power generation capacity.
(Source: Malaysia Renewable Energy Roadmap: Pathway Towards Low Carbon Energy System, 2021)

RE Sources	RE Potentials in Malaysia	
	GW	**%**
Solar PV	269	93.1
Bioenergy	3.6	1.25
Small Hydro	2.5	0.87
Large Hydro	13.6	4.71
Geothermal	0.2	0.08
Total	**288.9**	**100**

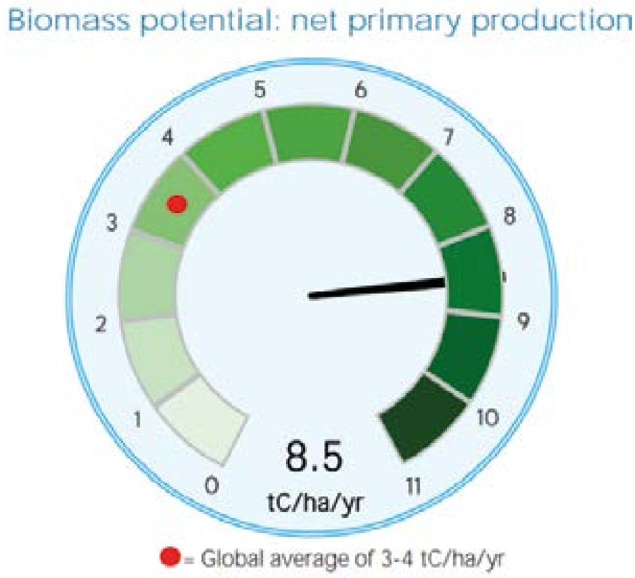
MALAYSIA – Renewable Resource H_2 Potential





Solar PV: Solar resource potential has been divided into seven classes, each representing a range of annual PV output per unit of capacity (kWh/kWp/yr.). The bar chart shows the proportion of a country's land area in each of these classes and the global distribution of land area across the classes (for comparison)

Onshore wind: Potential wind power density (W/m2) is shown in the seven classes used by NREL, measured at a height of 100m. The bar chart shows the distribution of the country's land area in each of these classes compared to the global distribution of wind resources. Areas in the third class or above are considered to be a good wind resource.



Biomass: Net primary production (NPP) is the amount of carbon fixed by plants and accumulated as biomass each year. It is a basic measure of biomass productivity. The chart shows the average NPP in the country (tC/ha/yr.), compared to the global average NPP of 3-4 tonnes of carbon per year.

Conclusions:
Renewable resource H_2 potential in Malaysia 2019 contribute by Hydro/marine - 6275MW (72%), solar PV - 1493MW (17%) and Bioenergy – 931MW (11%).

Hydro/marine is leading the renewable resource H_2 potential and perhaps with hundreds million tonnes of biomass from Oil Palm per year in Malaysia, we can enhance to utilise the palm oil biomass as renewable resource $_{H2}$ potential in the future.

2.3 Current Industry Landscape

To-date, Malaysian industries are slowly finding their way into the hydrogen ecosystem, as evidenced in the following sections. However, there is neither a roadmap nor a legal framework that provides a strategic and concerted direction for Hydrogen Economy development in Malaysia. Therefore, it is crucial to dive into the current industry landscape and status as tabulated and analysed in Table 6 to strategise the way forward for the country.

What is required is a well-devised strategy at a national level to steer the technological and commercial efforts to turn Malaysia into a hydrogen powerhouse.

2.3.1 Industry Value Chain and Players

Table 6: Hydrogen Economy Industry Value Chain and Players

	Government Linked									Multinational Company				Large Enterprise					Start-ups and SMEs			
	PETRONAS	Sarawak Energy	SEDC Energy	[illegible]	SIRIM	UPMW	Sime Darby	[illegible] / digi	[illegible]	[illegible]	Air Products	[illegible]	Air Liquide	DIALOG	Indah Water	cenergi	FELDA	[illegible]	reNIKOLA	Pulsar	[illegible]	HYPER TECH INDUS-TRIES
Feedstock	✓	✓		✓	✓							✓			✓	✓	✓	✓	✓			
Production/ Generation	✓	✓	✓		✓		✓		✓	✓	✓	✓	✓	✓								
Conversion and Storage	✓		✓		✓	✓		✓	✓	✓	✓	✓	✓	✓						✓	✓	
Transport	✓		✓							✓	✓		✓	✓								
Reconversion										✓			✓									
End-use	✓	✓	✓			✓		✓	✓	✓	✓	✓	✓							✓		✓

2.3.2 Industry Direction

The industry in Malaysia consists of several players spanning across different parts of the hydrogen value chain. PETRONAS through Gentari covers most of the supply side of hydrogen starting from feedstock enabled by their production of natural gas via steam methane reforming and hydrocarbon cracking/ reforming – generating grey hydrogen in the process which can be blue hydrogen if the carbon dioxide produced is captured through the use of Carbon Capture, Utilisation and Storage (CCUS) or the life cycle assessment of its carbon footprint is determined as "low-carbon" based on an acceptable certification using ISO standard calculation methods. Currently, PETRONAS through Gentari is exploring the feasibility to establish CCS hub in both Peninsular and East Malaysia.

As of 2021, PETRONAS through Gentari is targeting export of blue hydrogen to Japan in the short-term target. PETRONAS through Gentari is targeting the export of blue hydrogen to Japan, South Korea, and other hydrogen net importing countries. Hydrogen will be transported in the form of ammonia from Malaysia and Canada to Japan and/ or South Korea, as well as in the form of methylcyclohexane (MCH) from Malaysia to Japan. PETRONAS through Gentari is also looking to generate green hydrogen from hydropower via collaboration with Sarawak Energy Berhad (SEB), and Tenaga Nasional Berhad (TNB), leveraging on the hydropower advantage in Sarawak. SEB on the other hand, are planning to construct an integrated hydrogen plant, utilising excess hydroelectricity to generate green hydrogen. Apart from addressing the supply side of the hydrogen value chain, SEB is also looking at the demand side, particularly in mobility where they have demonstrator projects consisting of hydrogen refuelling station, as well as Sarawak's first hydrogen-powered vehicles (Buses & Hyundai Nexo FCV). Apart from mobility, they aim to utilise hydrogen for industrial purposes such as a coolant for thermal power plants and as feedstock for oil & gas and fertiliser industries.

In terms of mobility, UMW is spearheading the effort for FCEVs particularly for light passenger vehicles such as Toyota Mirai and they are looking to push for hydrogen-powered forklifts for the industry. Apart from mobility, they are heading towards creating fuel cell use cases in residential applications.

Sime Darby as a plantation giant in Malaysia has the potential to generate hydrogen from biomass particularly from Palm Oil Mill Effluent (POME) as well as from Empty Fruit Brunches (EFB).

For the use-case of hydrogen in off-grid telecommunication power, Digi in a collaboration with MTSFB and MCMC have embarked on the utilisation of hydrogen in telecommunication tower by harnessing solar power to generate hydrogen hybrid power solution. NanoMalaysia Berhad are focused on the On-Site Hydrogen Production as well as hydrogen hybrid energy storage system (H2SS), which ultimately can be utilised in mobility. Linde and Air Products in Malaysia have several solutions across the hydrogen value chain, in which the production technology focuses on steam methane reforming from natural gas. Construction and operation of the hydrogen production plant and refuelling station was undertaken by Sarawak Energy Berhad (SEB) in collaboration with Linde EOX Sdn. Bhd., a subsidiary of Linde Malaysia.

The Linde Group is among the world's leading industrial gases and engineering companies. Air Liquide through its Air Liquide Engineering & Construction division offers technology that revolves from hydrogen production, storage, and distribution in the past 50 years and today is the market leader for hydrogen liquefaction technologies, providing extensive experience in the design, engineering, and operation of ultra-low temperature liquefaction plants for customers. Moving forward, Air Liquide is exploring the use of hydrogen in the transportation sector by supporting the global roll-out of the necessary hydrogen refuelling stations. Having said that, Air Liquide has a joint venture with Iwatani Corporation, Japan's major player in developing hydrogen refuelling stations and ITOCHU to scale up Japan hydrogen mobility markets. The technologies landscape among the local key-players against hydrogen value chain are summarised in Table 7 and the industry directions are summarised in Table 8.

Table 7: Benchmarking of current technologies among the local key-players against hydrogen value chain

	PETRONAS gentari	sarawak energy	UMW	Sime Darby	MCMC digi	NANO MALAYSIA	Linde	AIR PRODUCTS	Air Liquide
Feedstock	• Natural gas (Blue hydrogen) • Hydropower (Green hydrogen) – Collaborating with SEB, TNB & other potential RE suppliers	Hydropower (Green hydrogen)					Natural gas (methane)	Natural gas (methane)	Desulfurized natural gas, refinery off gas, liquefied petroleum gas or naphtha
Production/ Generation	• Steam methane reforming and Hydrocarbon cracking/ reforming • Green hydrogen production testing facility with advanced electrolyser in collaboration with Sarawak Energy Berhad (SEB)	• Integrated Hydrogen Production Plant using electrolyser. • 130 kg of hydrogen per day at a purity of 99.999 %		RM 15 million investment for R&D on biomass gasifier technology and biohydrogen production		• On-Site Hydrogen Production	• Steam-methane reforming process (SMR). • Linde EOX Sdn Bhd provides technological expertise across the hydrogen value chain to Sarawak Energy Berhad (SEB) specifically on the construction and hydrogen production plant and refueling station	• Steam methane reforming process (SMR) with production capacity of more than 1.5 million standard cubic feet per day. • Hydrogen plants in Banting, West Port and Kuantan.	• SMR-X™ - Zero Steam Hydrogen Production • Gas POX - Natural Gas Parti–l Oxidation • Steam Methane Reforming • Cryocap™ H2 – Cryogenic CO_2 Separation (captures the CO_2 released during hydrogen production)
Conversion and Storage	Continuously exploring and developing solutions for CCS in Malaysia	Hydrogen stored as liquid based/ liquefaction			Technical code for hydrogen storage at telco sites	Hydrogen Hybrid Energy Storage System (H2SS)		Liquid hydrogen and compressed hydrogen gas	Pressure Swing Adsorption (PSA) with advanced adsorbents

	PETRONAS gentari	sarawak energy	UMW	Sime Darby	MCMC digi	NANO MALAYSIA	Linde	AIR PRODUCTS	Air Liquide
Transport	• Hydrogen transportation in the form of Ammonia and Liquid Organic Hydrogen Carrier (LOHC), e.g., methyl-cyclohexane • Compressed hydrogen (350 to 700 bar)							Vessel by land to local customers	Hydrogen Liquefiers - to service the gr–wing hydrogen mobility market and industrial applications
Reconversion		Compressed to gaseous state for transportation and industry feedstock							Pressure Swing Adsorption (PSA) with advanced adsorbents
End-use	Hydrogen for export (power, marine bunkering, refinery, feedstock); to further explore clean hydrogen use for internal use as power, in refineries, petrochemical processes and other uses	• Hydrogen refuelling station (Petros Darul Hana Multifuel station) • Sarawak's first hydrogen-powered vehicles (Buses & Hyundai Nexo FCV) • Coolant at thermal power plan • Feedstock for oil & gas and fertiliser– Toyota Mirai,,Fuel cell forklift • Residential – Residential fuel cell		Telecommu-nication - Solar hydro-gen hybrid power solu-tion for telco base station towers	• Hydrogen-powered UAV • Hydrogen Paired Electric Race Car • Hydrogen Paired E-Bikes		Oleochemical manufactures that produce fatty alcohols, fatty acid and methyl esters		

**Information is non-exhaustive. Only existing and on-going initiatives/projects were included.

Table 8: Direction of hydrogen players in Malaysia mapped against the hydrogen value chain which are crucial to the development of Hydrogen Economy

	PETRONAS gentari	sarawak energy	SEDC ENERGY	UMW	Sime Darby		SIRIM
Feedstock	• Natural gas ■ • Steam-methane reforming ■ • Hydrogen as co-product from petrochemical plant ■	2020: 68 % hydro capacity that generates 5052 MW■ 2030: 69 % hydro capacity that generates 7279 MW■ 2040: 70 % hydro capacity that generates 7629 MW■	• Natural gas ■ • Hydropower ■			Solar energy (solar photovoltaic system) ■ Solar Energy Purchase (SEP) ■	Domestic waste, municipal solid waste & low value biogas streams from wastewater treatment plants and landfill sites. ■
Production/ Generation	• Collaboration with UKM through Group Research & Technology in developing a PEM electrolyzer ■ • Low-carbon hydrogen through CCUS ■ • Production of hydrogen as co-product from petrochemical plant ■	50 – 55 kWh needed to produce 1kg of hydrogen through electrolysis ■	• Hydrogen plant in Bintulu projecting up to 10,000 tonnes of green hydrogen per year (Sumimoto-ENEOS-SEDC) ■ • Aiming to supply hydrogen and ammonia to Korea and Sarawak (H2Biscus Project) ■				Biomethane that is produced from POME can be cracked to produce carbon black and hydrogen. ■ Refinement of carbon black to graphene. ■
Conversion and Storage			Hydrogen to MCH for export ■	Compressed hydrogen tank (e.g.: Composite) ■			Hydrogen storage technology using light weight composite cylinder ■
Transport	• Ammonia ■ • LOHC: Methylcyclohexane ■ • Metal hydrates: Pilot stage ■		LOHC: Methylcyclohexane ■				
Re-conversion							
End-use	Internal operation as fuel & feedstock. ■		• Multifuel refuelling station which includes hydrogen for FCEVs ■	UMW partner MIRAI has on-board hydrogen HEXAGON composite tank (1.4L can carry 5.6kg H_2 load) ■	Hyundai NEXO Fuel Cell Vehicle • On board electric motor - 163PS – 0.9kg H2/100km ■ • NEXO's high-pressure storage tanks. ■	Collaboration with PETRONAS on coal co-firing: • Energy production from co-firing of ammonia with coal ■ • Co-firing hydrogen with natural gas ■	

	Galaxy FCT	Pulsar UAV	UTM	Linde	Air Products	Air Liquide
Feedstock				Natural gas (methane)	Natural gas (methane)	
Production/ Generation			Laser-based Electrolyser - green hydrogen generation through water electrolysis using lasers	Steam-methane reforming process (SMR).	• Steam methane reforming process (SMR) with production capacity of more than 1.5 million standard cubic feet per day.	• Bio gas reforming • Water electrolysis • CCUS Technology
Conversion and Storage	NaBH$_4$ as hydrogen-storage and transportation				Liquid hydrogen and compressed hydrogen gas	Possess hydrogen storage technology in liquid form
Transport					Vessel by land to local customers	Transportation of hydrogen through pipeline
Re-conversion	Hydrogen released through hydrolysis. The hydrolysis is performed with water and catalyst at temp <100°C			Provides its technological expertise across the hydrogen value chain to Sarawak Energy Berhad (SEB) specifically on the construction and operation of hydrogen production plant and refueling station		
End-use	NaBH$_4$ for PEM fuel cell as the hydrogen release temperature from sodium borohydride is close to PEM fuel cell temperature.	On-board hydrogen powered drone - High Endurance Fuel Cell Powered UAV (On-board H2 Generation)			Oleochemical manufacturers that produce fatty alcohols, fatty acid and methyl esters	Hydrogen charging stations for various mobility applications Posses on-board fuel cells as well as stationary fuel cells.

Addresses Short-term Target

Addresses Mid-term Target

Addresses Long-term Target

1. PETRONAS/Gentari

On 15th September 2022, PETRONAS launched its clean energy solutions entity Gentari Sdn Bhd (Gentari) to independently pursue and deliver integrated sustainable energy solutions, and to capture opportunities in the energy transition. Gentari offers lower carbon solutions through three initial core pillars – Renewable Energy, Hydrogen and Green Mobility, forming a portfolio of solutions cutting across the electron value chain to help customers achieve net zero emissions. Gentari is currently embarking on several hydrogen-related projects:

a. Blue Hydrogen (2024 – 2025):

- Production of by-product low carbon hydrogen
- In the form of ammonia or Liquid organic hydrogen carrier LCOH as per customers' requirement
- Supply from peninsular Malaysia with ready facilities and resources

b. Green Hydrogen 2025 & 2027

- Collaboration with partners to produce green hydrogen from renewable energy (hydro)
- Hydrogen can be transported as per customer's Requirements.
- Supply from peninsular Malaysia and East Malaysia.

2. Credibility and abilities as end-to-end cleaner energy provider:

- Geographic Advantage – Strategic location of supply nodes, proximity to H2 demand centers
- In-house Capacity – Availability of resources and logistics to supply competitively
- Ready Assets – On the ground facilities for lower cost of entry
- Strong Partnership – Building partnership in supply & demand, creating a complete chain
- Capability Technology – Leadership in development of energy solutions
- Supply Hub Expansion – Actively seeking new competitive hubs to be close to customers
- Value Relationship – Long history and trusting relationship as reputable LNG supplier
- Alternative Offering – H2 as an alternative product complementing LNG
- Developing local capability while taking advantage of current demand and gaining export revenue.

Example: Develop strategic export projects and ensure capability transfer

2. Tenaga Nasional Berhad

TNB Research Sdn Bhd

TNB Research Sdn. Bhd. is a subsidiary of Tenaga Nasional Berhad (TNB), which conducts research and development towards the decarbonisation initiative for power generation. TNB Research started their Technology Roadmap back in 2004. Technology Roadmap 1(TRM 1) has identified hydrogen as one of the enablers under the Proactive Environmental Management Theme. TNB Research Sdn. Bhd. is focusing on providing technical and economic assessment of green hydrogen production as the production of hydrogen via sustainable energy will ensure the production of the energy would not emit carbon dioxide into the atmosphere. As a result, one pilot project and one R&D project was executed. Since 2016 hydrogen has been applied in carbon capture and utilisation while carrying out technology benchmarking. Utilising hydrogen in ESI is not without its challenges due to an unattractive local market, environmental implications as well as technology maturity. These are the main hurdles in implementing the hydrogen economy for ESIs.

1. Pilot Project:

- Production from biomass gasification.
- TNB with IHI Corp (Japan) and PETRONAS/Gentari had formed a joint study into Co-Firing Ammonia at coal power stations to reduce carbon emissions. Ammonia is viewed as the most viable carrier of hydrogen to be used as fuel.

2. R&D Project:

- Application of Carbon Capture Utilisation in combination with CO_2 through:
  a) Chemical Approach Carbon Capture
  b) Biological Approach Carbon Capture
  c) Carbon Utilisation

- Alternative method for green hydrogen such as production through two stage Anaerobic Digestion (TSAD) process of organic waste e.g.: Palm Oil Mill Effluent and food waste

3. Sarawak Green Hydrogen Planning

Sarawak's Hydrogen Economy Vision

Sarawak as the front runner for Green Hydrogen Economy in the ASEAN Region by 2030 via renewable sources with minimal impact to the environment. As the first in ASEAN to promote the hydrogen economy, Sarawak is optimistic to become a developed State by 2030 with hydrogen economy as one of its key strategies.

To realise the State's aims, they are committed to reduce petroleum use, GHG emissions, and air pollution to contribute to a more diverse and efficient energy infrastructure by enabling the widespread usage and commercialisation of hydrogen and fuel cell technologies.

A solid framework was presented to achieve the Vision. The key strategic pillars consist of:

i. Production & Storage,
ii. Transportation,
iii. Commercialisation,
iv. Application, and
v. Research & Development.

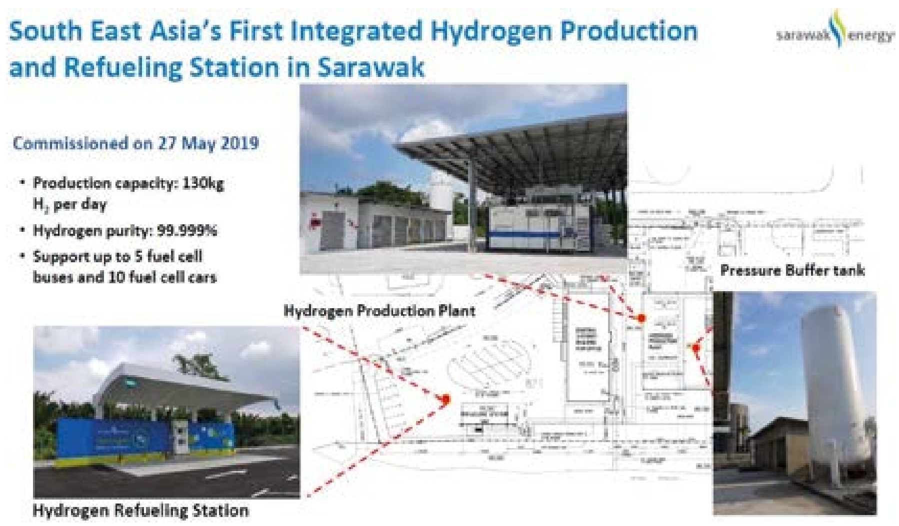
Sarawak is positioning itself to be a commercial hydrogen producer by 2027 thus realising the Vision of turning the state into a hydrogen economy. Based on the Memorandum of Understanding (MoU), that has been signed between Sarawak Energy, SEDC Energy, Samsung Engineering, Lotte Chemical, as well as Posco Holdings, that aims to study the supply of renewable hydropower for the green hydrogen and ammonia project in Sarawak, its projected for the green hydrogen export to begin by 2027. SEDC Energy Sdn Bhd has also signed for a tripartite Memorandum of Understanding (MoU) with Japan's Sumitomo Corp and ENEOS to build a hydrogen plant in Bintulu which will be locally used and for export in the form of methylcyclohexane (MCH) to Japan. The export of hydrogen is expected to take place within the time period of 2027 to Quarter 4 of 2028.

Sarawak Metro Sdn. Bhd., a wholly owned subsidiary of Sarawak Economic Development Corporation (SEDC), has been entrusted by the Sarawak Government to implement the Kuching Urban Transportation System (KUTS) project. Sarawak Metro was entrusted by SEDC to manage the trial operations of the hydrogen bus in Kuching – which is the first hydrogen bus service in Southeast Asia. In line with the development of Sarawak's hydrogen economy and moves to decarbonise the public transport sector, the Kuching Urban Transportation System (KUTS), developed by Sarawak Metro Sdn. Bhd. will use hydrogen-powered autonomous rapid transit (ART) vehicles. The local production in Kuching for hydrogen supply to Sarawak Metro are aimed to begin in 2025.

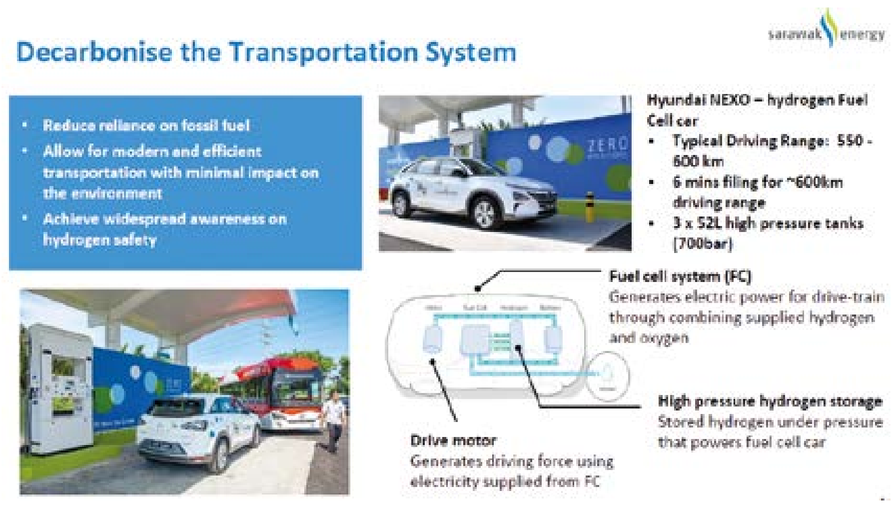
Education and capacity building were also taken into account to educate the public to embrace the idea of a hydrogen economy and to support the capacity building, dedicated training, and development centre to develop new talents.

To encourage private sector investments in the building of the hydrogen infrastructure, subsidies and financial support shall be required. The key elements in the framework are supported via policies from the Sarawak government.

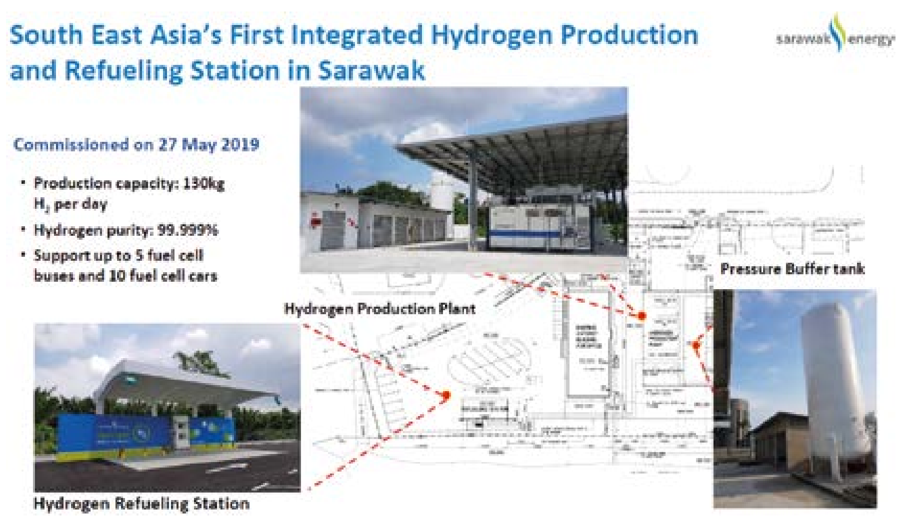
Sarawak's Lead Hydrogen Projects



Decarbonising Urban Transportation System



Sarawak Metro – Kuching Urban Transportation System (KUTS)

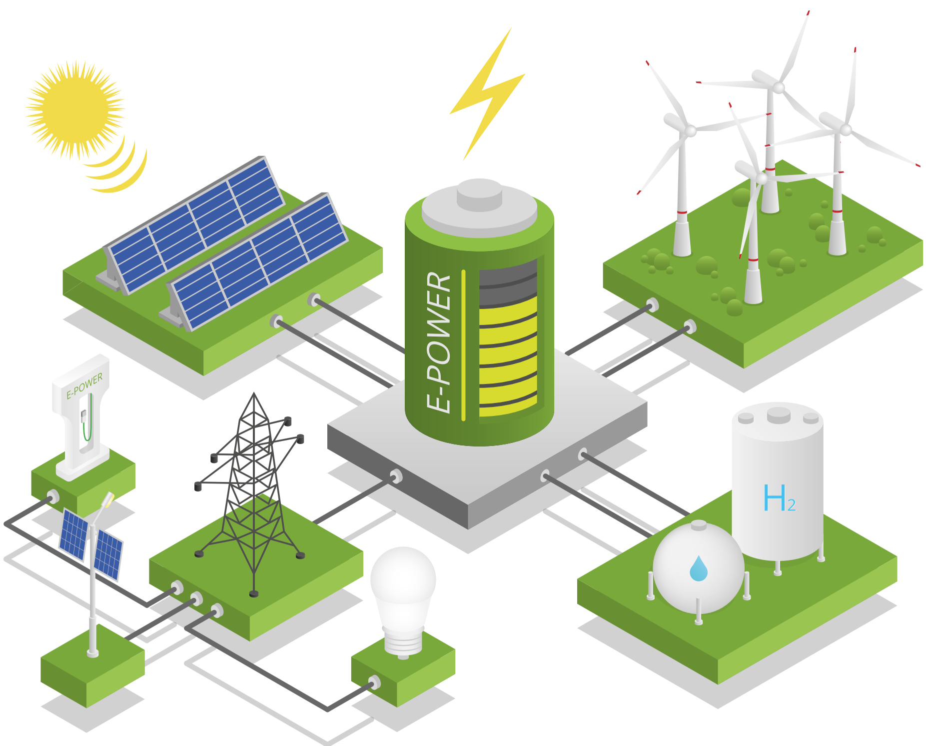


Malaysia-Japan Collaboration – Project H2ornbill

Targets to commence operation of 25MW or 3,000 tonnes per year capacity plant in Bintulu by 2023. Scalable up to 75MW or 10,000 tonners per year capacity by 2025. A joint collaboration between Sumitomo Corporation and Sarawak Economic Development Corporation in 2019. In 2020, ENEOS joined the consortium leveraging on their expertise and technology in hydrogen transportation.

Upcoming Hydrogen related Projects in Sarawak

- 100 multifuel stations (including hydrogen) in 2030
  a. Petros Darul Hana Multifuel Station by Q4 2022 to be equipped with hydrogen refuelling
- SEDC led projects through subsidiaries SEDC Energy and Sarawak Metro
  a. Manufacturing or assembling hydrogen fuel cell components
  b. Multifuel refuelling stations
  c. MoUs with Korea and Japan for hydrogen export business
- Fuel Cell buses and Autonomous Rapid Transit (ART) to replace existing fossil fuel system
- Sarawak Government agencies to use FCEVs
- Plan to establish a regional hub for testing of fuel cell aviation technologies
- Kuching Hydrogen Park includes a domestic hydrogen production plant & information centre.
- Plan to replace existing usage of grey hydrogen being used to green hydrogen in industries.
- SEDC Energy collaborates with Airbus and Rolls Royce through Aerospace Malaysia Innovation Corporation (AMIC) to undertake research and development on green hydrogen and fuel cells as future aviation fuel.



4. NanoMalaysia's Hydrogen EcoNanoMY Programme

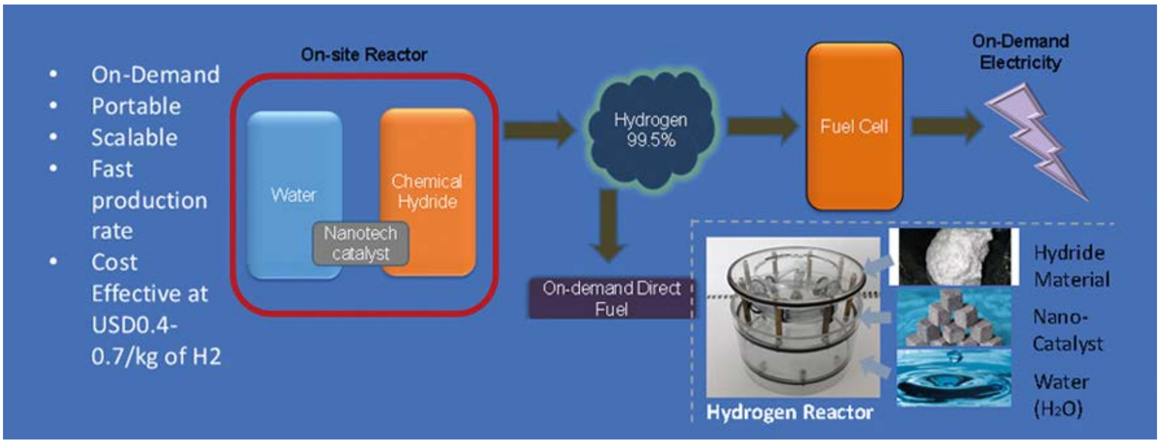
Hydrogen EcoNanoMY

The Hydrogen EcoNanoMY programme under the facilitation of NanoMalaysia Berhad aims to develop and produce local game-changer technologies that are able to generate hydrogen on-demand and on-site, which is cost effective while also looking into the ecosystem surrounding the value chain and addressing market interest in hydrogen economy including technology, both locally and internationally.

As an energy carrier, hydrogen has the potential to play a pivotal role in the transition to a new energy paradigm based on renewable sources. However, the application in the transportation sector is limited due to its difficult storage and lack of distribution infrastructure. *In-Situ* hydrogen generation through chemical reactions is presented as a viable solution to these challenges providing an added advantage towards energising the mobility system and economy. By embracing the Hydrogen Economy, reliance on fossil fuels in the energy supply and mobility sectors can be minimised, thereby reducing carbon emissions and advancing sustainable energy solutions.

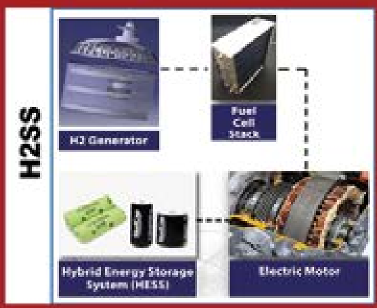
NanoMalaysia's Hydrogen Project Pipeline

NanoMalaysia *In-Situ* Hydrogen Production



Hydrogen Hybrid Energy Storage System (H2SS)

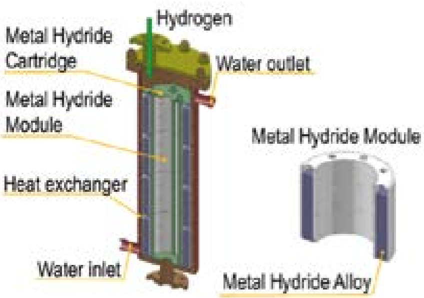
Hydrogen Hybrid Energy Storage System (H2SS)



First locally developed energy storage system that combines the advantages of Onboard hydrogen (H2) generation for Fuel Cell, Lithium-ion battery and Graphene-based UltraCapacitor (GUC)

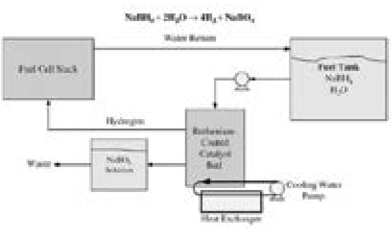
Component	Advantage
Onboard H2 generator	Improved safety & Cleaner H2 production
Fuel Cell	Improved efficiency & Zero emission
Li-Ion battery	High energy density
Graphene-based Ultracapacitor	High power density & Over 1 million charge-discharge cycle.

EcoNanoMY's Hydrogen Storage Technologies



Metal Hydrides

- Metal hydrides are metals which have been bonded to hydrogen to form a new compound. Any hydrogen compound that is bonded to another metal element can effectively be called a metal hydride.
- Metal hydrides are often used in fuel cell applications that use hydrogen as a fuel. Lithium hydrides and sodium borohydride both serve as reducing agents in chemistry applications. Most hydrides behave as reducing agents in chemical reactions.
- Beyond fuel cells, metal hydrides are used for their hydrogen storage and compressors capabilities.



Chemical Hydrides

- Chemical hydride storage is an alternative method of producing hydrogen via a chemical reaction. These reactions involve chemical hydrides, water, and alcohols. The chemical reactions are not reversible, and the byproducts must be discarded. Hydrogen fuel can also be produced through a chemical reaction with solid "chemical hydrides."
- This technique lies somewhere between metal hydrides and reforming. Chemicals such as lithium hydride, lithium aluminum hydride, and sodium borohydride can be combined with water to evolve hydrogen gas exothermically:

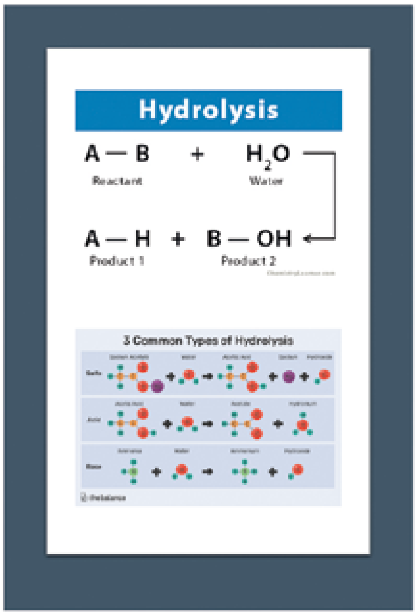
$$LiH + H_2O \rightarrow LiOH + H_2 \ (\Delta H = -312 \text{ kJ/mol LiH})$$

$$LiAlH_4 + 4\,H_2O \rightarrow LiOH + Al(OH)_3 + 4\,H_2 \ (\Delta H = -727 \text{ kJ/mol LiH})$$

$$NaBH_4 + H_2O \rightarrow NaOH + H_3BO_3 + 4H_2$$

- Hydrolysis reactions are chemical hydrides that react with water to produce hydrogen. One of the most commonly studied reactions is sodium borohydride and water

EcoNanoMY's Hydrogen Generation Technologies

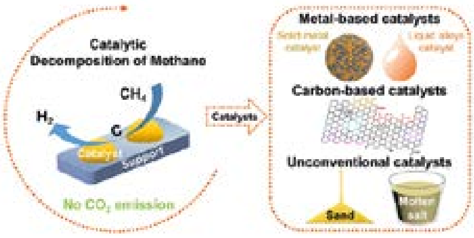


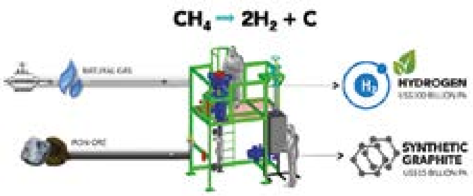
Hydrolysis

- Hydrolysis means the act of separating chemicals when water is added. There are three main types of hydrolysis: salt, acid, and base hydrolysis:
  - **Salts**: Hydrolysis occurs when salt from a weak base or acid dissolves in liquid. When this occurs, water spontaneously ionizes into hydroxide anions and hydronium cations. This is the most common type of hydrolysis.
  - **Acid**: Water can act as an acid or a base, according to the Bronsted-Lowry acid theory. In this case, the water molecule would give away a proton. Perhaps the oldest commercially-practiced example of this type of hydrolysis is saponification, the formation of soap.
  - **Base**: This reaction is very similar to the hydrolysis for base dissociation. Again, on a practical note, a base that often dissociates in water is ammonia.
- Polymer Electrolyte Membrane Electrolyzers
- Alkaline Electrolyzers
- Solid Oxide Electrolyzers

Catalytical Gas Cracking

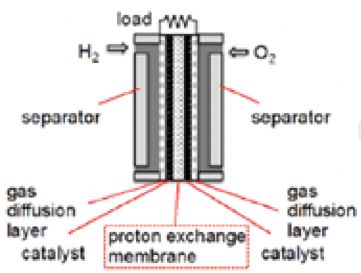
- The challenges raised by intensive CO_2 emission from the traditional conversion of methane have provoked emission-free hydrogen production from methane.
- The catalytic decomposition of methane (CDM) to produce hydrogen and advanced carbon hence comes into consideration due to the short process and environmental benignity





High Endurance Hydrogen Fuel Cell Developments

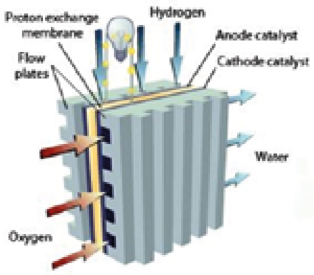
Phase 1a – Development of Membrane Component



- Membrane is one of the main component in fuel cell.
- It acts as a separator and plays an important role in the transfer of protons from anode to cathode.
- Nafion is a membrane commonly used in fuel cells.
- The main issues with this component are the rate of oxygen transfer, cation delivery, membrane relaxation and substrate depletion.
- NanoMalaysia undertakes a PEM development project in collaboration with the National Fuel Cell Institute, National University of Malaysia and the Faculty of Industrial Science and Technology, University of Malaysia Pahang.

Objectives	Methods
• Improve PEM performance and efficiency • Save the fuel • Extend the lifespan of the PEM	• Replacement of PEM with new material • Customize PEM with nano (nanocomposite) technology

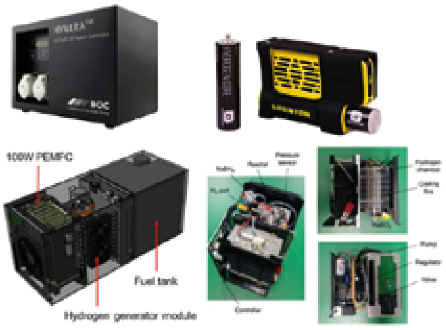
Phase 1 – Development of Catalyst Component



- The catalyst is a substance that increases the reactivity rate by lowering the required activation energy.
- In fuel cell technology, catalysts play a role in hydrogen and oxygen reactions. .
- Platinum is the commonly used catalyst in fuel cells.
- Among the disadvantages of platinum catalyst are the high cost, disruption of the reaction by carbon monoxide (fuel cell methanol) and also the lack of specificity that can cause short circuits in the fuel cell.

Objectives	Methods
• Enhance the catalyst activation • Reduce the PEM fuel cell poisoning • Increase the oxygen reduction rate (ORR) • Reduce the cost of fuel cell due to the use of platinum-based catalyst • Produce a catalyst that can operate at high temperatures	• Modification of the catalyst surface • Replacement of platinum with new composite catalyst • Thermal treatment to the catalyst

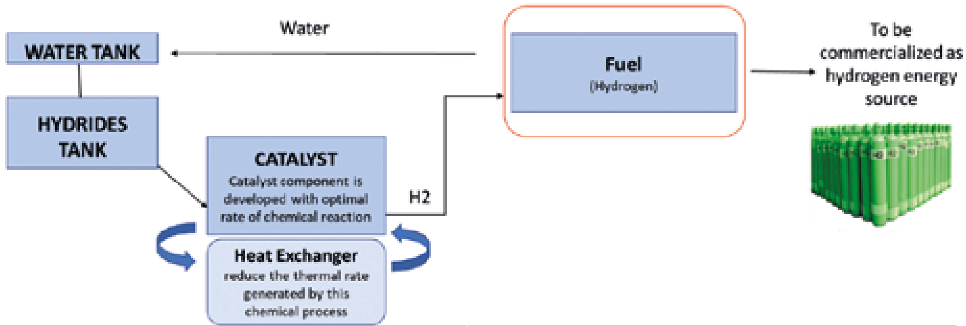
Phase 2 – Development of Hydrogen Reactor



- With the advances in electrochemistry, fuel cells have the potential to be developed as portable power generators.
- There are several companies that offer hydrogen reactors as power generators.
- However, most of the hydrogen reactors on the market serve as power reserves.
- The hydrogen reactor is a consumer choice due to the availability of hydrogen sources, absence in pollution (both air and sound), environmental friendly and more energy efficient than diesel.
- There are several factors that hinder the use of hydrogen reactors such as cost of ownership, difficulties in storage and refill of hydrogen.
- Two technologies owned by NanoMalaysia (two IPs in filing process) will be used in this development phase.

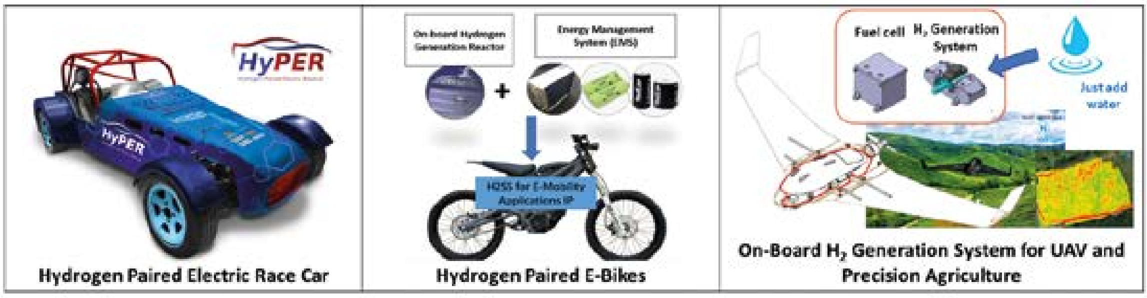
Objectives	Methods
• Developing a hydrogen reactor with the ability of onsite hydrogen delivery • Produce a hydrogen reactor at a competitive price	• Modify the mechanism of hydrogen supply to fuel cells • Apply the PEMs and catalysts developed in the Hydrogen EcoNanoMY project (previous development phase) • Produce the complete set of hydrogen reactors at large scale

Phase 3 – Development of Hydride Recycling Process



Objectives	Methods
• To optimize the production of hydrogen energy through the reuse of chemical hydrides • To commercialize the fuel (hydrogen) generated through this process as raw materials; or to integrate the fuel into portable and compact components.	• Recycle water and chemical hydrides to produce high quantity of hydrogen • Use chemical hydrides that can operate at minimum temperature

Existing/Future Projects under EcoNanoMY

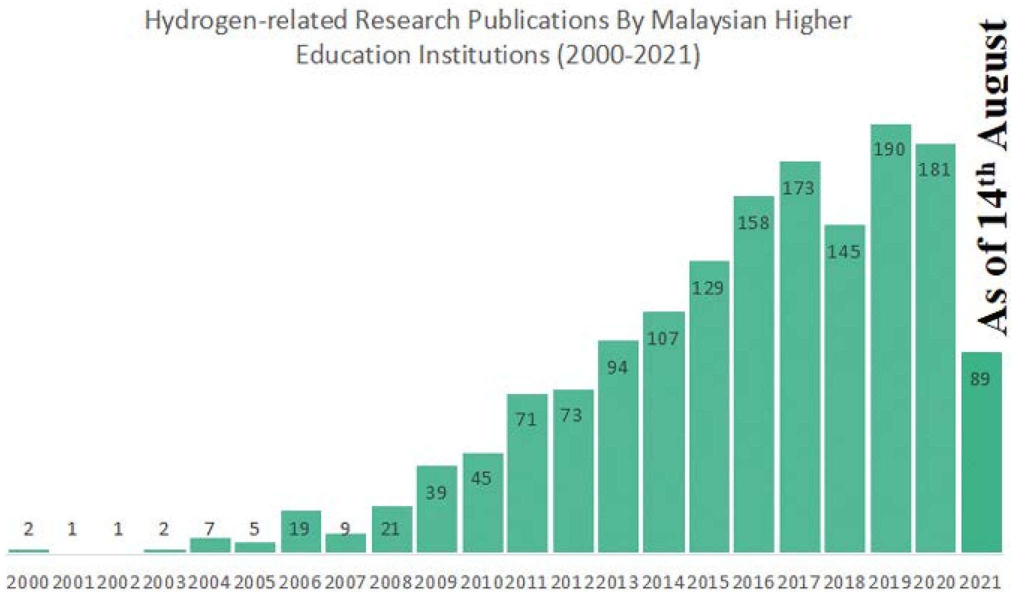


2.4 Research and Development

2.4.1 Research publications

Based on the data generated from Lens.org, there has been an increase in the number of scholarly articles related to hydrogen within the past 10 years, with a CAGR of 14.9% as shown in Figure 9. Back in 2010, only 45 articles were published whereas in 2020, the number of articles has increased to 181. As of 14th August 2021, 89 articles were published, indicating the numbers in 2021 will be higher than what was reported in 2020. Universiti Kebangsaan Malaysia are leading in the number of research publications with 499 publications followed by Universiti Teknologi Malaysia (311) and Universiti Malaya (UM) with 171 publications. Apart from Institutions of Higher Learning (IHLs), publications from research institutes were also included in the study albeit at limited numbers such as Malaysian Nuclear Agency with 17 publications, SIRIM (1), Malaysian Rubber Board (MRB) (1), Malaysian Palm Oil Board (MPOB) (1) and Malaysian Agricultural Research and Development Institute (MARDI) (1) and TNB Research with 1 publication.

These findings relate to the growing number of research interests amongst the academia and research institutes, fueled by the formation of hydrogen-oriented research institutes at universities.



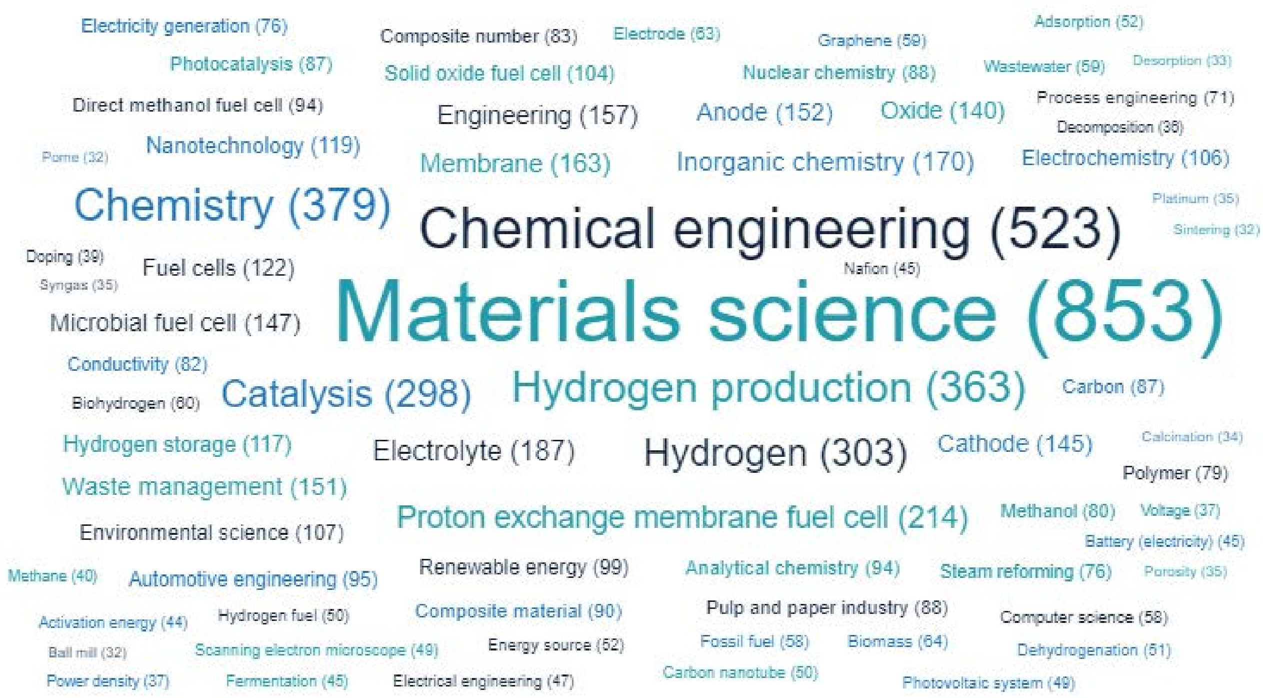
Source: Lens.org

Figure 9: Hydrogen-related research publications by Malaysian Higher Education Institutions (2000 – 2021)

Amongst these publications, the keywords generated from the search using Lens are as follows:

a. Material science – the use of advanced material to achieve the intended purpose of hydrogen production;
b. Chemical engineering – signifying the importance of chemical engineering, as hydrogen is produced through various chemical pathways;
c. Chemistry – indicating hydrogen research are concentrated in the chemistry field of study;
d. Hydrogen production – signifying the urgency to find a feasible hydrogen production method at lower cost and higher efficiency;
e. Hydrogen storage – showing interest among academia to develop a cost-effective, reliable, and safe method of storing hydrogen;
f. Hydrogen – showing interests in studying hydrogen.

In addition, nanotechnology has been mentioned in 119 articles – noting the importance of nanotechnology as one of the technological drivers for hydrogen technology particularly through the use of advanced materials. The list of keywords relevant to the publications are shown in the Figure 10 word cloud:



Source: Lens.org

Figure 10: Category of hydrogen research with most publications

In terms of research funding, we have seen consistent hydrogen-related funding from 2010 to 2020. UKM is leading the hydrogen research initiative through its Fuel Cell Institute, with a total number of 71 research initiatives since 2006.

2.4.2 Research projects and fundings

Table 9: List of hydrogen-related research by research institutions and universities funded from 2006-2020

Fund Recipients	Year 2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	Total
Agensi Nuklear Malaysia (ANM-RMC)	1					1										**2**
Ecsense Sdn Bhd							1									**1**
G-Energy Technologies Sdn Bhd		1														**1**
Monash University Malaysia (Monash-Sunway)							1	1		1						**3**
Nanomalaysia Berhad											3					**3**
Sirim Berhad	1									1						**2**
The University Of Nottingham Malaysia			1													**1**
Universiti Kebangsaan Malaysia (UKM-CRIM)	3	4	1		1	1	1	1	1		9	11	10	20	8	**71**
Universiti Malaya (UM)															1	**1**
Universiti Malaya (UM-IPPP)						1	1		1							**3**
Universiti Malaysia Perlis (UNIMAP-LAB)								1								**1**
Universiti Malaysia Terengganu (UMT-CRIM)	1	1														**2**
Universiti Putra Malaysia (UPM-HALAL)	1						1			1						**3**
Universiti Sains Islam Malaysia (USIM)							1							1		**2**
Universiti Sains Malaysia	1	1	1													**3**
Universiti Teknologi Malaysia (UTM-CPERTAMA)	2	5	3	1			2	1								**14**
Universiti Teknologi Mara (UiTM Shah Alam)			2				1									**3**
Universiti Teknologi Petronas (UTP)	2	1				1										**4**
Universiti Tenaga Nasional (UNITEN)				1												**1**
Grand Total	**12**	**13**	**8**	**2**	**1**	**4**	**9**	**4**	**2**	**3**	**12**	**11**	**10**	**21**	**9**	**121**

**Data were obtained from KRSTE.my search based on the keyword “hydrogen” on 14 August 2021.

Table 10: List of funding disbursed to hydrogen-related research from 2006-2020

Fund Organisation/Fund Name	Year Started															
	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	Total
Dana Universiti Penyelidikan (RU)											**7**	**10**	**10**	**9**	**6**	**42**
Dana Impak Perdana (DIP)											2	4	3	5		14
Dana Modal Insan (DMI)													2	2	1	5
Dana Penerbitan Buku (DPB)															2	2
Geran Galakan Penyelidik Muda (GGPM)											1	3		1		5
Geran Universiti Penyelidikan (GUP)											4	3	5	1	3	16
Ministry of Higher Education											**1**	**1**		**12**		**14**
Fundamental Research Grant Scheme (FRGS)											1	1		6		8
Trans-disciplinary Research Grant Scheme (TRGS)														6		6
Ministry of Science, Technology and Innovation (MOSTI)	**12**	**13**	**8**	**2**	**1**	**4**	**8**	**4**	**2**	**3**	**3**					**60**
COMMERCIALISATION OF R&D FUND(CRDF)			1													1
Program Pengkomersialan Nanoteknologi											3					3
SCIENCEFUND	12	12	7	2	1	4	8	4	2	2						54
TECHNOFUND		1								1						2
PETRONAS															**1**	**1**
PETRONAS															1	1
Universitas Sriwijaya (UNSRI)											**1**					**1**
Universitas Sriwijaya (UNSRI)											1					1
USIM							**1**									**1**
Geran Penyelidikan USIM							1									1
Universiti Malaya															**1**	**1**
Geran Penyelidikan Fakulti															1	1
Nano Commerce Sdn Bhd															**1**	**1**
Nano Commerce Sdn Bhd															1	1
Grand Total	**12**	**13**	**8**	**2**	**1**	**4**	**9**	**4**	**2**	**3**	**12**	**11**	**10**	**21**	**9**	**121**

**Please note that there are 1 project funded by foreign university in 2016 to UKM. Data were obtained from KRSTE.my search based on the keyword “hydrogen” on 14 August 2021.

2.4.3 Patents from Research at Universities

Apart from academic publications, the funded research yielded a total of 12 patents with granted status. Out of this total, 9 Malaysian patents were granted to UKM. Most of these publications of granted patents as tabulated in Table 11 are centered around hydrogen production, particularly on the use of catalysts to support hydrogen production as well as fuel cell research.

Table 11: Lens.org search on research patents based on all hydrogen fields.

No	Publication Year	Application Number	Title	Applicants	Inventors
1	2011	MY PI20072055 A	AN ELECTROCHEMICAL POWER GENERATOR	UNIVERSITI KEBANGSAAN MALAYSIA	• DAUD WAN RAMLI BIN WAN • HUSAINI T • SITANGGANG RAMLI • SAHARI JAAFAR BIN • SOPIAN KAMARUZZAMAN BIN • HARON CHE HASSAN BIN CHE • MOHAMMAD ABU BAKAR BIN • KHADUM ABDUL AMIR HASSAN • ROSLI MASLI IRWAN BIN • MASDAR MOHD SHAHBUDIN BIN MASTAR • MAJLAN EDY HERIANTO
2	2011	MY PI20072119 A	A PHOTOCATALYST FOR HYDROGEN PRODUCTION	UNIVERSITI KEBANGSAAN MALAYSIA	• DAUD WAN RAMLI WAN IR • KASSIM MOHAMMAD • DAIK RUSLI • RAHMAN FADHLI HADANA
3	2012	MY PI20092218 A	SINGLE CHAMBER MEMBRANE-LESS MICROBIAL FUEL CELL	UNIVERSITI PUTRA MALAYSIA	• RADU SON • CHING CHAI LAY • FEN CHAI LI
4	20 17	MY PI20084656 A	A METHOD OF SYNTHESIZING PHOTOCATALYST FOR HYDROGEN PRODUCTION	UNIVERSITI KEBANGSAAN MALAYSIA	• WAN RAMLI BIN WAN DAUD • MOHAMMAD BIN KASSIM • RUSLI BIN DAIK • FADHLI HADANA RAHMAN
5	2013	MY PI20082673 A	AN AIR-COOLED ELECTROCHEMICAL POWER GENERATOR	UNIVERSITI KEBANGSAAN MALAYSIA	• DAUD WAN RAMLI BIN WAN • HUSAINI T • SITANGGANG RAMLI • SOPIAN KAMARUZZAMAN BIN • SAHARI JAAFAR BIN • HARON CHE HASSAN BIN CHE • MOHAMAD ABU BAKAR BIN • KHADUM ABD AMIR HASSAN • MASDAR MOHD SHAHBUDIN BIN MASTAR • ROSLI MASLI IRWAN BIN • MAJLAN EDY HERIANTO

No	Publication Year	Application Number	Title	Applicants	Inventors
6	2011	MY PI20072279 A	INNOVATIVE MEMBRANE ELECTRODE ASSEMBLY (MEA) DESIGN FOR PROTON EXCHANGE MEMBRANE FUEL CELL (PEMFC)	UNIVERSITI KEBANGSAAN MALAYSIA	• MOHAMAD ABU BAKAR BIN • DAUD WAN RAMLI BIN WAN • KHADUM ABDUL AMIR HASSAN • SITANGGANG RAMLI
7	2011	MY PI20093256 A	WATER-COOLED POLYMER ELECTROLYTE MEMBRANE FUEL CELL STACK	UNIVERSITI KEBANGSAAN MALAYSIA	• DAUD WAN RAMLI BIN WAN • HUSAINI T • SITANGGANG RAMLI • SOPIAN KAMARUZZAMAN BIN • SAHARI JA AFAR BIN • HARON CHE HASSAN BIN CHE • MOHAMAD ABU BAKAR BIN KHADUM ABD AMIR HASSAN • ROSLI MASLI IRWAN BIN • MASDAR MOHD SHAHBUDIN BIN MASTAR • MAJLAN EDY HERIANTO
8	2011	MY PI20080487 A	CU-ZN-AI CATALYST SUPPORTED ON ZEOLITE FOR HYDROGEN PRODUCTION FROM METHANOL	UNIVERSITI KEBANGSAAN MALAYSIA	• YAAKOB ZAHIRA BINTI • DAUD WAN RAMLI BIN WAN • IBRAHIM MOHD ADIB
9	2018	MY PI20072270 A	CU-ZN-AL CATALYST PROMOTED WITH VANADIUM FOR HYDROGEN PRODUCTION FROM METHANOL	UNIVERSITI KEBANGSAAN MALAYSIA	• ZAHIRA BINTI YAAKOB • WAN RAMLI BIN WAN DAUD • MOHD SABRI BIN MAHMUD
10	2014	MY PI20072030 A	CU-ZN-AL CATALYST PROMOTED WITH PALLADIUM FOR HYDROGEN PRODUCTION FROM METHANOL	UNIVERSITI KEBANGSAAN MALAYSIA	• YAAKOB ZAHIRA BINTI • DAUD WAN RAMLI BIN WAN • MINGGU LORNA BINTI JEFFERY
11	2011	MY PI20080349 A	SPEEK/BPO4 COMPOSITE MEMBRANE FOR DIRECT METHANOL FUEL CELL (DMFC)	UNIVERSITI MALAYSIA TECH	• ISMAIL AHMAD FAUZI • JAAFAR JUHANA • MUSTAFA AZEMAN • OTHMAN MOHD HAFIZ DZARFAN
12	2018	MY PI20080488 A	MO-NI-CU CATALYST ON Y-AL2O3 SUPPORT FOR HYDROGEN PRODUCTION FROM METHANOL	UNIVERSITI KEBANGSAAN MALAYSIA	• ZAHIRA BINTI YAAKOB • WAN RAMLI BIN WAN DAUD • M RUSLI YOSFIAH

Keywords used are “hydrogen production, hydrogen generation, hydrogen storage, hydrogen carrier, hydrogen vector, hydrogen supply chain, hydrogen value chain, hydrogen economy, fuel cell, proton battery, oxygen reduction reaction, hydrogen distribution and solar hydrogen”. Accessible at https://link.lens.org/qjOE4o13qgc . Retrieved on 14 August 2021.

There has been an increase in research and development activities undertaken by local universities since the last 10 years. The Malaysian fuel cell and hydrogen energy R&D community initially started in UKM and UTM, followed by increased number of researchers in UM, UiTM and UNITEN, and to date has garnered research funding of over RM 40 million from MOSTI and Ministry of Higher Education (MOHE) and over RM 11 million from the industry. Examples of research projects and achievements are subsequently summarised in the following pages.

Universiti Kebangsaan Malaysia (UKM)

UKM conducted research and development activities related to power, building, transportation, palm oil industry (utilisation of palm oil mill waste for bioenergy) from 2010 untli 2020 at Technology Readiness Level 3, 4,5,6. UKM researchers are from Fuel Cell Institute. Their research projects are funded by PETRONAS, UKM-YSD: Chair for Sustainable Development: Zero Waste Technology, Ministry of Higher Education and Sime Darby Plantation Research. The project team also collaborated with external partners such as University of New South Wales (UNSW), Sime Darby Plantation Research Sdn. Bhd. Michigan State University (USA), Feng Chia University (Taiwan). Petroliam Nasional Bhd (PETRONAS) and Universiti Kebangsaan Malaysia (UKM) has also tied up on hydrogen energy. The PETRONAS -UKM partnership involves several projects that have been implemented in stages. UKM has appointed Prof Datuk Ir Dr Wan Ramli Wan Daud from the Fuel Cell Institute as the professor of sustainable hydrogen energy. Recently, PETRONAS Research Sdn Bhd awarded a professorial chair of sustainable hydrogen energy at the UKM Institute in 2019 to the tune of RM8 million to conduct R&D in green hydrogen production technology. The electrolyser design is the parties' first intellectual property. In the same vein, a green hydrogen production testing facility has been built at PETRONAS Research Sdn Bhd (PRSB). The two parties are looking into the production of hydrogen gas from water through electrolysis technology, covering five areas – bipolar plate design, membrane electrode assembly, coating materials, construction materials and economy of scale.

Other research projects by UKM included:

1. Hydrogen storage alloys for remote area power supply
2. Pre-treatment of Oil Palm Empty Fruit Bunch for the production biohydrogen using locally isolated Enterobacter sp. KBH 6958
3. Polymeric Scaffolding of Granular Activated Carbon Immobilized Bacteria via Hot Melt Extrusion
4. Utilization of POME Biohydrogen Production

Universiti Teknologi Malaysia (UTM)

UTM conducted research activities related to Biohydrogen. Researchers in UTM are from the Agritechnology for Advanced Bioprocessing Innovation Center (ICA), UTM Pagoh; Centre of Hydrogen Enegy and Institute of Future Energy, UTMKL and UTM Skudai. Their research projects are funded by Universiti Teknologi Malaysia and Ministry of Education with a total grant of RM5 Million. The project team also collaborated with external partners such as SP MultiTech Renewable Energy Sdn Bhd (SPMRE)

Research projects included:

1. Simultaneous Production of Bioethanol and Biohydrogen From Pineapple Residue Biomass
2. Biohydrogen Purification Using Methyldiethanolamine (MDEA) and Caustic in Two Stages Absorption System
3. Hydrogen And Methane Production From Palm Oil Mill Effluent Using Two-stage Encapsulated Sludge Reactor
4. Characterisation Of Azolla Weed As Natural Substrates For Hydrogen Production By Esterobacter Cloarae Bacteria
5. Hydrogen Storage On Carbon Doped With Metal
6. Synthesis Of Nanocomposite Thin Film By Oxidize Polymer Monomer With Zeolite Catalyst And Metal Oxide For Hydrogen Gas Detection
7. Design Of Ni-plated Microreactor For Hydrogenation of CO
8. New Electrocatalyst And Mea For High Temperature Pem Electrolyzer
9. Iron-promoted Mesostructured Silica Nanoparticles For CO_2 Hydrogenation
10. Electricity Production From Soil Microbial Fuel Cell (SMFC) For Light Emitting Diode (LED) Application
11. Development of A High Temperature Aqueous CuCl/HCl And Solar PV Based Electrolyser For Hydrogen Production

Universiti Malaya (UM)

UM conducted research and development activities related to chemicals from 2016 unti 2020 at Technology Readiness Level 2 (Technology concept), 7 (System prototype demonstration in an operational environment and Analytical and experimental critical function and characteristic proof of concept, manufacturing process and recycling of catalyst) and 9 (1kW PEMFC Generator commercialized). Researchers in UM are from the Faculty of Engineering, Chemistry Department, Physics Department, UM Power Energy Development Advanced Centre (UMPEDAC), Institute of Ocean and Earth Sciences (IOES) and Nanotechnology and Catalysis research centre (NANOCAT) and Centre of Energy Sciences (CES). Their researh projects are funded under Galaxy FCT Sdn Bhd and Universiti Malaya with a total fund of RM 1.2 Million. The project team also collaborated with external partners such as Galaxy FCT and Coretronic Corp Taiwan and Eco-Energy Technology Co., Ltd. (EETEco-Energy Technology Co., Ltd.). From the commercialisation aspect, in house catalysts are used for hydrogen generation, which can serve as mobile application for hydrogen generation using a solid material.

One copyright are granted under the IP submission related to hydrogen research

WO2018143791 - Hydrogen Gas Generating System And Method With Buffer Tank

List of Research Projects included:

1. Hydrogen gas generation from solid hydrogen carrier (NaBH4) – selection and evaluation of effective catalysts for hydrolysis
2. Generation1 (G1) – hydrogen generator
3. Recycling of "spent" NaBH4 (sodium metaborate or NaBO2) back into sodium borohydride (NaBH4) using Aluminium Metal Exchange
4. Start-up study of biohydrogen production from palm oil mill effluent in a lab-scale up-flow anaerobic sludge blanket fixed-film reactor
5. Development of a solar PV integrated water electrolysis system for Oxy Hydrogen production for solid municipal waste incinerator
6. Plan development of hydrogen production through renewable energy source of wind and solar power (Singapore)

Universiti Teknologi MARA (UiTM)

UiTM conducted research and development activities related to transport sector, proton chemical fuel cells, proton ceramics fuel cell, system and stack design technology from 2009 unti 2023 at Technology Readiness Level 5, 6 and 7. Researchers in UiTM are from UiTM Shah Alam, Faculty of Applied Science, UiTM Tapah and Faculty of Civil Engineering, UiTM Arau. Their researh projects are funded under Fundamental Research Grant Scheme, Ministry of Education, Malaysia and UiTM Internal Research Grant (Dana Kecemerlangan, BESTARI and RAGS) with total fund of RM 1,540,970.00. The project team also collaborated with external partners such as Institut Sel Fuel, UKM, Institute of Future Energy UTM, G-energy Technologies and Waldania Automation. For IP submission, 2 copyrights were granted ;

1. Compositional Gradient Anode Functional Layer: A Study on Its Properties and Function for Proton Conducting Fuel Cell- CRLY00023115
2. Structural Analysis of BCZY Electrolyte and Composite Electrodes - CRLY00025100.
   List of Research Projects included:
   1. Solid-state Thermal Analysis of Air-Cooled PEM Fuel Cell Stacks with Predictive Empirical Profiling
   2. New Flow Field Configuration And Process Visualization of a Polymer Electrolyte Membrane Fuel Cell Biopolar Plate In Effective Water Flooding Management
   3. Fuel Cell Power Plant Modeling and Development for Racing Vehicles
   4. Fuel Cell Mini Vehicle Development for Shell Eco-marathon Asia 2012
   5. Multiple Reactant Inlet Configurations In PEM Fuel Cell Flow Field Pressure Control
   6. Numerical Modeling and Characterization of Dynamic Responses for a Hydrogen Fuel Cell System In Vehicles
   7. Air Flow Properties Investigation Through New Plenum of Open Cathode PEM Fuel Cell
   8. Characterization of Thermofluids and Electrochemical Behaviour of Nanofluid Coolants in a Closed Cathode PEM Fuel Cell Stack
   9. Application of Nanofluid as Cooling Medium in a Proton Exchange Membrane Fuel Cell System for Vehicles
   10. Energy Balance Model of An Electric Hydrogen Propulsion System with Energy Regeneration
   11. Effects of Energy Recovery Methods to the Efficiency of A Hydrogen Propulsion System
   12. Adopting Nanofluids as Potential Coolant for Liquid Cooled PEM Fuel Cell
   13. Correlations of Performance Parameters For Al2O3 and SiO2 Nanofluid Coolants In PEM Fuel Cell System
   14. Thermal Management Improvement for a Liquid Cooled PEM Fuel Cell Through The Adoption of Nanofluids as an Alternative Cooling Medium
   15. Heat Removal Characterization of Hybrid AL2O3-SIO2 Nanoparticles In ‘Green’ Bioglycol Subjected to an Active Electrical Field
   16. Integrated Energy Recovery System For Fuel Cell Vehicle Power Enhancement
   17. Synthesis, local electrical properties and thermal expansion of Ba(Ce,Zr)O3 electrolyte as proton conductor for an intermediate temperature solid oxide fuel cell
   18. Enhancement of Power Generation of Proton Conducting Button Cell Through Cathode Modification
   19. Fabrication of NiO-Ba(Ce,Zr)O3 Anode-supported Button Cell for High Power Proton Conducting Fuel Cell

Universiti Malaysia Pahang (UMP)

UMP conducted research and development activities related to industry, energy and power sectors from 2013 until 2021 at Technology Readiness Levels 3,4, 6 and 8. Researchers in UMP are from the Faculty of Civil Engineering Technology, Faculty of Industrial Sciences and Technology, and Faculty of Chemical and Process Engineering Technology. Their research projects are funded under Fundamental Research Grant Scheme, Ministry of Education, Japan Science and Technology Agency (JST-CREST), The Ministry of Education, Culture, Sports, Science and Technology (MEXT). New Energy and Industrial Technology Development Organization (NEDO), Japan and Academy of Finland grant with total grants of RM15.883Million.

The project team also collaborated with external partners such as Universiti Teknologi Malaysia, Tokyo Institute of Technology and University of Oulu, Finland. There are patents submission of core technology of electrodes and membrane electrode assembly for solid alkaline fuel cells (SAFC) and Materials and Cells for Alkaline Water Electrolysis. Meanwhile, carbon-free platinum alloy inter-connected nanoparticle catalyst and polyphenylene pore filling electrolyte membrane are at commercialisation phase for residential and automobile applications.

Research projects included:

1. Fundamental study of immobilized-cell reactor technology for enhanced sustainable bio-energy and treatment efficiency of palm oil mill effluent
2. Development of core technology of electrodes and membrane electrode assembly for solid alkaline fuel cells (SAFC) with liquid fuels
3. Design and Development of Materials and Cells for Alkaline Water Electrolysis – Water Electrolyser
4. Development of carbon-free platinum alloy inter-connected nanoparticle catalyst and polyphenylene pore filling electrolyte membrane and its deployment to high-voltage, high-power MEA for H2-O2 fuel Cells
5. Ab initio study of hydrogen sensing in Pd and Pt functionalized GaN [0 0 0 1] nanowires

Universiti Sains Malaysia (USM)

USM conducted research and development activities related to environment and biohydrogen from 2012 until 2015 at Technology Readiness Level 6. Researchers in USM are from the School of Chemical Engineering. Their research projects are funded under Long Term Research Grant Project (LRGS), Ministry of Higher Education (MOHE) with total grants of RM100,000.

Research project included:

1. Carbon dioxide sequestration by cyanobacteria for biofuel production (by product is biohydrogen)

Universiti Putra Malaysia (UPM)

UPM conducted research and development activities related to energy (full water splitting on semiconductor nanocrystals into hydrogen), biofuel (biomass-derived hydrogen) from 2011 until 2021 at Technology Readiness Level 3. Researchers in UPM are from Catalysis Science and Research Centre (PutraCAT), Faculty of Science and Department of Chemical and Environmental Engineering.

Their research projects are funded under Fundamental Research Grant Scheme (FRGS), Ministry of Higher Education (MOHE), GP-IPS - Geran Putra Inisiatif Siswazah, Ministry of Higher Education, Exploratory Research Grants Scheme (ERGS) with total grants of RM100,000.

Research projects included:

1. All-in-one visible-light-driven water splitting by combining nanoparticulate and molecular co-catalysts on AgS nanorods (WATER2FIRE)
2. Catalytic Biomass Gasification for Hydrogen Production.
3. Hydrogen Production by Catalytic Gasification of Empty Fruit Bunch using Zeolite Supported Bimetallic Catalys
4. Catalytic Empty Palm Fruit Bunch (EPFB) Gasification Over Mixed Metal Oxide Catalysts for Hydrogen Production
5. Hydrogen Production Via Catalytic Reforming of Biogas: Novel Catalyst Development and Reaction Optimizatio
6. Hydrogen Production Via Low Cost Ni-Based Catalyst for Dry Reforming of Methane with Carbon Dioxide
7. Syngas Production Via CO2 Reforming of Methane Using Nanocatalysts

2.5 Technical Code for Hydrogen Fuel Cell

The International Standards Organisation (ISO) has published 18 and developing 17 standards specifically dealing with hydrogen under ISO/TC 197: Hydrogen Technologies. These standards are aimed at providing standardisation in the field of systems and devices for the production, storage, transport, measurement, and use of hydrogen. Malaysia is neither a Participating nor Observing members of ISO/TC 197. Nevertheless, it is worthwhile to note that, Hydrogen Safety Sub-Working Group under the Green Information and Communications Technology, Environment and Climate Change Working Group of the Malaysian Technical Standards Forum Bhd. (MTSFB) has developed three technical code that serves as guidance to facilitate telecommunication industries and any related industries who install the fuel cells module on-site as a power backup or auxiliary power unit as well as carry out decarbonisation exercises for their infrastructures system through the utilisation of hydrogen or hydrogen-rich fuel. Technical Code (TC) is a voluntary industry code that sets out the requirements and best practices to ensure network facilities, services and equipment are interoperable and safe. The three TC registered by Malaysian Communications & Multimedia Commission (MCMC) are as follows:

1. **MCMC MTSFB TC 2010R0** - Deployment of Stationary Fuel Cell as a Backup Power Solution for the Telecommunication Sites.
2. **MCMC MTSFB TC G023:2020** - Hydrogen Storage and Safety with Fuel Cell as Power Generator for Information, Communications and Technology Infrastructure
3. **MCMC MTSFB TC 2101R0** - Requirements and Safety Aspect for Fuel Cell System.

MCMC being the regulatory body provides Certificate of Approval (COA) indicating that a communications device is certified for compliance to standards according to the Communications and Multimedia (Technical Standards) Regulations 2000. The first two Hydrogen Technical Code (MTSFB TC 2010R0 and MTSFB TC G023:2020) is to assist the telecommunication and ICT industries that carry out their decarbonisation exercises by utilising hydrogen-powered fuel cells that act as backup power supplies to ICT infrastructure which include base stations, data centres, satellite base stations and Internet of Things (IoT) network infrastructure. This has attracted DIGI to pilot its hydrogen-powered base stations near Rompin, Pahang to reduce its base stations' dependency on diesel generators as sources of power. Following to the positive acceptance of the technical code by Communications and Multimedia industry in Malaysia, MTSFB has developed technical code to facilitate other industries in adopting fuel cells for power generation (MTSFB TC 2101R0).

2.6 Cross-Cutting Challenges of Hydrogen Economy and Technology in Malaysia

From the Focus Group Discussions (FGDs) and Strategic Engagements with relevant ministries, academia, researchers, industries, and associations, the issues and challenges on developing Hydrogen Economy that were raised revolve around the main issues that were also discussed regarding Science, Technology and Innovation (STI) of the country. Among others, governance to coordinate hydrogen economy initiatives, obstacles of renewable sources, financial intervention for technology adoption and commercialisation, legislation, and awareness by end-users. Overall, the main issues and challenges that need to be addressed on Hydrogen Economy towards charting the country's path to becoming net zero carbon nation by 2050 are listed across the hydrogen economy value chain interlinked with the elements in the ecosystem as shown in Table 12.

Table 12: Cross-Cutting Challenges of Hydrogen Economy and Technology in Malaysia

	Industry	Research & Development	Legislation
Feedstock	• Unsustainable renewable feedstock source for hydrogen production as industries are already utilizing the feedstock for other applications • Challenges in standardizing feedstock price. • Present policies are unclear with regards to renewable source utilisation for hydrogen production. • Most RE plants is for commercial production purpose and due to the Power Purchase Agreement (PPA) certain amount is committed to be supplied to grid every year. • The challenge for Large Scale Solar (LSS) is the land clearance, because certain area required for solar installation is a reserved forest that serve purpose as carbon sink.	Limited research on CCUS for blue hydrogen, as research are focused on green hydrogen from renewable sources	Malaysia is not a member of ISO/TC 197 – Hydrogen Technologies, resulting in low adoption among industries in the renewables sector
Production/ Generation	• Standalone technologies are not sufficient for green hydrogen production, due to limitations in renewable sources. • Cost of production is still expensive (large CAPEX and OPEX). For green hydrogen, 70% of the cost relies on power cost (Hydro power tariff is expensive)	Research that is not market-driven after reaching a certain TRL level due to feasibility issues at industrial scale	• No hydrogen-specific policies or standardized legal framework for hydrogen development in Malaysia. • Incoherent enforcement on carbon legislations (e.g.: carbon credits and carbon emission tax)
Conversion and Storage	• High investment for technology adoption into the existing process for conversion. • Storage in gaseous form is a hurdle due to light gas molecules properties & high capital investment for the high-pressure hydrogen	Research and funding is limited on hydrogen storage as most funding goes to hydrogen production and end-use application using fuel cell technology.	Inconsistent standards and regulations among players in the same cluster, as it was customised based on project requirement
Transport	• Decentralisation to maximize existing infrastructure for domestic-use versus high investment to develop technologies for logistics supply chain. • High cost and energy intensive process for transportation in liquid or gaseous form to cater to end-user demand. • Global trade route for hydrogen is still under development which requires global collaboration amongst G2G and industry players		
Re-conversion	Technology that is yet to mature and losses during re-conversion		
End-use	• Readiness of infrastructure for adoption by end-use sectors. • Lack of vibrant incentives and subsidies • Poor G2G and B2B partnership between producer and end-user • Utilisation of hydrogen for power generation has limited application (e.g.: co-combustion or in micro-grid)	Incomplete hydrogen ecosystem causes challenges for end-use technology to be commercialized.	Malaysia is not a member of ISO/TC 197 – Hydrogen Technologies, and does not have visibility on current trends on standards related to hydrogen technologies.


HYDROGEN

CHAPTER 3

HETR ROADMAP DEVELOPMENT

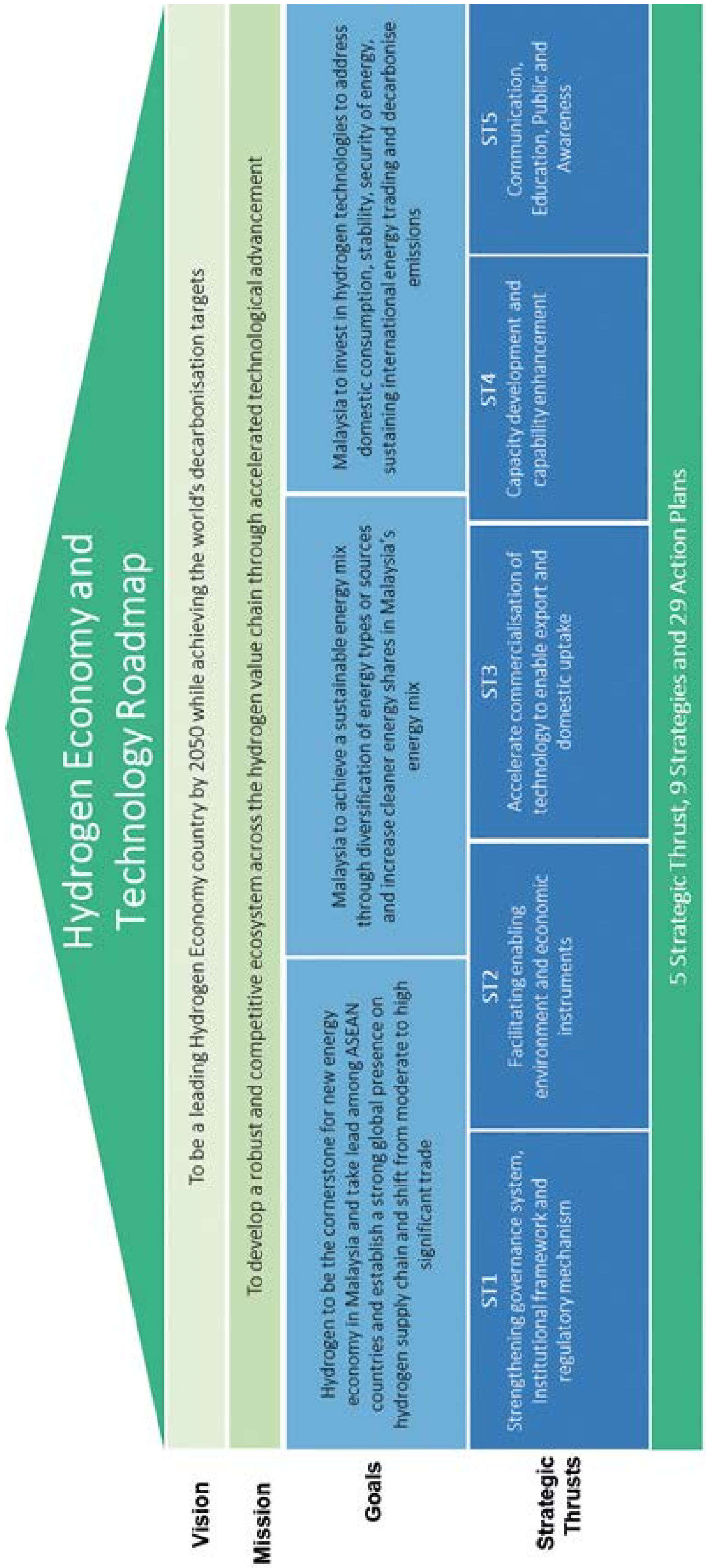


Figure 11: Framework of the Hydrogen Economy and Technology Roadmap 2022 - 2050

3.1 Background of the Roadmap

Hydrogen Economy and Technology Roadmap (HETR) is a living document for a long-term strategy, designed to drive the decarbonisation agenda of the country towards net zero carbon emissions and generate economic growth and opportunities. It is aligned with the aspirations set in Twelfth Malaysia Plan 2021-2025, National Renewable Energy Policy and Action Plan, Malaysia Renewable Energy Roadmap 2022 – 2035 (MyRER) and as a supporting document to the National Energy Policy 2022 – 2040, to achieve the aspiration for sustainable energy mix through diversification of energy types or sources and growth of RE industry in meeting the national energy security.

The decarbonisation of our industrial and electricity sectors requires the timely development of existing infrastructure for hydrogen adoption in parallel with the development of home-grown technology. To fulfil this aspiration, a dynamic hydrogen ecosystem needs to be established to bring forward the hydrogen technologies that is currently at nascent stage to maturity and create competitive supply chain. This is to ensure all segments of the governance, research institutes, universities and industries can benefit from it and explore their potential in the Hydrogen Economy.

3.2 Vision

To be a leading Hydrogen Economy country by 2050 while achieving the world's decarbonisation targets.

3.3 Mission

To develop a robust and competitive ecosystem across the hydrogen value chain through accelerated technological advancement.

3.4 Goals

a. Hydrogen to be the cornerstone for new energy economy in Malaysia and take lead among ASEAN countries and establish a strong global presence on hydrogen supply chain and shift from moderate to high significant trade;
b. Malaysia to achieve a sustainable energy mix through diversification of energy types or sources and increase cleaner energy shares in Malaysia's energy mix;
c. Malaysia to invest in hydrogen technologies to address domestic consumption, stability, security of energy, sustaining international energy trading and decarbonise emissions.

3.5 Hydrogen Economy Techno-Economic Modelling

3.5.1 The Hydrogen Supply Value Chain – Superstructure Model

Most of the hydrogen used globally is produced from unabated fossil fuels, but reduction in the cost of renewable power generation and developments in carbon capture and storage are lowering the cost of low-carbon hydrogen. A Hydrogen Supply Value Chain - Superstructure Model that fits to Malaysia's energy supply and demand sectors have been developed which depicts the relationship between energy sources and technology across the production to end-use for both domestic and export pathway.

Technologies that have been considered in this superstructure model is the current and emerging technologies for mass market deployment. Based on the maturity of these technologies, there are potential for further cost reduction throughout the learning curves. The hydrogen superstructure model shown in Figure 12, shows the production technology for different type of hydrogen production using energy sources from fossil fuels in natural gas form and renewables that serves purpose in reducing the total cost of the hydrogen system while meeting the hydrogen demand set in the model.

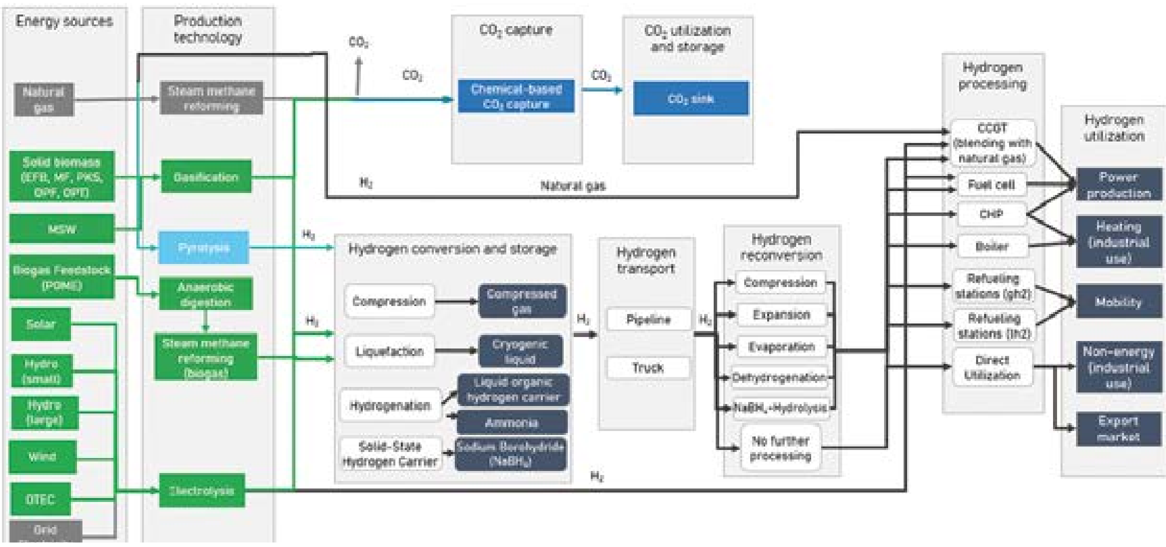


Figure 12: Hydrogen Supply Value Chain Superstructure Model

Through this model, the total system cost will be looking at the sum of production, delivery, and end-use technology cost for each sector application such as resource cost, energy production cost, hydrogen production cost, hydrogen transport cost, hydrogen storage cost, hydrogen conversion or re-conversion cost, and hydrogen utilisation cost.

3.5.2 Technology Across the Hydrogen Economy Value Chain

The technologies that are covered in the model focuses on different types of hydrogen, where green hydrogen forms the majority. In terms of hydrogen delivery, several processes were grouped together such as densification, storage, transport, and reconversion. The technology involved across the hydrogen economy value chain are grouped according to the hydrogen end-use consisting of power, heat, non-energy, and mobility. Considering on the improvements on efficiency and cost of producing hydrogen in the long term, the technologies were grouped following to the least cost optimisation model. Figure 13 presents the pathway of technology that has been taken into the techno-economic modelling for blue hydrogen (considered as low carbon hydrogen), and green hydrogen production all the way to end-use.

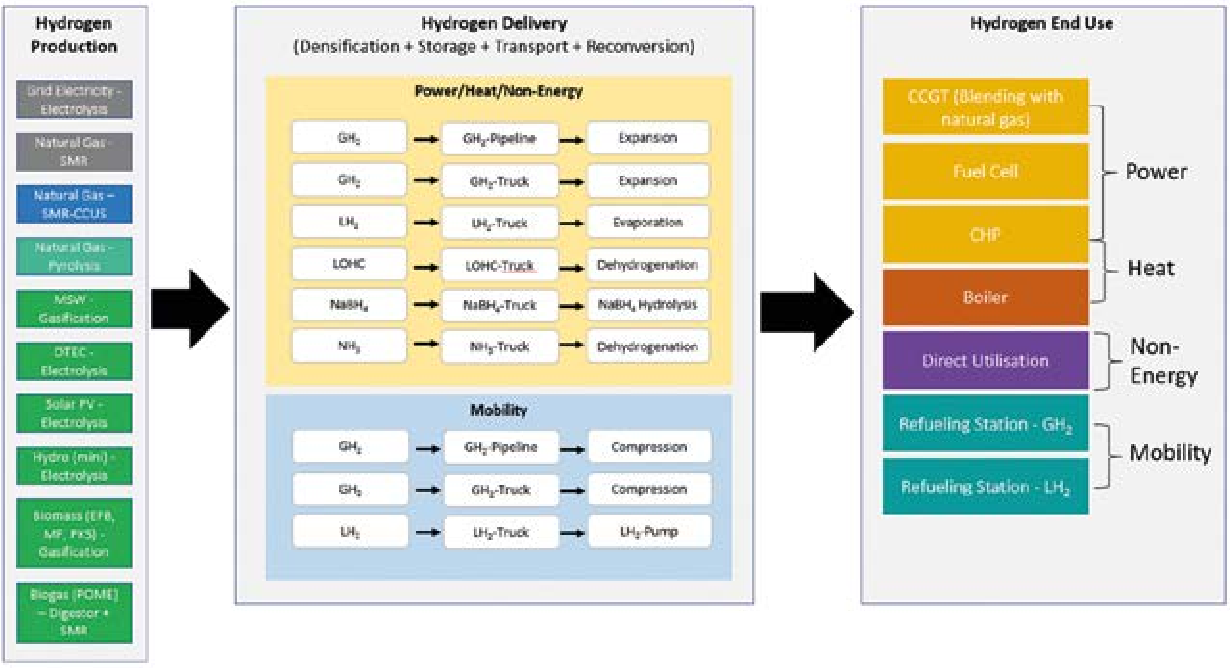


Figure 13: Technology across hydrogen economy value chain

3.5.2.1 Hydrogen Production

3.5.2.1.1 Grey Hydrogen

Natural Gas – Steam Methane Reforming (NG-SMR)

Grey hydrogen has been in the production for past many years. Production of grey hydrogen are sourced from fossil fuel source, whereby in this techno-economic modelling natural gas are the chosen feedstock following the utilisation of coal for power generation that is to be phased-out by 2030 to reduce carbon emission. According to the U.S. Energy Information Administration, natural gas emits almost 50 % less CO_2 than coal.

Steam-methane reforming (SMR) is a mature production process in which high-temperature steam (700 °C – 1,000 °C) is used to produce hydrogen from a methane source in natural gas. In SMR, methane reacts with steam under 3 – 25 bar pressure (1 bar = 14.5 psi) in the presence of a catalyst to produce hydrogen, carbon monoxide, and a relatively small amount of carbon dioxide. Further reaction of carbon monoxide with steam (water-gas shift) over a catalyst produces additional hydrogen and carbon dioxide, and after purification, high-purity hydrogen is recovered.

Its advantage arises from the high efficiency of its operation and the low operational and production costs. The energy efficiency of the steam reforming process is about 65 % to 75 %, among the highest of current commercially available production methods. The cost of hydrogen produced by SMR is acutely dependant on natural gas prices and is currently the least expensive among all bulk hydrogen production technologies.

The downside from this technology is, CO_2 is not being captured and released into the atmosphere. Besides that, steam reforming is an energy intensive process due to its endothermic properties—that is, heat must be supplied to the process for the reaction to proceed. The existing process can be innovated through durable reforming catalysts, development of advanced reforming and shift technologies.

3.5.2.1.2 Blue Hydrogen

Natural Gas – SMR – CCUS

In addressing the emission of CO_2 from NG-SMR process as shown in Figure 14, the combination of Carbon Capture, Utilisation and Storage (CCUS) has potential to limit the amount of CO_2 release to the atmosphere. CCUS is a technology that can capture and make effective use of the high concentrations of CO_2 emitted by industrial activities. Consequently, it has a key role to play in decarbonisation and addressing the challenge of global climate change. Through this NG-SMR-CCUS process the production of 1 kg hydrogen emits approximately 10 kg CO_2. In the production of blue hydrogen in Malaysia, there are 2 challenges for CO_2 capture and sequestration, as follows:

a. CCS for natural gas production from reservoirs with high CO_2 contents. CO_2 is processed, captured, and sequestered offshore.
b. CCS for hydrogen production from SMR process, which emits CO_2. Since SMR is being done onshore, CO_2 needs to be captured onshore and transported offshore where the CO_2 is stored in empty reservoirs.

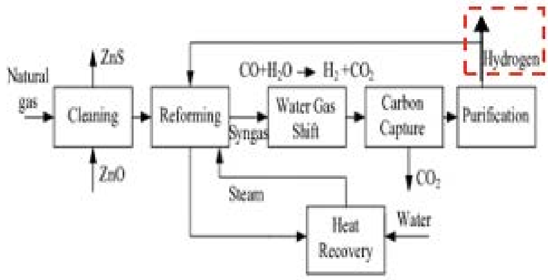


Figure 14: Hydrogen production from NG-SMR-CCUS

Although SMR is highly energy-efficient (75 %), the production of high CO_2 emissions forces the separation and sequestration of CO_2 via a Carbon Capture and Storage (CCS) process. The greenhouse gas emissions are decreased using CCS systems, but the net energy efficiency drops to 60 %. Nevertheless, onshore capture-offshore storage is ~70 % more expensive than offshore capture-offshore storage. There are two points of CO_2 emissions in producing hydrogen from natural gas, which is during the production and processing of the natural gas during the SMR process. Thus, CO_2 needs to be captured twice, which may pose technical and commercial challenges. CCUS delivers 38 % of the CO_2 emissions reductions needed in the chemical subsector and 15% in both cement and iron and steel *(Source: IEA at COP26, 2019)*. There are many other CO_2 capture technology available such as membrane, absorption and others,which would make CO_2 capture effective (<1kg CO_2/kg hydrogen), subject to application.

3.5.2.1.3 Turquoise Hydrogen

Natural Gas-Pyrolysis

Production of hydrogen from natural gas pyrolysis has thus gained interest in research and energy technology in the near past. Pyrolysis of natural gas is a well-known technical process applied for production of carbon black. In the future it might contribute to carbon dioxide-free hydrogen production. Methane pyrolysis has an energy efficiency of 58%, which is comparable to SMR when the separation of CO_2 is considered.

Natural gas has an energy potential coming partly from its carbon atom and partly from its four hydrogen atoms. The minimum energy required, 38 kJ/mol H_2, is much less than for water splitting via electrolysis, 285 kJ/mol H_2 or steam methane reforming, 252 kJ/mol H_2.

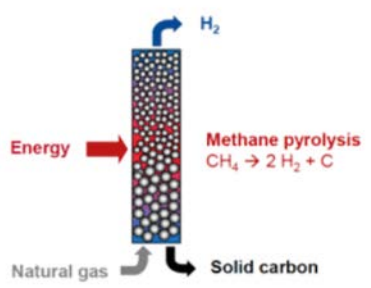


Figure 15: Methane pyrolysis for hydrogen and solid carbon production

Monolith Process uses plasma furnace/reactor for thermal decomposition of methane contained in natural gas. Monolith's plasma pyrolysis technology transforms natural gas into emissions-free "turquoise hydrogen" and production of high-purity carbon black. Nevertheless, the application of methane pyrolysis is limited by the requirement of a solid catalyst, which rapidly deactivates. Additionally, although the carbon product is marketable, there is absence of established markets for the large carbon by-product quantities. The development of new markets and applications for the produced carbon may improve the economics of this process.

3.5.2.1.4 Green Hydrogen

MSW – Gasification

Municipal solid waste (MSW) is one of the significant issues in any modern society due to urbanisation and industrialisation. Waste-to-energy plants based on gasification utilise municipal solid waste as their fuel rather than conventional sources of energy like coal, oil, or natural gas. Thermal gasification of municipal solid waste (MSW) generates a gaseous, fuel-rich product that can be combusted in a boiler, producing steam for power generation. This technology produces a gas with a low heating value (4–6 MJ/m^3) and an 8–14 vol% H_2 content only.

The drawbacks in the properties of raw MSW present substantial challenges for the gasification process, so generally a separation is needed, including mechanical homogenisation and the separation of glass, metals, and inert materials before the treatment of residual waste. The municipal solid waste steam gasification for hydrogen production is still under research stage in addressing energy efficiency of the process for a large-scale production.

Biomass (EFB, PKS, MF) – Gasification

Biomass gasification is a mature technology pathway that uses a controlled process involving heat, steam, and oxygen to convert biomass at high temperatures (>700°C) to hydrogen and other products, without combustion. Biomass to hydrogen efficiencies (LHV based) of up to 69% are achieved from gasification. Oil palm biomass gasification has gained lots of interests due to its high conversion efficiency and surplus availability from the oil plantation sites. Regardless of tremendous experimental studies done on effectiveness of using oil palm waste for production of hydrogen, the process implementation in industry is still discouraging due to lack of proven technology at demonstration scale and high capital cost of investment.

OTEC – Electrolysis

Ocean Thermal Energy Conversion (OTEC) is a technology that converts thermal energy into electricity. OTEC is a process or technology for producing energy by harnessing the temperature differences (thermal gradients) of (20°C or greater) between ocean surface waters and deep ocean waters. Tropical and sub-tropical regions where the water temperature at the ocean surface is relatively high are best suited for its use. Despite its benefit in creating electricity without the discharge of greenhouse gases, the low efficiency of these plants coupled with high capital cost and maintenance cost makes them uneconomical to supply electricity for small plants. Hybrid OTEC systems consisting of energy and water production are currently under research and validation.

Solar PV – Electrolysis (PEM)

Electrolysis is a promising option for carbon-free hydrogen production from renewable and nuclear resources. Electrolysis is the process of using electricity to split water into hydrogen and oxygen. Hydrogen production via electrolysis from renewable (solar) using Polymer Electrolyte Membrane (PEM) electrolyser that has an electrical efficiency of about 80% in working application, in terms of hydrogen produced per unit of electricity used to drive the reaction. PEM electrolysis is the electrolysis of water in a cell equipped with a Solid Polymer Electrolyte (SPE) that is responsible for the conduction of protons, separation of product gases, and electrical insulation of the electrodes. The efficiency of PEM electrolysis is expected to reach 82-86 % before the year 2030, while maintaining durability as progress in this area continues at a pace.

Hydropower (mini and excess) – Electrolysis (AWE)

Alkaline Water Electrolysis (AWE) is a mature and safe technology and is currently used in many industrial applications and currently locally used by Sarawak Energy for its First Integrated Hydrogen Production Plant under the ownership and management of Sarawak Economic Development Corporation (SEDC). Commercial alkaline electrolyser systems have efficiencies in the range of 43–69%. A 100 % efficient electrolyser requires 39 kWh of electricity to produce 1 kg of hydrogen. In that case, presently a typical electrolyser operation needs no less than 55 kWh/kg of hydrogen. Industrial AWE electrolysers have the capacity to produce 650 m^3 of hydrogen per hour. In alkaline electrolysis, a reaction occurs between two electrodes in a solution composed of water and liquid electrolyte. The key performance parameters of AWE are provided in the Appendix.

Biogas (POME) – Digestor + SMR

The uses of POME as feedstock of biogas production have attracted many industries to produce energy because the abundance of POME that is not fully utilised. Methane from biogas production has shown to have a significant potential to replace the depleting sources as it can be produced from renewable feed stocks. To build a hydrogen production plant from POME, the location of the plant to be built also is an important matter where the consideration of the raw materials availability, space and utilities availability, local community, climate, political consideration, and transportation facilities. The operational process of hydrogen production from POME are presented in Appendix, however further validation at commercialisation scale is required.

3.5.2.2 Hydrogen Delivery

(a) Power/Heat/Non-Energy

i. GH2/GH2-Pipeline/GH2-Truck-Expansion

Gaseous hydrogen is most delivered either by trucks or through pipelines. Because gaseous hydrogen is typically produced at relatively low pressures (20–30 bar), it must be compressed prior to transport. Trucks that haul gaseous hydrogen are called tube trailers. Gaseous hydrogen is compressed to pressures of 180 bar (~2,600 psig) or higher into long cylinders which are stacked on the trailer that the truck hauls. Gaseous hydrogen can also be transported through pipelines much the way natural gas is today. This is common for long distance and high-volume transport. Most existing hydrogen pipelines are installed at oil refiners as hydrogen is used in the petroleum upgrading process

ii. Liquid Hydrogen LH2/LH2-Truck-Evaporation

Hydrogen is commonly transported and delivered as a liquid when high-volume transport is needed in the absence of pipelines. To liquefy hydrogen, it must be cooled to cryogenic temperatures through a liquefaction Trucks transporting liquid hydrogen are referred to as liquid tankers. Gaseous hydrogen is liquefied by cooling it to below −253°C (−423°F). Once hydrogen is liquefied it can be stored at the liquefaction plant in large, insulated tanks. It takes energy to liquefy hydrogen—using today's technology, liquefaction consumes more than 30% of the energy content of the hydrogen and is expensive. Evaporation process is used to generate gas from liquid H_2 at a given pressure, composed of a series of finned heat exchangers that can be heated indirectly by air, water, or steam process.

iii. Liquid Organic Hydrogen Carriers LOHC-LOHC-Truck-Dehydrogenation

Hydrogen carriers store hydrogen in some other chemical state rather than as free hydrogen molecules. Additional research and analyses are underway to investigate novel liquid or solid hydrogen carriers for use in delivery. Carriers are a unique way to deliver hydrogen by hydrating a chemical compound at the site of production and followed by dehydration either at the point of delivery or once it is on-board the fuel cell vehicle. This method of hydrogen delivery is still in the early stages of research and development, and yet to prove its energy or cost efficiency.

Potential carriers include metal hydrides, carbon or other nanostructures, and reversible hydrocarbons (e.g., Methylcyclohexane,MCH) or other liquids, among others in the early stages of research. Utilisation of such novel carriers would be a technological transformation shift from the way transportation fuels are delivered today.

iv. Sodium Borohydride NaBH4-NaBH4-Truck-NaBH4-Hydrolysis

Solid Hydrogen Carriers, also known as SHCs, metal hydrides are a commercially viable alternative to compressed or liquid hydrogen if the aim is to safely store gas of the highest purity (7.0), at low pressures (2 bars to 40 bars), in a small space (up to 0.15 kgH_2/dm^3; compared to 0.04 kgH_2/dm^3 for hydrogen below 700 bars) and without boil-off losses. In the event of a leak, the gas will not be released into the atmosphere all at once but in small amounts over time. SHCs take up hydrogen by forming a chemical bond with solid-state carrier material transportation fuels are delivered today. Sodium borohydride (NaBH4) is an attractive hydrogen carrier owing to its reactivity with water and at a reaction temperature was 108 °C, the average hydrogen production rate was 1.72 L/min with conversion efficiency of 91.2% (Catalyst, 2020). From the engagement with one of the local players, Galaxy FCT that is developing NaBH4 (Galaxy FCT) it was recommended for Solid Hydrogen Carriers (SHCs) to be utilised for decentralised hydrogen system - able to provide clean energy to areas and applications which are not adequately served by the clean electricity grid, by providing the ability to store, move and distribute clean energy safely and easily. As the release temperature of hydrogen from NaBH4 is close to fuel cell temperature, further study on the feasibility/ total system efficiency of using NaBH4 for PEM fuel cell need to be investigated.

(b) Mobility

v. GH2/GH2-Pipeline/GH2-Truck/ Compression

The application of hydrogen for mobility is in the form of compressed hydrogen. As such the compression operations for hydrogen in gas form can be differentiated based on capacity and pressurisation needs. For pipeline transport, high flow rate (thousands of kg/hr) and relatively low pressures (<10 MPa) and compression ratios (10:1) are required. Loading operations at terminals generally have intermediate needs. High flow rate reciprocating piston compressors are typically employed for pipeline transport and terminal pressure vessel loading operations and high-pressure diaphragm compressors are used at hydrogen fuelling stations (although small reciprocating and intensifier compressors are also used).

The opposite is true at fuelling stations, where compressor flow rates may be 5–100 kg/hr and compression pressures as high as 100 MPa (1,000 bar). Ionic liquid compressors are beginning to be commercialised for use in low-to-moderate flow rate and high-pressure gas compression operations. Ionic technology is used to compress gaseous H_2 to up to 100 MPa and the cryopump efficiently supplies hydrogen in liquid form ready for refuelling. This technology has been commercialised by Linde for hydrogen refuelling station in Sarawak.

vi. LH2/LH2-Truck/LH2-Pump

It is critical that liquid hydrogen pumps are hermetically sealed and leak only very small trace amounts hydrogen to the outside environment. Liquid hydrogen (LH2) temperatures are typically close to 20 K; hence it is critical that heat input is minimised. On that note, liquid hydrogen is typically pressurised with specially designed centrifugal pumps. Liquid hydrogen piston pumps are used for refuelling H_2 and CcH2 vehicles and trains at hydrogen refuelling stations. They are also used for the filling of hydrogen tube trailers and containers, as well as hydrogen injection into pipelines, gas turbines and dual ICE. Linde's high-performance cryogenic piston pump sets new standards for hydrogen fuelling stations. The extremely efficient process takes full advantage of the direct compression of liquid hydrogen and thus reduces energy consumption to a minimum.

3.5.2.3 Hydrogen End Use

(a) Power

A combined-cycle power plant uses both a gas and a steam turbine together to produce up to 50% more electricity from the same fuel than a traditional simple-cycle plant. The technology is typically powered using natural gas, but it can also be fuelled using coal, biomass, and even solar power as part of solar combined cycle plants. Mitsubishi Hitachi Power Systems (MHPS) has targeted for conversion of a unit at the Magnum gas-fired combined cycle power plant in the Netherlands to run 100% on hydrogen by 2023. The project is designed to lower the plant's carbon emissions and test the feasibility of hydrogen as a fuel source for a combined cycle gas turbine. For a start, operating a gas turbine on a hydrogen/natural gas blend instead of 100% hydrogen reduces the hydrogen flows and amount of feedstock required to generate the hydrogen.

Combined Heat and Power (CHP) plants is a decentralised, energy-efficient method of heat and electricity production. There are CHPs that run on biofuels such as oil, wood, and methane but there are also a few that run on a mixture of gas and hydrogen and, in other countries, some that run on pure hydrogen.

Hydrogen fuel cells produce electricity by combining hydrogen and oxygen atoms. The hydrogen reacts with oxygen across an electrochemical cell like that of a battery to produce electricity, water, and small amounts of heat. Many different types of fuel cells are available for a wide range of applications for distributed power generation. These fuel cells use natural gas, biogas, or hydrogen as the primary feedstock into the generator.

(b) Heat

Future hydrogen demand may come from the heat and power sector. For heat generation, hydrogen will be used through Combined Heat and Power (CHP) and boiler. As hydrogen is a carbon-free energy carrier and combustion of hydrogen produces no CO_2 at the point of use, the blending of hydrogen with ammonia or natural gas sees 20% of the fuel source powering the appliance being hydrogen gas, with the remaining 80% being natural gas.

Technical studies from Blending Hydrogen into Natural Gas Pipeline Networks: A Review of Key Issues (National Renewable Energy Laboratory, NREL) imply that a range of 3 - 20% of hydrogen blending in natural gas pipeline is possible and is largely determined by the existing condition of the pipelines. Heat and power are the two big consumers of hydrogen. For specific industries that require medium to high grade heating (e.g., paper, aluminium) where electrification may not be efficient, hydrogen can serve as an alternative energy.

(c) Non-energy

Ever since past decades and many years back, hydrogen is used in many industries, from chemical and refining to metallurgical, glass and electronics. It is used in synthesis of ammonia and the manufacture of nitrogenous fertilisers. In advanced countries, clean hydrogen is expected to first be used as industrial feedstock in the existing industries (e.g., steel, ammonia, methanol, refining) as a replacement to the grey hydrogen.

Since these industries are already using hydrogen as feedstock, as a means for decarbonisation, Malaysia may also target the same industries domestically that are already using grey hydrogen as feedstock first before exploring the use of clean hydrogen in mobility which would require new technology, infrastructure, and large investments.

(d) Mobility

Under mobility, hydrogen will be used as fuel for land, ammonia as fuel for marine and e-fuels for aviation transport. Marine transportation may pose a great potential following many consortia of industry players that are exploring the feasibility of such supply chain, anchored on regulations by the International Maritime Organization (IMO) to reduce GHG emission by 50 % by 2050. Hence, having ammonia or hydrogen fuelled engines for vessels and ships, and supporting facilities for bunkering is an attractive segment for Malaysia.

This can be followed by aviation with a longer time horizon. These two segments (marine and aviation) relatively do not require a massive country-wide infrastructure overhaul. Investment in technology development by industry players in these two sectors would determine the future market competitiveness to adopt hydrogen into mobility.

3.5.3 Basis and Assumptions for the Techno-Economic Model

For the HETR scenario projection, the time horizon chosen was from the year 2022 to 2050, given Malaysia's commitment to be a net zero nation by the year 2050. Hydrogen technology though not relatively new is still currently limited in terms of implementation and scale except for the current production and use cases of emission intensive hydrogen by the oil and gas industry. The potential for improvement and scale-up however is massive as many technological innovations and advancements are yet to mature and many are at lower Technology Readiness Levels (TRL). Most of the exhibits and scenario projections that are produced by the techno-economic model depict the results for the year 2025 onwards as the year 2022 to 2024 are the significant years to build capability and capacity for a smaller scale production and pilot end-use projects. Most of the new domestic demand for hydrogen will also start from the year 2025 onwards.

This scenario projection was built based on Malaysia's national energy balance (end-use demand and primary energy supply), national GDP and population growth projection, and availability of resources. The population growth rate is estimated to decrease in a time step, (from 1.8% in 2010 to 0.8% in 2040) based on the projection by the Department of Statistics, Malaysia (DOSM). For GDP growth rate, it was projected based on historical data with reference from the annual growth rate from Economic Research Institute for ASEAN and East Asia (ERIA). The GDP Annual Growth rate is projected at 3.57% in 2021-2025 and slow growth is anticipated in the long term (2035-2050) within the range of 2.59%. Gross Domestic Product value per Capita for Malaysia could reach 3,398,223 (RM Million at 2015 prices by 2050. For the end-use demand and primary energy supply, the values are referred to Energy Commission's latest publications on the National Energy Balance and Malaysia Energy Statistics Handbook. Energy sources for different routes of hydrogen production are considered from various resources such as fossil fuel (natural gas) and renewables (solar, wind, hydro, biomass, biogas, OTEC).

The availability of resources and the current stock or reserves are also considered and has excluded the commitment for other sectors such as agriculture, commercial and residential. The HETR model covers the cost for hydrogen production, transportation and delivery and end-use processing for different pathways. Efficiency and percentage conversion values were also considered in the model.

Figure 16 shows the hydrogen supply chain and end-to-end pathway from hydrogen production, delivery to end-use that will be used for the scenario projection. Figure 17 shows the hydrogen supply chain in the form of modules that will be used in the modelling system to project the Levelised Cost of Hydrogen (LCOH), delivery cost of hydrogen (LCOH + delivery cost), and the Levelised Cost of Energy (LCOE) (LCOH + delivery cost + end-use system cost) for each end-use technology in its associated sectors. Meanwhile, Levelised Cost of Hydrogen (LCOH) according to selected hydrogen production pathways from 2025 – 2050 compared with LCOH hydrogen exporting countries is presented in Figure 18. This is to benchmark to the current and projected LCOH that Malaysia could offer as to estimate the country's competitiveness level in price of green hydrogen.

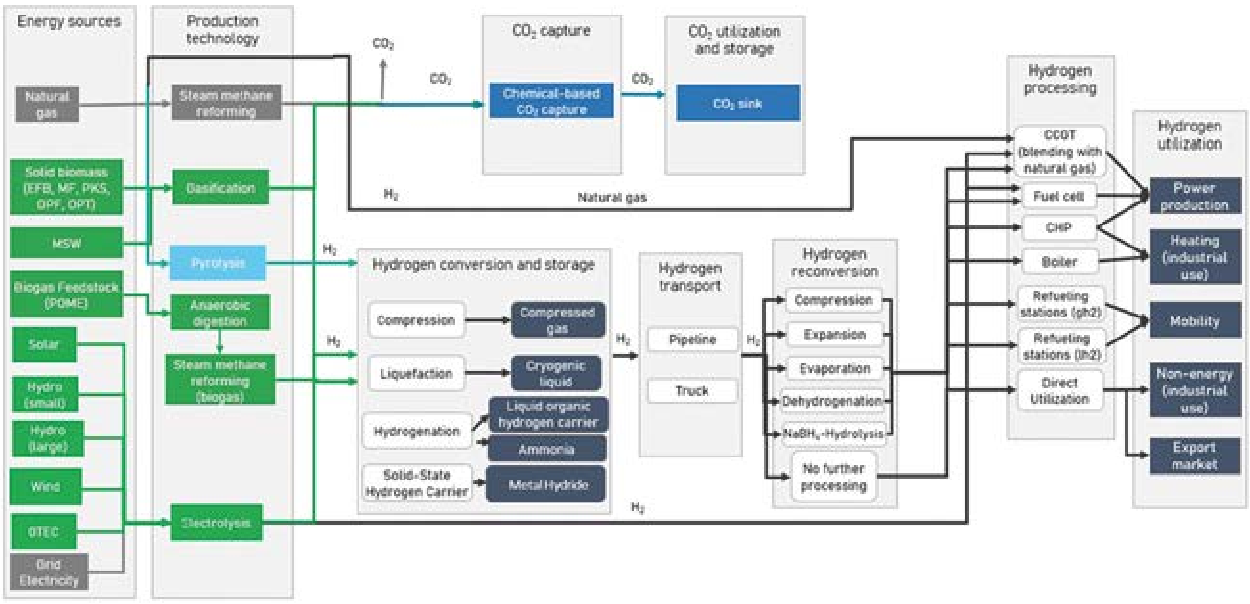


Figure 16: Hydrogen supply chain that is modelled in the HETR.

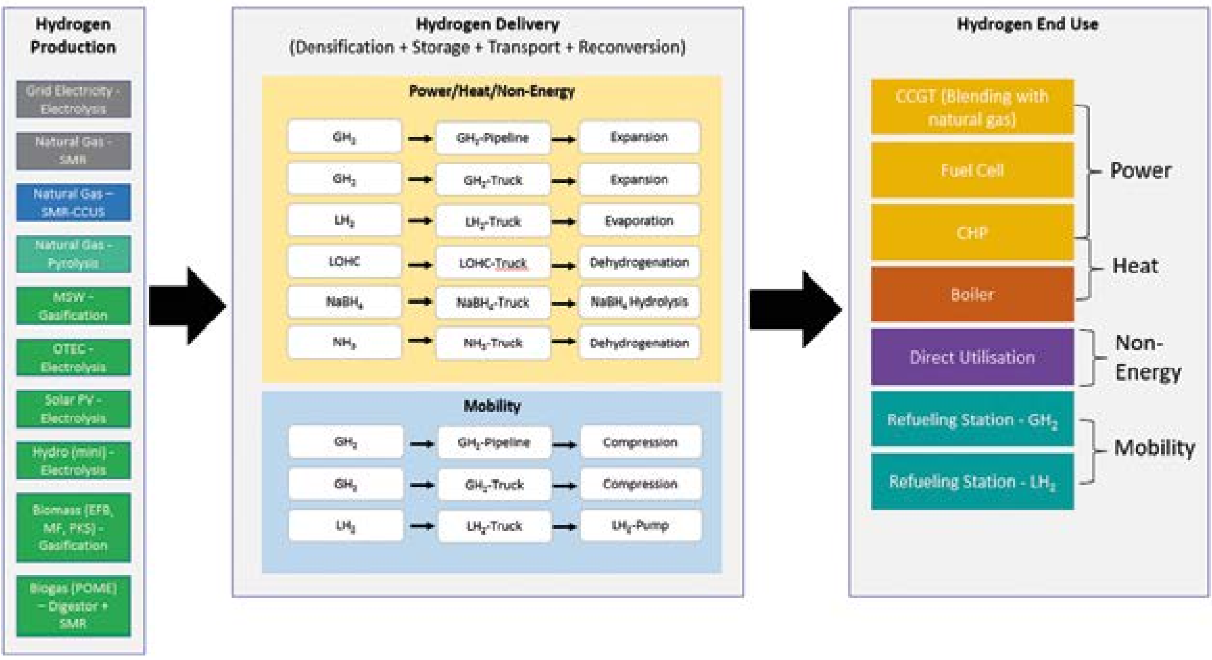


Figure 17: The HETR model in the form of modular components.

Energy sources for different routes of hydrogen production are considered from various resources such as fossil fuel (natural gas) and renewables (solar, wind, hydro, biomass, biogas, wastes and OTEC). In terms of Renewable Energy (RE) capacity, the modelling has excluded capacity committed for generating electricity to be exported to the grid and the remaining RE potential capacity (unutilised energy resources) was considered for the hydrogen production. As stated in the Malaysia Renewable Energy roadmap (MyRER), the following RE resource potential (technically feasible) has been identified in Malaysia:

- 269 GW potential for solar PV, dominated by ground-mounted configurations (210 GW), rooftop PV system (42 GW) and floating configurations (17 GW);
- 13.6 GW (13,619 MW) resource potential for large hydro; 3.1 GW is identified in Peninsular Malaysia, 493 MW in Sabah, and 10 GW in Sarawak.
- 3.6 GW resource potential for bioenergy, including biomass (2.3 GW), biogas (736 MW), municipal solid waste (516 MW);
- 2.5 GW resource potential for small hydro (up to 100 MW); and
- 229 MW of geothermal resource potential.

While the theoretical solar potential in Malaysia is considerably large with a total of 269 GW capacity, deeper technical and economic feasibility studies will be required to ascertain the viability of developing that amount of solar potential in Malaysia, which should also take into account the land mass required and other alternative energy sources. RE installed capacity grew by 12.1% annually between 2012 and 2020 (from 3.7 GW to 8.5 GW). With the latest Government of Malaysia's target of 31% RE share in the national installed capacity mix, the New Capacity Target scenario contemplates additional new capacity of 4,466 MW in Malaysia by 2025 while additional 5,080 MW is needed from 2025 to arrive at 40% RE in 2035.

Plant side-based hydrogen production has been given priority for hydrogen production to avoid double conversion or energy losses from exporting of RE electricity to the grid and reutilise the electricity to produce hydrogen. There is a possibility to produce hydrogen at similar sites of RE projects that generate electricity under Feed in Tariff, Net Energy Metering, Self-Consumption (SELCO) or Large-Scale Solar (LSS) programmes. Project developers of FiT programme (applicable for biomass, biogas, and hydro projects) who have signed Power Purchase Agreement with TNB may opt for value added businesses when they embark on hydrogen production should the design capacity of the plant enable them to generate more electricity than the commitment to supply to the grid. For the case of Large-Scale Solar, unsuccessful bidders may opt for alternative to expand the facilities at the project sites for on-site generation of green hydrogen.

The production cost of hydrogen was projected through different routes and means of production, from green hydrogen through electrolysis (hydro, solar photovoltaics, OTEC, alkaline or PEM electrolysers, municipal solid waste or biomass gasification, and biogas steam reforming); and blue hydrogen (natural gas steam reforming with carbon capture and storage). The different cost components form the basis of the Levelised Cost of Hydrogen (LCOH) that is projected over the time horizon of 30 years. Turquoise hydrogen was not included as available data is only relevant for production from natural gas pyrolysis (grey hydrogen) while biomass pyrolysis technology commercialisation report has not been published at the time HETR was prepared.

The cost elements that were considered by the model are the lifetime of the plant, the availability or capacity factor of the energy sources, energy price, electricity tariff, interest rate, efficiencies, and cost learning rates. The model has also considered that the hydrogen produced is at high purity (99.9%) in which the purification cost is included.

Coal gasification is not considered as one of the hydrogen production pathways to align with the New Energy policy of dephasing coal and no new coal-based power plants establishment. Most of Malaysia's coal power plants are reliant on imported coal except for the power plants managed by SEB that utilises local resources that is situated in Sarawak. Since Malaysia is reliant on imported coal, the possibility and feasibility of using low carbon ammonia for co-firing in the coal-fired power plant, to extend the life of the plants has been proposed as one of the technologies in Figure 24. The transition to Green Hydrogen Economy could provide option for Malaysia to explore importing of green hydrogen as substitute to coal especially from Australia knowing the shorter distance of the country to Malaysia. In an announcement by the Minister of Energy and Natural Resources (now known as the Ministry of Natural Resources, Environment and Climate Change; NRECC), an electricity tariff is anticipated with a surcharge of RM0.037/kWh affecting the commercial and industrial electricity rates. The adjustment is mainly reflected from the increase of coal price by 45%.

Figure 19 shows delivery cost of hydrogen in gas and liquid forms based on different types of technology and projected for year 2025 – 2050. The production cost of hydrogen was projected through different routes and means of production, from green hydrogen through electrolysis (large and small hydro, solar photovoltaics, ocean thermal energy conversion, alkaline or PEM electrolyser, municipal solid waste or biomass gasification, and biogas steam reforming); turquoise hydrogen; and blue hydrogen (natural gas steam reforming with carbon capture and storage). The different cost components form the basis of the Levelised Cost of Hydrogen (LCOH) that is projected over the time horizon of 30 years.

The cost elements that were considered by the model are the lifetime of the plant, the availability or capacity factor of the energy sources, interest rate, efficiencies, and cost learning rates. The model has also considered that the hydrogen produced is at high purity (99.9%) in which the purification cost is included. The end-use sectors that are considered for the projection in HETR are power, industrial heating, land mobility (road vehicles), marine transportation and non-energy industrial use sectors. The following sectors are the most suitable to be diffused with hydrogen use due to its scale and contribution to GHG emissions, and demonstration of use in other relatively advanced countries. However, there are always constraints to be deliberated. These include the cost of retrofit and development of new system(s) to accommodate hydrogen and the necessary infrastructure to scale-up hydrogen use and to drive down cost.

For the power and heating sectors, grey hydrogen is not considered by the model as it will be contributing to a higher level of emissions and more energy losses and cost impairments as opposed to directly using natural gas as the combustion fuel. For these two sectors, only blue, green, and turquoise hydrogen will be considered.

For the power sector, green hydrogen will be blended with natural gas for the combined cycle gas turbine and coal fired power plants (including co-firing with biomass) to reduce emissions and provide better combustion. For heating, it is expected that hydrogen will be combusted for use in industrial boilers or heaters. For non-energy industrial use, hydrogen will be directly utilised as a feedstock for many chemical processes such as to produce ammonia, for oil and gas refining (hydrotreatment, hydrocracking), methanol production as well as hydrogenation in the oleochemicals industry. For mobility, hydrogen is utilised by hydrogen fuel cell vehicles. The vehicle stock that is to be considered is based on the Total Industry Volume (TIV) and the percentage of the vehicle category out of the total TIV.

Today, around 80% of the global ammonia supply is used as fertiliser. Ammonia is one of the most promising future fuels in the maritime industry. Availability of zero emission alternative fuels such as green ammonia is an important pre-requisite to decarbonise the global shipping industry. The fuel can also be categorised as “brown” (produced from fossil fuel sources), “blue” (produced from fossil fuel sources with carbon capture) or “green” (produced from renewably sourced hydrogen via electrolysis).

The technology for hydrogen combustion in aviation is also significantly different than those that are used in the power sector as the current fuel in use is different (aviation fuel such as kerosene compared to natural gas). However, it is worth noting that a separate study can be conducted subsequently on the aviation sector given access to information and higher technology readiness levels.

3.5.4 Levelised Cost of Hydrogen

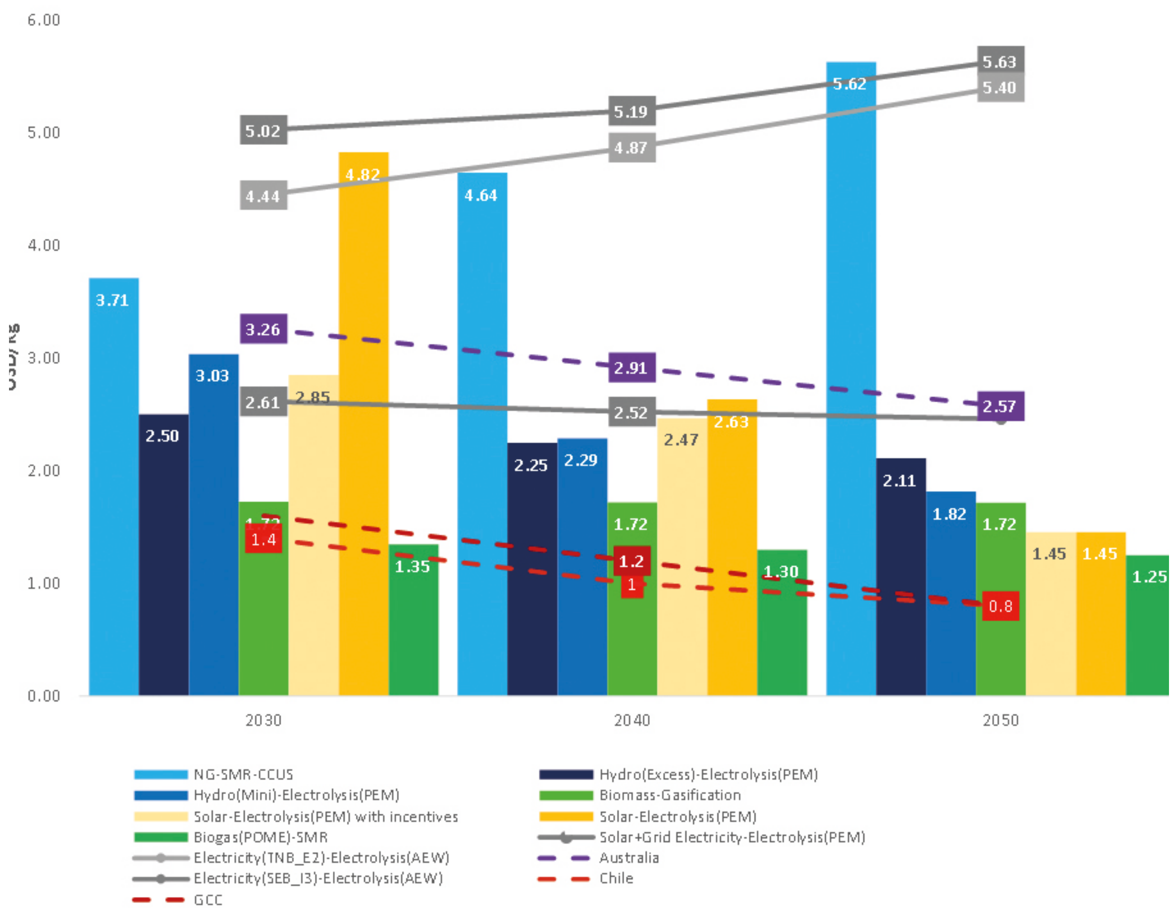


Figure 18: LCOH according to hydrogen production pathway from 2025 – 2050 compared with hydrogen exporting countries.

The Levelised Cost of Hydrogen (LCOH) is a methodology used to account for all the capital and operating costs of producing hydrogen and therefore enables different production routes to be compared on a similar basis. The Levelised Cost of Hydrogen (LCOH) is projected over a time horizon of 30 years until the year 2050. There are many more hydrogen production pathways that were modelled for the study but only 10 relatively more prominent ones are provided in Figure 18. These 10 production routes are the main production technology pathways chosen by the model based on the least cost optimisation objective.

The lowest LCOH over the time horizon is expected to be from green hydrogen that is based on biogas (1.347 USD/kg in 2030, 1.298 USD/kg in 2040 and 1.250 USD/kg in 2050), biomass resources (1.723 USD/kg in 2030, 1.720 USD/kg in 2040 and 1.716 in 2050) and followed by grey hydrogen produced from steam methane reforming (1.815 USD/kg in 2030, 1.799 USD/kg in 2040 and 1.799 in 2050). For biomass and biogas-based hydrogen, the concerns are towards the consolidation of resources due to the scattered nature of palm oil plantations and oil mills. It is important to address the logistics' constraint of the feedstocks especially for biogas produced from Palm Oil Mill Effluent (POME) that is more suitable to be used *in-situ*. Another concern is the availability of resources as some biomass stocks are being reserved for the export market that offers a higher selling price, especially after being pelletised. There are limited amount of biogas and biomass resources in Malaysia, and this can be seen later in the scenario driven projections whereby the hydrogen production that is based on biomass and biogas will be capped to a certain extent.

To meet the objectives of net zero carbon, the hydrogen supply chain model only considers low carbon hydrogen and green hydrogen. The blue hydrogen production pathway could contribute to the national target of emission reduction and climate action ambition as a bridge towards the transition to green and turquoise (bioenergy based) hydrogen production with the assumption of technology maturity is reached to capture up to 98% methane leakages throughout the conversion processes. This is aligned with many studies that suggested that low carbon hydrogen is required for the emission avoidance in the hard-to-abate sectors such as metal and steel industry, oil and gas refining industry and the chemicals industry such as for ammonia and methanol production. Emission avoidance however requires Marginal Abatement Cost (MAC) unless grey hydrogen is more expensive than the other types of hydrogen.

The solar PV based electrolysis is the most improved route of hydrogen production due to significant decline in electrolysers' cost especially for the Proton Exchange Membrane (PEM) electrolyser and solar photovoltaics module (that forms a major part of the Levelised Cost of Electricity, LCOE component). It is projected the cost of solar based hydrogen in Malaysia to be 4.823 USD/kg in 2030, 2.632 USD/kg in 2040 and 1.454 USD/kg in 2050. This can be further lowered down as the model considered a higher value of capital expenditure for the solar PV installation and is a more conservative value compared to the lowest LSS bid levelised tariff achieved in the latest LSS round (LSS4). Most of the cost decline of the solar PV and electrolyser technology is due to the high learning-by-doing rate and increasingly large-scale production and implementation of solar PV across the globe. The advancement in PV technology such as perovskite technology, materials with higher radiation bandwidth absorption that can accommodate Malaysian diffuse sunlight, and cheaper contact technology (copper as opposed to silver contacts), may again disrupt the price of solar PV modules and drive even lower electricity cost that will in turn make green hydrogen cost cheaper.

Other countries such as Chile, Australia and Saudi Arabia are utilising their high solar irradiance that is available on dry non-arable land to take advantage of the global insurgence of green hydrogen demands and drive their LCOH to be as low as 1.5 USD/kg by the year 2030. From 2045 onwards, the model shows that for Malaysia the solar based electrolysis of hydrogen will be the second least cost of green hydrogen production route after biogas steam reforming and will be the most preferred in the long term as to take advantage of the low system price of solar PV in the future. It is interesting to note that the lower LCOH of those countries are also driven by incentives provided by the government. Therefore, Malaysia can offer competitive LCOH and create impact to the market with significant support and assistance from the government.

For blue hydrogen production which essentially is grey hydrogen production in combination with a Carbon, Capture, and Storage (CCS) system, the cost component that is of the biggest concern is the carbon capture system cost and the carbon sequestration or storage cost. The issue becomes more prevailing when the current best technology for CCS is used to improve recovery of oil or gas from depleting well. This concept is known as enhanced oil recovery and the process that takes place is known as the Water Alternating Gas (WAG) injection. Therefore, capturing CO_2 and sequestering it is also taking more oil from the ground that is not needed. The capture (Pressure Swing Adsorption; PSA) process also requires heat that may not make the system clean if the source of heat is not from renewables or from waste (recovered heat).

The technology for CO_2 separation and capture is also well understood as it has been used for decades in the oil and gas industry for desulphurisation and to separate CO_2 from the oil and gas streams. To have a system with highly selective CO_2, the system can be enhanced by improving the membrane, adsorber and/or solvent properties. The technology learning rate for the CCS system is set at 0.32-0.35% annually with a starting capital expenditure of 65 USD per tonne of CO_2.

The LCOH represented in Figure 18 has also been crosschecked and verified through various stakeholders' engagements and actual local project cost benchmarking. This is to ensure that the LCOH data is reflective of the Malaysian cost and representative of the Malaysian context. The feedstock value is based on a single actual or average value depending on the production type and technology, their associated capital and operating costs.

The LCOH however does not show the sensitivity of the feedstock price and the possible drastic improvement of technology through different scales of learning rate. That may be explored through a more detailed sensitivity analysis.

Another important hydrogen production route to note is the green hydrogen production technology using hydropower either from mini-hydro or the hydro-based grid electricity of Sarawak to power up the electrolysis process. The model projected that the LCOH from hydropower to be around 2.33 USD/kg in 2030, 1.91 USD/kg in 2040 and 1.82 USD/kg in 2050. This is assuming that there is technological learning rate of 0.16-0.17% each year for a mini-hydro system. There are also advantages of using mini-hydro to the normal large scale hydropower system which requires an extensive civil infrastructure and the flooding of the area in vicinity.

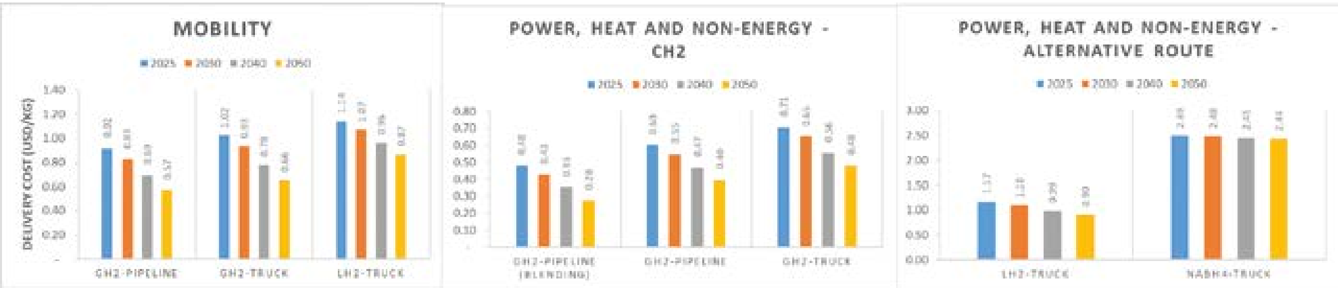
Many cases of hydropower dam construction resulted in the displacement of the local population especially native tribes, along with potential environmental impacts to the biodiversity located in the area. These effects need to be considered and it is critical that the construction of the hydropower system complies to sustainability standards such as the recently established Hydropower Sustainability Standard by the Hydropower Sustainability Council that set the required Environmental, Social and Governance (ESG) parameters to help the involved parties achieve certain minimum performance expectations for their projects. This is an improvement of the previous Hydropower Sustainability Assessment Protocol (HSAP) that was released in 2010 after the review of the World Commission on Dams' recommendations, the World Bank Safeguard Policies and IFC Performance Standards, the Equator Principles, and the International Hydropower Association's (IHA) earlier sustainability tools.

Sarawak has a big hydropower potential compared to the other states in Malaysia. It will be important that Sarawak develop plans to harness this vast potential of renewable resources to an even greater height to drive greater economic growth for the state especially and for Malaysia generally.

The LCOH for green hydrogen in Malaysia from various resources is compared with the LCOH from the solar PV based electrolysis (using PEM) for Chile[1], Australia[2] and Gulf Cooperation Council (GCC)[3] countries (e.g., Saudi Arabia, United Arab Emirates) to assess where Malaysia is at in terms of production cost compared to the exporting countries. Comparison based on solar based electrolysis hydrogen production cost, Malaysia is not in the position to lead and cannot compete due to a lower PV peak hours potential and lower capacity factor compared to the three countries. The value for Australia that was projected however did not assume a steeper learning curve for solar PV and electrolyser technology compared to the other two scenarios for Chile and the GCC countries. The value for Malaysian LCOH from PV is significantly high especially in the earlier years in the time horizon. Even in the longer term, it is projected not to be competitive with Chile and the GCC countries, but however is more competitive than Australian LCOH.

As for biomass and biogas resources and mini hydropower-based green hydrogen, Malaysia is cost-competitive in the short term, but the stock is limited and constrained to a certain volume that are scattered throughout Malaysia. If there are expansions of palm oil plantations and increase of oil mill in some locations in Malaysia, the amount of waste that can be recovered to be made as feedstock for the hydrogen production processes will be higher. Its availability and coverage will also be more extensive and can be utilised to produce a higher volume of bio-based green hydrogen.

3.5.5 Hydrogen Delivery Cost



Note: Based on 150km X 2 average distance for transportation. This is relevant to domestic use of hydrogen. An example would be an NREL study on Hydrogen blending.

Figure 19: Hydrogen delivery cost by type of technology (2025, 2030, 2040 and 2050)

The hydrogen delivery cost differs from one technology to another as shown in Figure 19. For the cost projection, the model considers various conversion, delivery, and transportation pathways that are relevant for Malaysia. This includes transportation of hydrogen through compression and natural gas pipeline blending, compression and delivery trucks, liquefaction and delivery trucks, hydrogenation, and delivery trucks (using liquid organic hydrogen carrier such as methylcyclohexane (MCH) or N-ethyl carbazole) and solid-state hydrogen (such as Sodium Borohydride, $NaBH_4$) and delivery trucks. Each delivery pathway has their pros and cons and may be suitable in certain area or niche applications over the others. This analysis is based on the cost comparison criteria alone and may not be able to accommodate their differences and various strengths.

For all four time-horizon checkpoints evaluated (the years 2025, 2030, 2040 and 2050), the compression and natural gas blending is the least cost option except for 2025. This pathway however requires the introduction of hydrogen in the pipeline that may cause issues and problems to the system that have yet to be encountered previously. Some modification with the piping system, and inner coating of the pipe may be required to allow for hydrogen to blend with natural gas, without causing corrosion, embrittlement, fracture, leakage, and other issues that are discussed in Hydrogen Blending into Natural Gas Pipeline Infrastructure: Review of the State of Technology and the previous chapters and/or subchapters.

The second least cost option projected by the model is using liquid organic hydrogen carrier which allows for the hydrogen to be delivered in liquid form. The third and fourth least cost option is the delivery of hydrogen through a new dedicated pipeline system for hydrogen transportation, and the delivery of hydrogen through compression and transportation trucks. This, however, depends on the distance of the end-use facility to the hydrogen production site. The most expensive hydrogen delivery option out of all pathways is through the conversion of hydrogen to solid-state hydrogen. This is especially true as the technology is still in nascent stage and requires advancements, breakthroughs, and large-scale production to drive down the production or conversion cost.

For each delivery pathway, the end-use for mobility and the other three sectors (industrial heat, power, and non-energy industrial use) are segregated into two different categories. For mobility, the hydrogen gas shall be compressed (350 bar or 700 bar as of the current application) or liquefied prior to be used in the refueling stations whereas for the other three applications, they may only require hydrogen without compression.

3.5.6 Levelised Cost of Energy

The Levelised Cost of Energy (LCOE), also referred to as the Levelised Cost of Electricity or the Levelised Energy Cost (LEC), is a measurement used to assess and compare alternative methods of energy production. Alternatively, the LCOE can also be as the average minimum price at which the electricity generated by the asset is required to be sold to offset the total costs of production over its lifetime.

Figure 20 shows several shades of hydrogen were considered to determine the gaps between green and blue hydrogen against average electricity tariff, natural gas and diesel prices as projected starting from the year 2030.

The output shows that green hydrogen produced from solar energy will be expected to achieve cost parity to fossil fuels in the long term mainly in the power, mobility, industrial (non-energy use) and industrial (heat) pathways. As such, it is crucial for a subsidy mechanism to be introduced and accelerated domestic carbon trading programme to achieve cost parity.

The amount of subsidy required will be suggested to reach price parity for each pathway of the LCOE. The subsidies such as green technology incentives for renewable energy technologies, green hydrogen production and end use technologies are proposed for short term period (until 2030) to encourage public and private investment of the projects. As the project uptakes increased due to the provision of incentives, green hydrogen price parity may be realised much earlier than the year 2050.

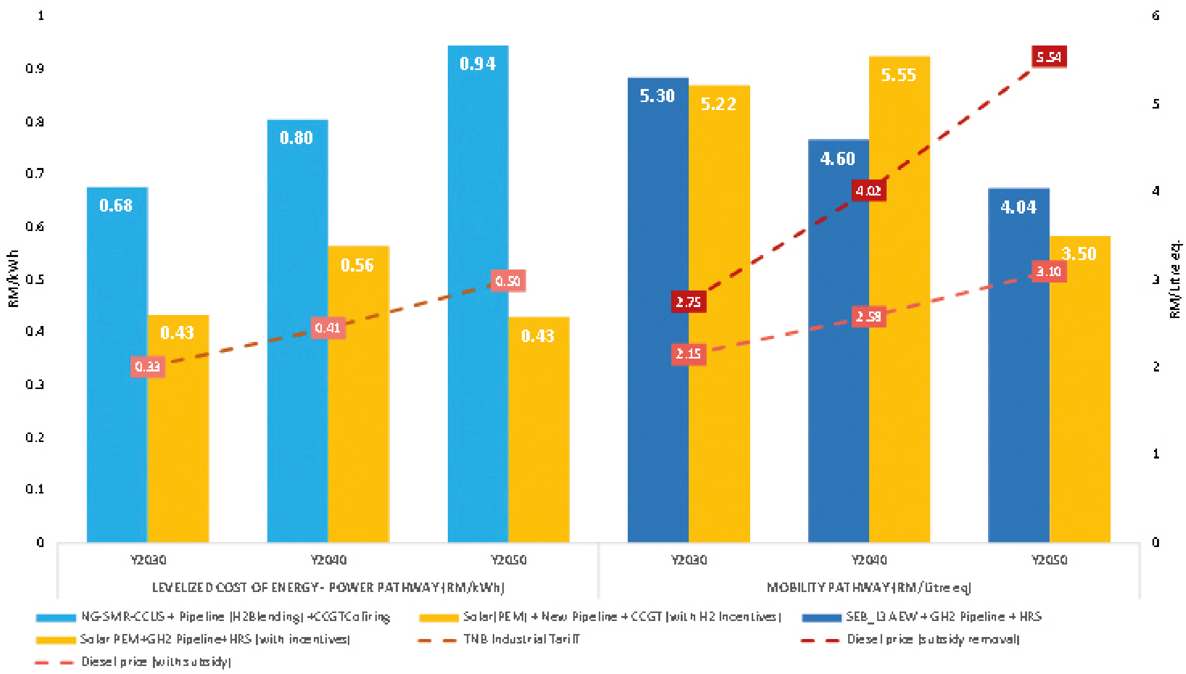


Figure 20: Levelised Cost of Energy (LCOE) for the shades of hydrogen according to the technology pathways for power and mobility sector, in RM/kWh and RM/Liter eq (2025 – 2050)

3.5.7 Hydrogen Economy Modelling Scenarios

	Business As Usual Scenario (BAU)			Emissions Driven Scenario (EDS)		
	2030 (Short-term)	2040 (Mid-term)	2050 (Long-term)	2030 (Short-term)	2040 (Mid-term)	2050 (Long-term)
GHG Emission Intensity Reduction	1.57 % reduction of GHG emission intensity by 2050			6.94 % reduction of GHG emission intensity by 2050		
Primary source	99.94% Low Carbon Hydrogen 0.06% Green Hydrogen	78.07% Low Carbon Hydrogen 23.13% Green Hydrogen	51.14% Low Carbon Hydrogen 49.53% Green Hydrogen	90.14% Low Carbon Hydrogen 9.86% Green Hydrogen	61.66% Low Carbon Hydrogen 38.34% Green Hydrogen (13.17% Imported)	53.37% Low Carbon Hydrogen 46.63% Green Hydrogen (6.3% Imported)
Production Volume	1 MT	4 MT	7 MT	2 MT	8 MT	16 MT
% Final Energy Consumption	1.1%	3.6%	6.0%	3.3%	10.6%	18.8%
Power (MTPA)				0.05	0.99	2.05
Industrial (Heat) (MTPA)	0.03	0.22	0.48	0.03	0.63	1.32
Industrial (Non-Energy) MTPA	0.32	1.32	2.32	0.97	2.7	5.58
Mobility (MTPA)	0.0006 (0.1% of TIV)	0.03 (1% of TIV)	0.46 (10% of TIV)	0.01 (1% of TIV)	0.12 (5% of TIV)	0.92 (20% of TIV)
Marine (MTPA)				0.03	0.21	0.41
Export (MTPA)	0.55	1.88	3.2	0.55	1.88	3.22
Cumulative Investment (RM Billion)	6.9	58	201	12	148	577
Revenue Generation (RM Billion)	7.4 (Domestic) 20.3 (Export)	37.1 (Domestic) 218.77 (Export)	151.7 (Domestic) 408.93 (Export)	12.1 (Domestic) 20.3 (Export)	151.8 (Domestic) 218.77 (Export)	497.2 (Domestic) 408.93 (Export)
GDP Contribution (RM Billion)	49	292	663	61	637	1,573
GNI Contribution (RM Billion)	61.6	595	1,350	99	829	2,200
Job Creation	168,000			211,680		

- The amount of energy for hydrogen production is accounted based on the **excess** energy projected in the **Malaysia Renewable Energy Roadmap (MyRER)**
- Malaysia to meet **10% of Japan, South Korea and Singapore hydrogen demand** in 2030, 2040 and 2050 comprising of 40% green hydrogen

[1] Current technical study imply that a range of 3 – 20% of H2 blending is possible and largely determined by existing conditions of pipelines (PETRONAS)

Figure 21: Assumptions and Target

As shown in Figure 21, there are two scenarios modelled for the HETR that are based on different parameters and conditions. All these scenarios are projected over a 30-year time horizon, with different resulting hydrogen production volume, final energy consumption, GDP contribution along with the values of GHG emissions' reduction. The model also only considered the diffusion of blue and green hydrogen in the economy and end-use demand, to meet the objective of hydrogen economy contribution to the GHG emission reduction based on the displacement of the national primary energy supply and demand by low carbon hydrogen.

The two scenarios were developed based on input from numerous stakeholders' engagements, and with different assumed targets that serve more of a guide to assist in understanding the impact of different levels of hydrogen diffusion towards the economy and GHG emissions' mitigation. The assumptions for hydrogen adoption by end-use sectors are outlined based on forward looking action plan projected based on Malaysian states' commitment for hydrogen end-use technology and applications, as follows:

Assumptions for Business-as-Usual (BAU) Scenario

(a) Power:
No Hydrogen demand is planned for electricity generation until 2050. With reference to the report on Peninsular Malaysia Generation Development Plan 2020 (2021-2039), published by Suruhanjaya Tenaga (Energy Commission) in March 2021;

(b) Mobility:
References were made to the Low Carbon Mobility Blueprint 2021-2030 (LCMB) and National Automotive Policy 2020 (NAP) targets which projected cumulative EV volume to reach 15% of the Total Industry Volume in 2030. Under the NAP, it is targeted to grow the Total Industry Volume (TIV) to 1.22 million units by 2030; Total Production Volume (TPV) to 1.47 million units;

(c) Industrial (Non-energy):
14:9 of power-to-heat ratio used as baseline to project the trend of hydrogen fuel demand for industrial heat;

(d) Industrial (Heat):
14:9 of power-to-heat ratio used as baseline to project the trend of hydrogen fuel demand for industrial consumption.

Assumptions for Emissions Driven Scenario (EDS)

(a) Power:
Driven by the 20% blending of hydrogen with natural gas in power plants starting from 2030. Co-firing of coal with green ammonia starting from 2030;

(b) Mobility:
The FCEV target are aligned with the Electric Vehicle target and NAP has targeted total industry volume to 1.22 million units with total production volume to 1.47 million units by 2030. Baseline on average kilometres and mileage travel is taken from the LCMB and are benchmark against National Energy Policy (NEP). The increase in fuel-cell vehicle was driven by an increase in sales of vehicle volumes per year starting from 2041 until 2050 and projected increase of Total Industrial Volume (TIV);

(c) Industrial (Non-energy):
Fertiliser, chemicals, and methanol. For the short term, target to replace 5% natural gas use in non-energy to be replaced with hydrogen produced from NG-CCUS and slowly increase to 20% by 2050. According to International Energy Agency and definition accepted by APAC, Non-energy use covers use of other petroleum products such as white spirit, paraffin waxes, lubricants, bitumen, and other products. It also includes the non-energy use of coal (excluding peat). These products are shown separately in final consumption under the heading non-energy use. It is assumed that the use of these products is exclusively for non-energy use. It should be noted that petroleum coke is included as non-energy use only when there is evidence of such use; otherwise, it is included as energy use in industry or in other sectors.

Non energy use includes energy products used as raw materials in the different sectors; that is not consumed as a fuel or transformed into another fuel. For example, most lubricants and bitumen are used for non-energy purposes, similarly natural gas is used as a raw material for the petrochemical industry and others.

(d) Industrial (Heat):
The trendline is based on ratio of natural gas based power and natural gas-based heat in NEB 2018. Natural gas is selected as fuel for heat as it accounts the biggest percentage of fuel used in this sector. In 2008, NG used for power sector was 12,816 ktoe and industrial heat 8255 ktoe.

(e) Marine: 10% fuel switching to green ammonia by 2050 in marine bunkering

The first scenario, the Business as Usual (BAU) scenario is based on forward looking action plan that are projected based on some Malaysian states' commitment for hydrogen end-use technology and applications as well as well the relevant policy documents.

The second scenario, the Emission Driven Scenario is the most aggressive route optimising the model to achieve maximum 10% of the GHG emissions reduction target by the year 2050 and aligned with Net Zero Carbon target scenario proposed by the IEA.

For the BAU, total GHG emissions reduction is 456,835tCO2 in 2030 and 20,646,933tCO2 in 2050. This has translated to 0.06% and 1.57% in terms of contribution to the reduction of GHG emissions intensity per GDP in 2030 and 2050. Hydrogen diffusion rate is 9% and shall contribute 6% of the final energy consumption, which is equivalent to 105TWhr in 2050. The highest demand will be from non-energy use sector (74TWh), followed by industrial heat (16TWh) and mobility sector (15TWh) in 2050. Cumulative investment needed until 2050 is RM 201 billion. Total revenue generation until 2050 for domestic consumption is RM152 billion while export market is RM408 billion. The impact to the economy shall create a significant number of jobs with cumulative 167,685 green jobs could be offered by the year 2050.

For the EDS, total GHG emissions reduction is 4,799,132 tCO2 in 2030 and 91,027,598 tCO2 in 2050. This has translated to 0.62% and 6.9% in terms of contribution to the reduction of GHG emissions intensity per GDP in 2030 and 2050. Hydrogen diffusion rate is 28.6% and shall contribute 18.8% of the final energy consumption, which is equivalent to 344TWhr in 2050. The highest demand will be from non-energy use sector (185TWh), followed by power sector (68TWh), industrial heat (43TWh), mobility sector (30TWh) and for marine (15TWh). Cumulative investment needed until 2050 is RM577 billion with potential revenue generation for domestic consumption until the year 2050 is RM 497.2 billion. Meanwhile, total revenue generated from export of hydrogen until 2050 is RM 408 billion. The positive impact on the economy shall create a significant number of jobs with cumulative 228,563 green jobs that could be offered by the year 2050.

Figures 22 and 23 the total hydrogen production volume in 2025 until 2025. The share of low carbon and green hydrogen. The consumption of hydrogen in the end-use sectors according to assumptions that have been outlined are shown in Figures 24 and 25 respectively. Various technology applications to utilise hydrogen at the end use sectors which include boiler, fuel cell, refueling station, combined cycle gas turbine and combustion. Figures 26 and 27 show the capacity of each technology application under the BAU and EDS respectively.

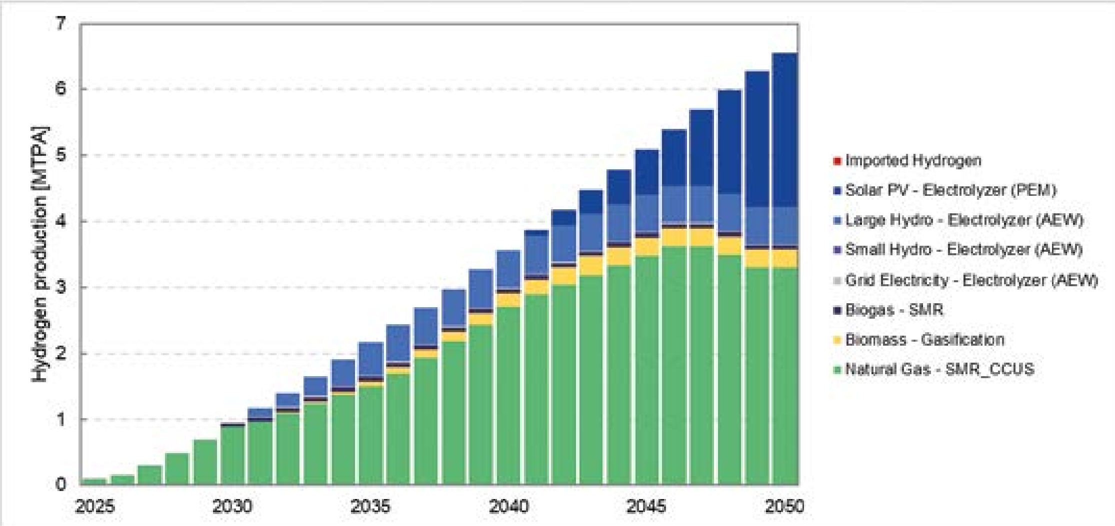


Figure 22: Hydrogen production (Business As Usual Scenario)

As shown in Figure 22, the BAU projected that hydrogen production shall start as early as 2025 with a production volume of 0.1MTPA. The volume shall increase to 0.9MTPA in 2030, 3.6 MTPA in 2040 and 6.6 MTPA in 2050 respectively. This is related to the announcement of the Sarawak state government for solar floating electricity generation of 800MW at Bakun Dam to be used for hydrogen production in Bintulu, 100 multipurpose refueling stations which can be assumed that 30% will be installed with Hydrogen Refueling Station (at 150kg production capacity per day). The source of hydrogen is limited to blue and green hydrogen to ensure that the Hydrogen Economy initiatives contribute significantly to the reduction of CO_2 emissions.

In terms of fuel and production technologies, hydrogen production from Natural Gas Reforming with CCUS shall be the dominant production method in 2025-2030 with share around 99.99% by 2030, followed by 4.06% biogas from anaerobic digestion (equivalent to 8.1MTonne of POME) and grid connected electricity shall have small percentage of 0.01% (19,336MWh). The share of natural gas will gradually reduce from 96% in 2030 to 76.25% in 2040 and 50.15% in 2050 while the share of grid connected electricity to run the electrolyser shall increase from 0.06% in 2030 to 0.62% by 2040 before the share reduced to 0.32% by the year 2050.

During the short-term period, hydrogen production shall be categorised as low carbon hydrogen. Hydrogen production using electrolyser with electricity sourced from the grid is aimed mainly from the Sarawak electricity grid. As reported in the Sarawak Energy Berhad Sustainability Report in 2020, Sarawak grid electricity emission intensity was reported at 0.203tCO2eq/MWh, a 12% reduction compared to carbon emissions in 2019. The state's carbon intensity for electricity supply also decreased by 71% from 2011 to 2020. In the medium and long terms, the share of green hydrogen is projected to increase to 23.14% in 2040 and 49.53% by 2050. The share of green hydrogen is contributed by Large Hydro (15.76%), Biomass Gasification (5.5%) and Biogas POME (1.83%). Solar PV hydrogen production shall be observed beyond 2040 and contribute to the largest share of green hydrogen (35.77% of equivalent to 53.5GW) by 2050. The capacity of Large Hydro shall be constant at 3.877GW while palm oil-based biomass gasification (empty fruit bunch, mesocarp fiber and palm kernel shell) at 4.272 Mtonne or equivalent to 778MW from 2040 until 2050.

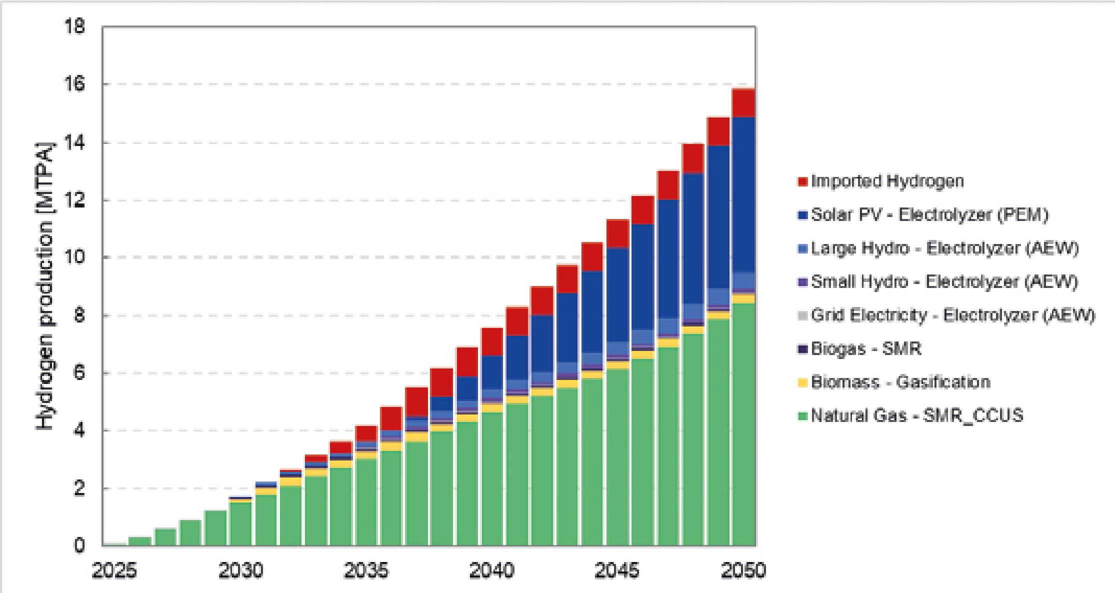


Figure 23: Hydrogen production (Emissions Driven Scenario)

Hydrogen production volume is projected at 2MTPA, 8MTPA and 16MTPA by 2030, 2040 and 2050 respectively. Assuming that the hydrogen roadmap implementation is backed by strong policy, regulation and economic instruments following Malaysia's commitment of becoming a carbon-neutral nation by as early as the year 2050, the EDS has projected higher target of hydrogen production to meet local demand of hydrogen at the respective consumption sectors. The targeted volume justifiable after comparing the high target of leading countries globally such as Japan, South Korea and the European Union. This scenario also considered the importing of green hydrogen from nearby exporting countries that could offer hydrogen at affordable price. During the preparation of HETR, the Australian Hydrogen Council is in their pre-budget submission to the Australian government in providing tax credits/incentives for investing in export hydrogen production and distribution where any Research, Development or Demonstration (RD&D) is undertaken. Australia could be the target country to supply low price of Green Hydrogen together with Chile and the GCC countries.

In terms of fuel and production technologies, hydrogen production from Natural Gas Reforming with CCUS shall be the dominant production method in 2025-2030 with share around 89.81% (52GWh) by 2030, followed by 4.21% biomass gasification (0.71 Mtonne), 3.74% biogas from anaerobic digestion (equivalent to 13.9MTonne of POME) and grid connected electricity shall have small percentage of 0.34% (193GWh). The share of natural gas will gradually reduce from 89.81% in 2030 to 76.25% in 2040 and 50.15% in 2050 while the share of biomass and grid connected electricity to run the electrolyser shall increase from 0.06% in 2030 to 0.62% by 2040 before the share is reduced to 0.32% by 2050.

During the short-term period, hydrogen production shall be categorised as low carbon hydrogen. Hydrogen production using electrolyser with electricity sourced from the grid is aimed mainly from the Sarawak electricity grid. In the medium and long terms, the share of green hydrogen is projected to increase to 38.34% in 2040 and 46.63% by 2050. Significant share of Solar PV hydrogen production shall be observed beyond 2040 and contribute to the largest share of green hydrogen (33.82% or equivalent to 122GW) by 2050. The is followed by Large Hydro at 3.877GW and constant capacity of palm oil-based biomass gasification (empty fruit bunch, mesocarp fiber and palm kernel shell) at 2.99 MTonne and biogas at 13.91MTonne from 2030 until 2050. As reported in the Malaysia Renewable Energy Roadmap (MyRER), the highest solar potential in Malaysia at 210 GW, driven by the availability of unused suitable land. It is estimated from land utilisation data that 4,085 km2 of unused suitable land, or 1.2% of total land area, are available in Malaysia. Comparing resource potential regionally, Sabah ranked the highest in ground-mounted solar PV resource at 97.2 GW, followed by Peninsular Malaysia with 94.9 GW and Sarawak at 18.2 GW. The abundant solar resources potential and availability of unused land provide the opportunity to tap solar resources (mainly ground mounted PV) for direct hydrogen production. Production of hydrogen can also be tapped from solar floating with more opportunity in Sarawak. At the same time, hydrogen could offer long term energy storage solution for variable Renewable Energy (RE) sources post 2025 considering the MyRER projection of 24% solar PV penetration of peak demand in Peninsular Malaysia and 20% in Sabah to meet the target of 31% RE by 2025 and 40% by 2035 for further decarbonisation of the power sector.

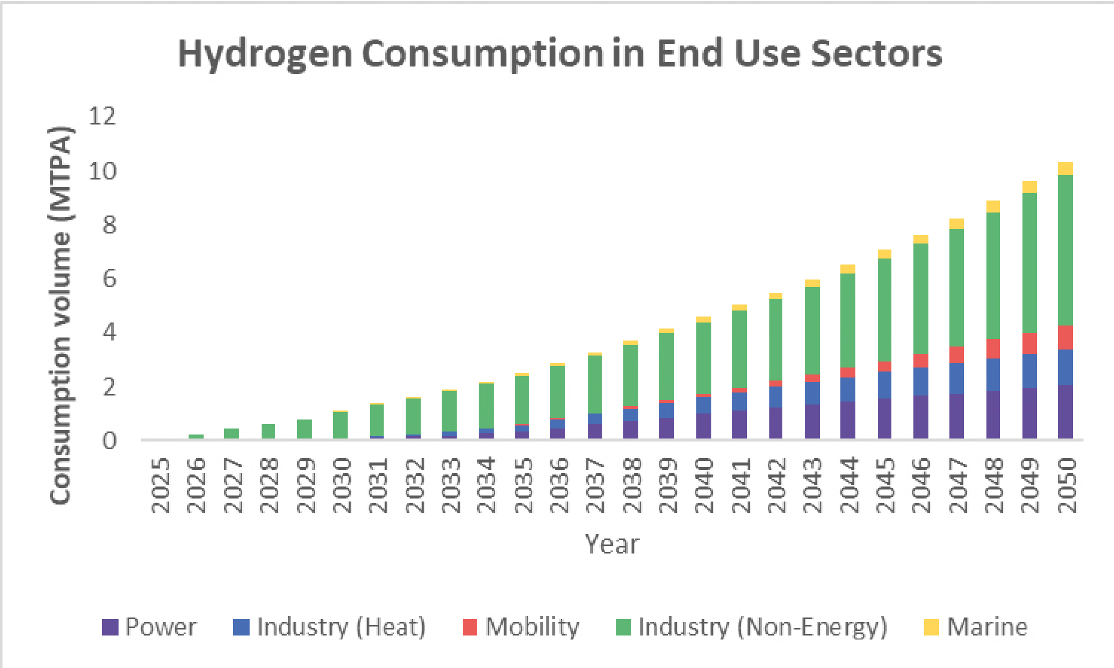


Figure 24: Hydrogen Consumption in End Use Sectors (BAU Scenario)

Industry (Non-Energy), Industry (Heat) and Mobility are the three main sectors that are projected to consume cumulative 1.09Million Tonne of hydrogen under the BAU as shown in Figure 24. In terms of final energy consumption, hydrogen share is projected at 1.1% in 2030, 3.6% in 2040 and 6% in 2050. As consulted with the key stakeholders in the power generation sector, hydrogen consumption in the electricity generation has been excluded from the modelling analyses. This assumption is verified by the New Energy Policy and JPPET. Based on the Generation Development Plan 2020, Peninsular Malaysia will see an increase in RE share from 17% to 31% (with the interest to achieve 39% solar penetration target by 2039), whilst the thermal capacity share will reduce from 82% to 69% by the end of the horizon (until 2039). Therefore, it is assumed that there will be no hydrogen mix in the electricity generation achieve beyond 2039 as the power sector may continue to increase the share of RE further and balance with the capacity share of thermal energy until 2050.

With regards to the mobility sector, main consumption of hydrogen is targeted for land transportation sector with Hydrogen Fuel Cell vehicle where FCEV is assumed to have share of 2% of the Total Industry Volume (TIV) in 2030. FCEV is categorised under Electric Vehicles (EV) which EV has already confirmed target of 15% share of TIV by 2030. Further increase of EV share out of the TIV is anticipated until the year 2050. With the assumption that FCEV shall increase its share to 10% of the TIV by 2050, the consumption of hydrogen for FCEV is projected to reach 0.46MTPA by 2050. As reported in the Low Carbon Mobility Blueprint 2021-2030 (LCMB), heavy vehicles contributed to the second highest GHG emissions from mobility sector. With the improvement of fuel economy to cater for the longer driving range, the share of FCEV trucks and commercial vehicles shall be the main target for green hydrogen consumption in the transportation sector.

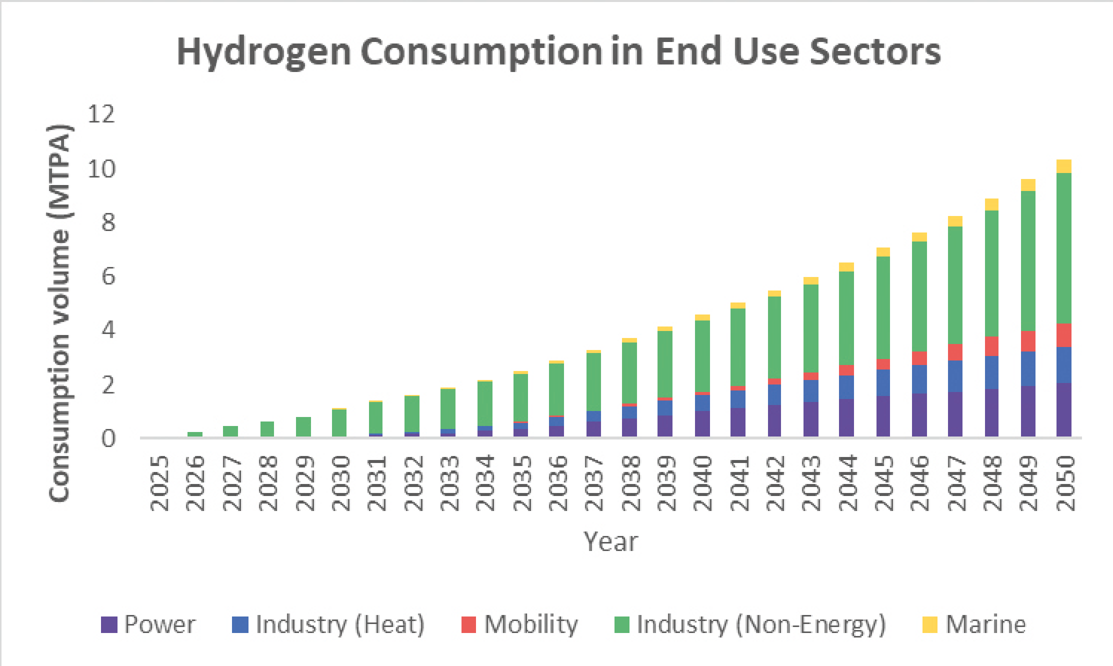


Figure 25: Hydrogen Consumption in End Use Sectors (Emission Driven Scenario)

As shown in Figure 25, the EDS showed projection results of hydrogen consumption in end use sectors such as Power, Industry (Non-Energy), Industry (Heat), Mobility and Marine with cumulative demand 1.09MTPA by 2030, 4.59MTPA by 2040 and 10.33MTPA by 2050. In comparison to the BAU scenario, the consumption of hydrogen in power sector is anticipated with the assumption of maximum 20% blending of green hydrogen in combined cycle gas turbine power plant and co-firing of coal with green ammonia in coal fired power plant. This scenario also showed the potential consumption in the marine sector, in addition to the existing potential of consumption in the land transportation sector.

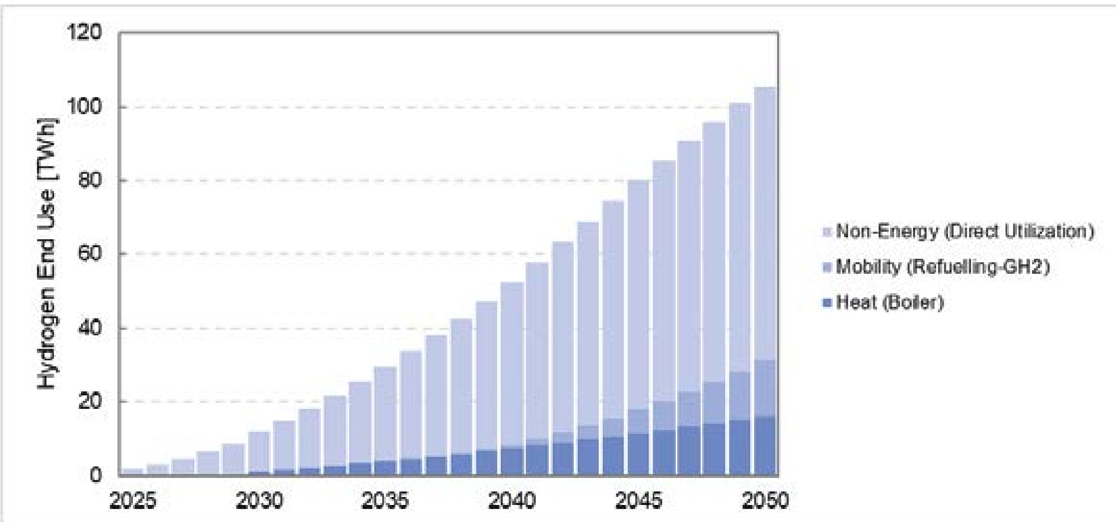


Figure 26: Hydrogen End Use Capacity by Technology Applications (BAU scenario)

In terms of technology applications as shown in Figure 26 for the BAU, hydrogen will be directly used as feedstock for non-energy industries with capacity of 10.766TWh, followed by industrial heat boiler at 1.068TWh and mobility sector at 0.19MWh in 2030. The capacity is projected to increase further for all sectors until 2050 with non-energy use demand at 44.026TWh and 74.350TWh by 2040 and 2050. Meanwhile, the capacity of hydrogen boiler shall achieve around 7.394TWh by 2040 and 15.96TWh by 2050. Lastly, the capacity of hydrogen refuelling station to fuel FCEV is projected at 0.945TWh by the year 2040 and 15.241TWh by the year 2050 respectively.

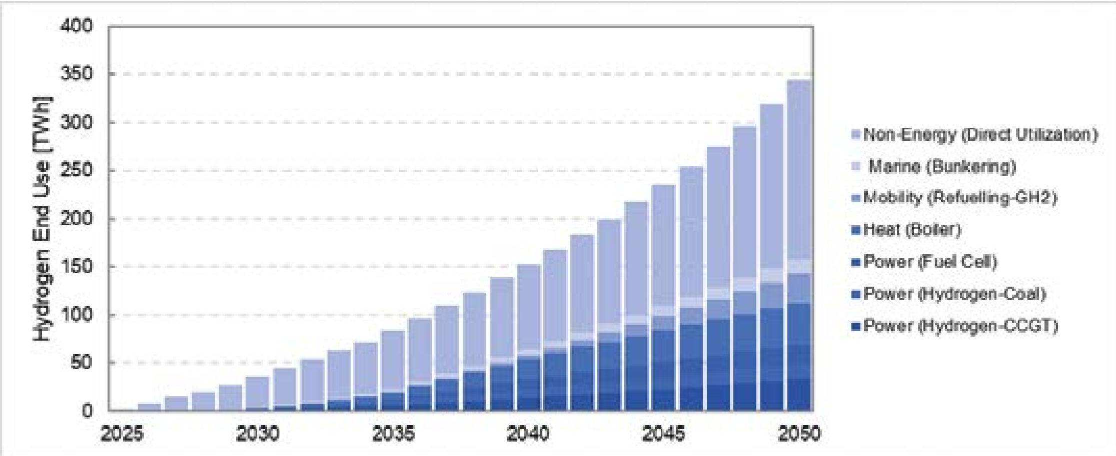


Figure 27: Hydrogen End Use Capacity by Technology Applications (Emissions Driven Scenario)

In the EDS as shown in Figure 27, there are more technologies adopted to meet hydrogen demand at the end use sectors. In 2030, the main applications will be direct use of hydrogen for non-energy industrial processes (32.297TWh), followed by industrial heat boiler (1.068TWh), combined cycle gas turbine (0.924TWh), co-firing of ammonia (carrier of hydrogen) in coal fired power plant (0.737TWh) and hydrogen refuelling station (0.191TWh). Direct use of hydrogen as feedstock non-energy industrial processes shall continuously create the highest demand with projected capacity at 88.048TWh by 2040 and could achieve 185.844TWh by 2050. The application in the power sector is also seen significant with combination of all technologies in the power capacity could generate 68.166TWh total capacity by 2050. In terms of technology applications in power sector, capacity of combined cycle gas turbine is projected at 13.818TWh by 2040 and 33.69TWh by 2050 while co-firing of ammonia (carrier of hydrogen) in coal fired power plant is projected to generate capacity of 8.140 TWh by the year 2040 and 15.963TWh by the year 2050 respectively.

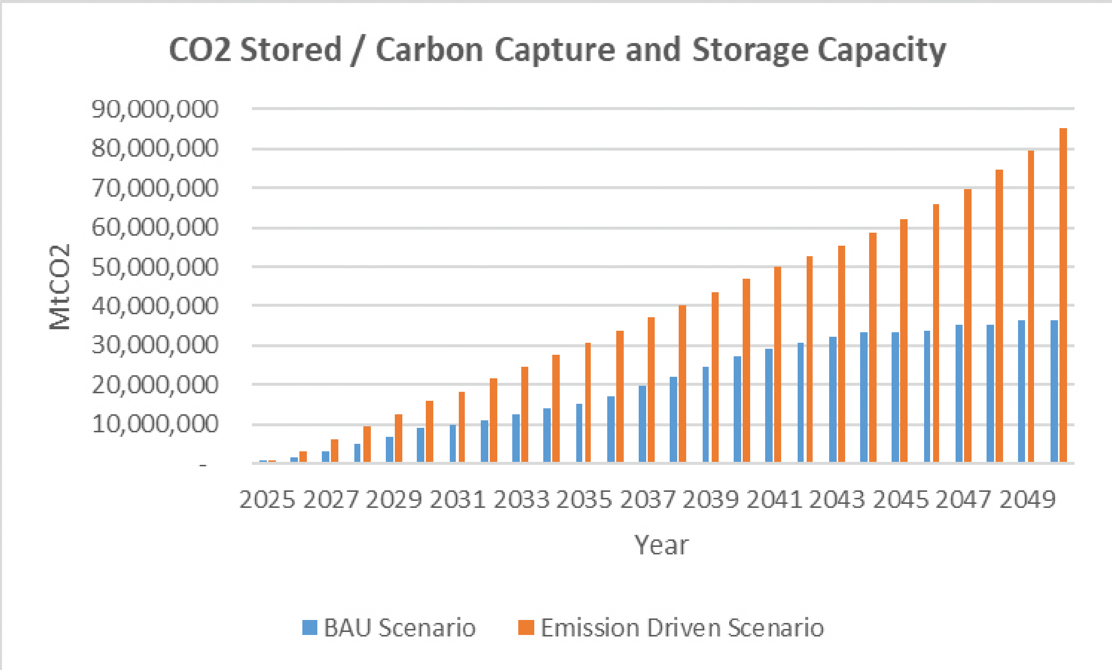


Figure 28: CO_2 stored and CCS Capacity

Figure 28 shows the Carbon Capture and Storage (CCS) capacity that is projected at 9.04Mtonne CO2 and 15.7Mtonne CO2 in 2030. The capacity shall increase further to 27.406MtCO2 (BAU) and 47.048MtCO2 (EDS) in 2040. By the year 2050, the total capacity shall reach 38.46MtCO2 under the BAU and 85.304MtCO2 under the EDS. The potential CO_2 storage could be at the Kasawari Carbon Capture and Storage (CCS) project site. As reported in various news articles, the Kasawari CCS project, once completed, will be the largest offshore CCS project in the world, with the ability to capture up to 3.3 million tonnes per annum of CO_2. Meanwhile, a total of about 71 to 76 million tonnes of CO2 from the Kasawari CCS project will be reinjected into the M1 field via pipeline, which is approximately 138km away from the platform.

With reference to a published paper entitled Basin Evaluation of CO_2 Geological Storage Potential in Malay Basin, it is identified that the potential injection zone that this basin can store is 84 Gt to 114 Gt CO_2. Another opportunity is to leverage on bilateral cooperation among ASEAN countries including Indonesia, Vietnam and Thailand that can lead to large businesses on CO_2 value chains such as CO_2 storage of depleted oil and gas fields, shipping and CO_2 reuse as raw material in industrial processes pertaining to the Circular Economy, for example, construction and petrochemicals. With references to the Tomakomai demonstration project in Japan and study for full chain project in Norway, scaling up of storage capacity could influence the cost reduction further. Both initiatives suggested that an estimated unit cost of US123 / tonne for a project with capacity of less than 1 million tonne. With scale up capacity of more than 1 million tonne per year, the unit cost is estimated to reduce to below US$100/tonne CO_2.

The model also suggested benefits from monetary credit for carbon oxide permanently stored via usage, tertiary oil injection, or in geologic formations. The credit amount may range from US$20.22 to US$ 31.77 for geologically sequestered CO_2 with enhanced oil recovery or other qualified use and projected to increase to between US$35 and US$50 tonne per CO_2 by 2026. The summarised version of the hydrogen end-use by sector is shown in Figure 29.

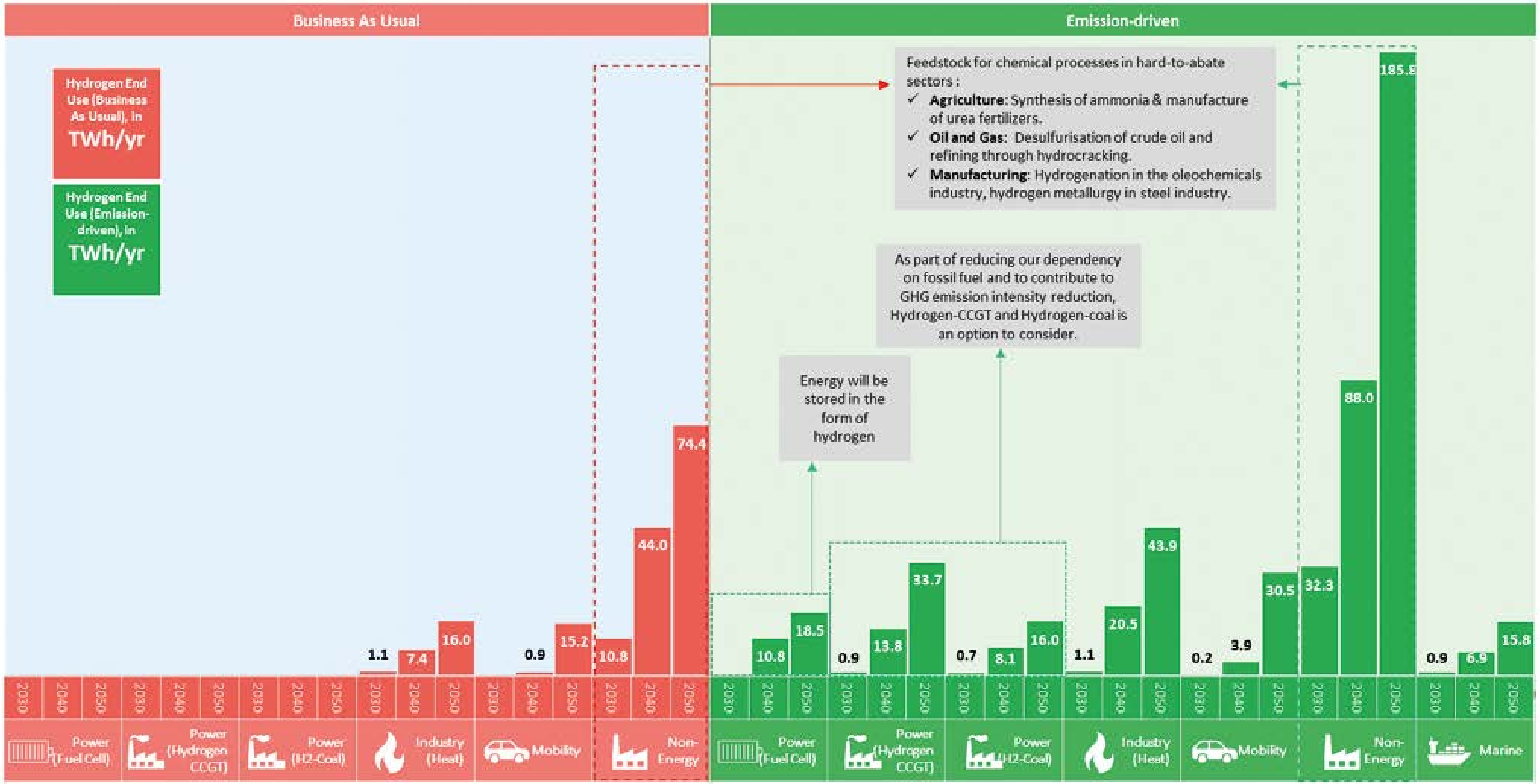
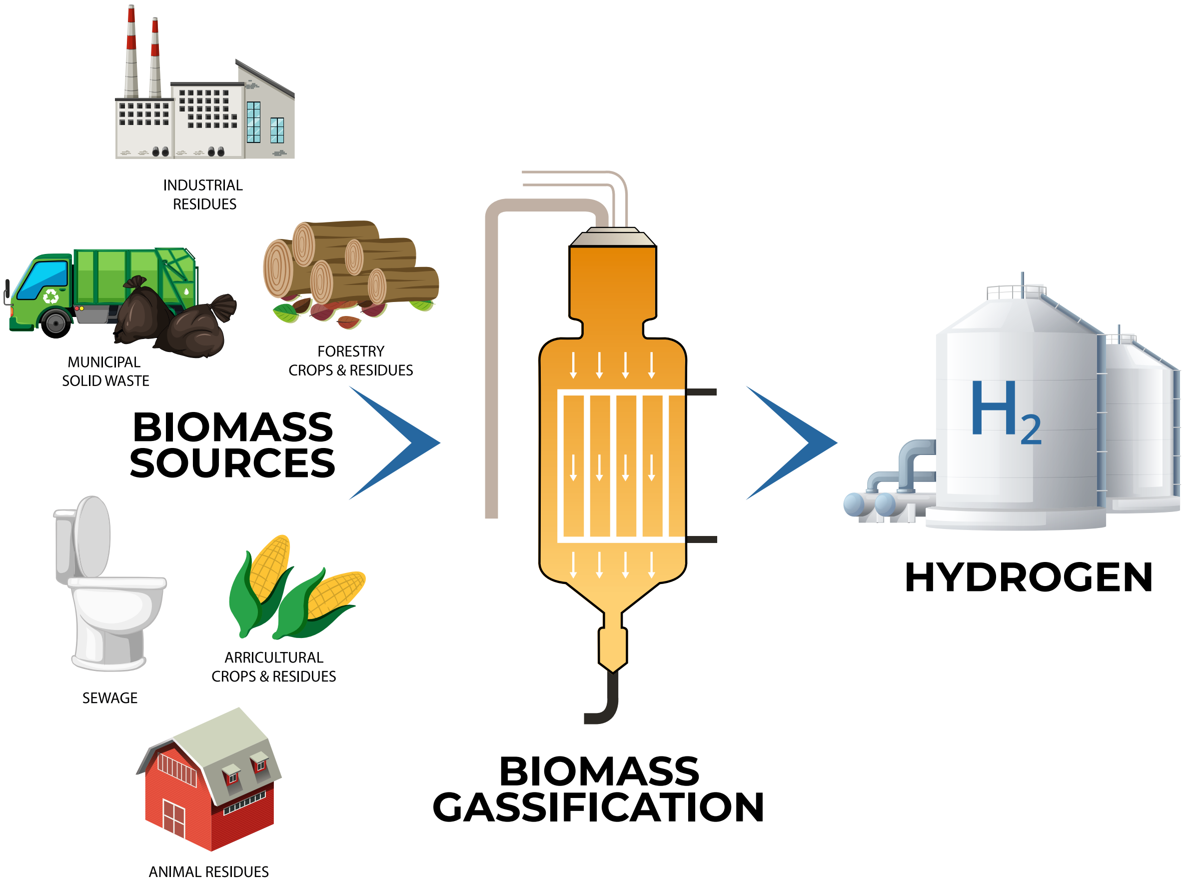


Figure 29: Hydrogen End-Use by Sector

3.6 Current and Future Technologies to Realise our Targets

Much needs to be done to ensure that every aspect in the Hydrogen Economy value chain meets the increase of efficiency to ultimately lower down the cost of hydrogen. As such, several technologies that are crucial for Malaysia to meet the targets are outlined as below.

Hydrogen Economy Value Chain	Technology	Current efficiencies	% Reduction to OPEX and Targeted Conversion Efficiency (Eff.)		
			2030	2040	2050
Production	Electrolyser (Green hydrogen)	Energy supplied to electrolyser for hydrogen generation lies in the range of 50 – 55 kWh/kg-H2	35.84% (PEM) +9% Eff. 22.50% (AEW) +7% Eff.	67.03% (PEM) +16.8% Eff. 44.3% (AEW) +11.1% Eff.	82% (PEM) +20% Eff. 60% (AEW) +15% Eff.
	Biomass Gasification (Green hydrogen)	Biomass to hydrogen efficiencies (LHV based) of up to 69% (Source: IEA Bioenergy, December 2018)	3.55% +1.4% Eff.	8% +3.2% Eff.	12.44% +5% Eff.
	SMR using natural gas with CCUS (blue hydrogen)	65% to 75%, among the highest of current commercially available production methods	-	-	-
	Carbon Capture Utilisation Storage (CCUS)	CCUS delivers 38% of the CO_2 emissions reductions needed in the chemical subsector and 15% in both cement and iron and steel (Source: IEA at COP26, 2019)	-	-	-
Storage and Transportation	Solid-State ($NaBH_4$)	4.75kg of $NaBH_4$ is required to produce 1kg of hydrogen	11.14% +5% Eff.	23.2% +11% Eff.	33.64% +15% Eff.
	Storage in the form of liquid organic chemical hydrides (LOCH), such as cyclohexane, methylcylohexane (MCH), cycloalkanes, decalin	Due to the high boiling points, LOCH are a potentially safe media as hydrogen carriers. MCH has high H_2 content up to 6–8 wt.%, or 60–62 kg/m^3 (volume based under ambient condition)	11.14% +3.5% Eff.	23.2% +7% Eff.	33.64% +10% Eff.
Re-Conversion	Catalytic Dehydrogenation of MCH	MCH conversion rate of 83.3 - 98.5%	11.14% +3.5% Eff.	23.2% +7% Eff.	33.64% +10% Eff.
End-use	Fuel cell (e.g.: Solid oxide fuel cells (SOFC))	Efficiency of 50 – 60 %	11.54% +5% Eff.	24.1% +10% Eff.	34.89% +15% Eff.



As biomass gasification will pave the way for hydrogen adoption in the short-term to mid-term period, it is crucial to develop technologies to convert biomass to hydrogen to increase the efficiency from 69% based on 2018 efficiency. Further improvement can be made to ensure efficiency to be improved starting at 3.55% in 2030, 8% in 2040 and ultimately in 2050 by 12.44%. In terms of dollars and cents, it is expected that the production cost of hydrogen to be lowered from 56,920 USD/MW/year to USD 49,837 /MW/year in 2050.

Electrolyser technology will be the most important technology for future R&D development, as it forms most of the hydrogen production in Malaysia during the long-term period. In fact, efficiency will be expected to increase by between 22.5%-35.84% in 2030, 44.3%-67.03% in 2040 and 60-82% in 2050 respectively, where the larger percentage were contributed by PEM electrolyser. Technologies for PEM electrolyser will contribute to reduction of hydrogen production cost from USD 77,000/MW/year to USD 13,864/MW/year in 2050. For AWE electrolyser the price will be lowered from USD 35,000/MW/year to USD 13,992/MW/year in 2050. Hence, it is imperative that technologies for both PEM and AWE electrolyser to be developed using the Buy-Some and Build-Some strategy.

3.7 Roadmap Summary

	Short term (2022 – 2030)	Mid term (2031 – 2040)	Long term (2041 – 2050)
Grey H2 = USD 1.5/kg Blue H2 = USD 3/kg Green H2 = USD 6/kg **Hydrogen production cost**	Grey Hydrogen : To be phased out Blue Hydrogen : USD 3.71/kg Green Hydrogen : USD 4.82/kg (Solar) USD 2.50/kg (Hydro) USD 1.72/kg (Biomass) USD 1.35/kg (Biogas)	Blue Hydrogen : USD 4.64/kg Green Hydrogen : USD 2.63/kg (Solar) USD 2.25/kg (Hydro) USD 1.72/kg (Biomass) USD 1.30/kg (Biogas)	Blue Hydrogen : USD 5.62/kg Green Hydrogen : USD 1.45/kg (Solar) USD 2.11/kg (Hydro) USD 1.72/kg (Biomass) USD 1.25/kg (Biogas)
	Long-term strategic goal is to utilise Green Hydrogen		
Environmental contribution	BAU: 0.4% GHG reduction EDS: 1.3% GHG reduction	BAU: 3% GHG reduction EDS: 8% GHG reduction	BAU: 6% GHG reduction EDS: 15% GHG reduction
Revenue generation	• BAU: Industrial Use (Non-Energy and Heat) **RM 7.4 billion** • EDS: Industrial Use (Non-Energy and Heat) **RM 12.1 billion** • **Capturing 10% of the hydrogen demand** from Japan, South Korea and Singapore resulting in **revenue of RM20 billion**	• BAU: **Industrial Use (Non-Energy and Heat) RM 37.1 billion** • EDS: **Industrial Use (Non-Energy and Heat), Power and Mobility RM 151.8 billion** • Potential and competitive **hydrogen export hub** generating revenue of **RM219 billion**	• BAU: **Power, Mobility and Industrial Use (Non-Energy and Heat) RM 151.7 billion** • EDS: **Power, Mobility and Industrial Use (Non-Energy and Heat) & Marine RM 497.2billion** • Position Malaysia to be a **major exporter in APAC** and generate revenue of **RM409 billion**
Technology agenda	• Available technologies to demonstrate, scale-up and deploy first **(Build Some)** • Complementary external technologies & solutions to be procured **(Buy Some)**	Increase in the **targeted conversion efficiency** of the technologies across the hydrogen economy value chain	**Mass deployment** in targeted renewable energy sectors (e.g.: solar, hydroelectric, biomass, OTEC)
Infrastructure and Utilisation	• Export terminal technologies and hydrogen transport technologies between production sites and export terminals. • To pilot utilisation of hydrogen as co-blended fuel	• Hydrogen used as **energy storage** in addressing the deployment of variable renewable energy (VRE) • Utilise hydrogen as **co-blend fuel** for power generation and mobility	Utilise hydrogen in the **mobility, industry (non-energy and heat), commercial and domestic sector**
Job Creation	Business-As-Usual – 168,000 Emission-Driven – 211,680		

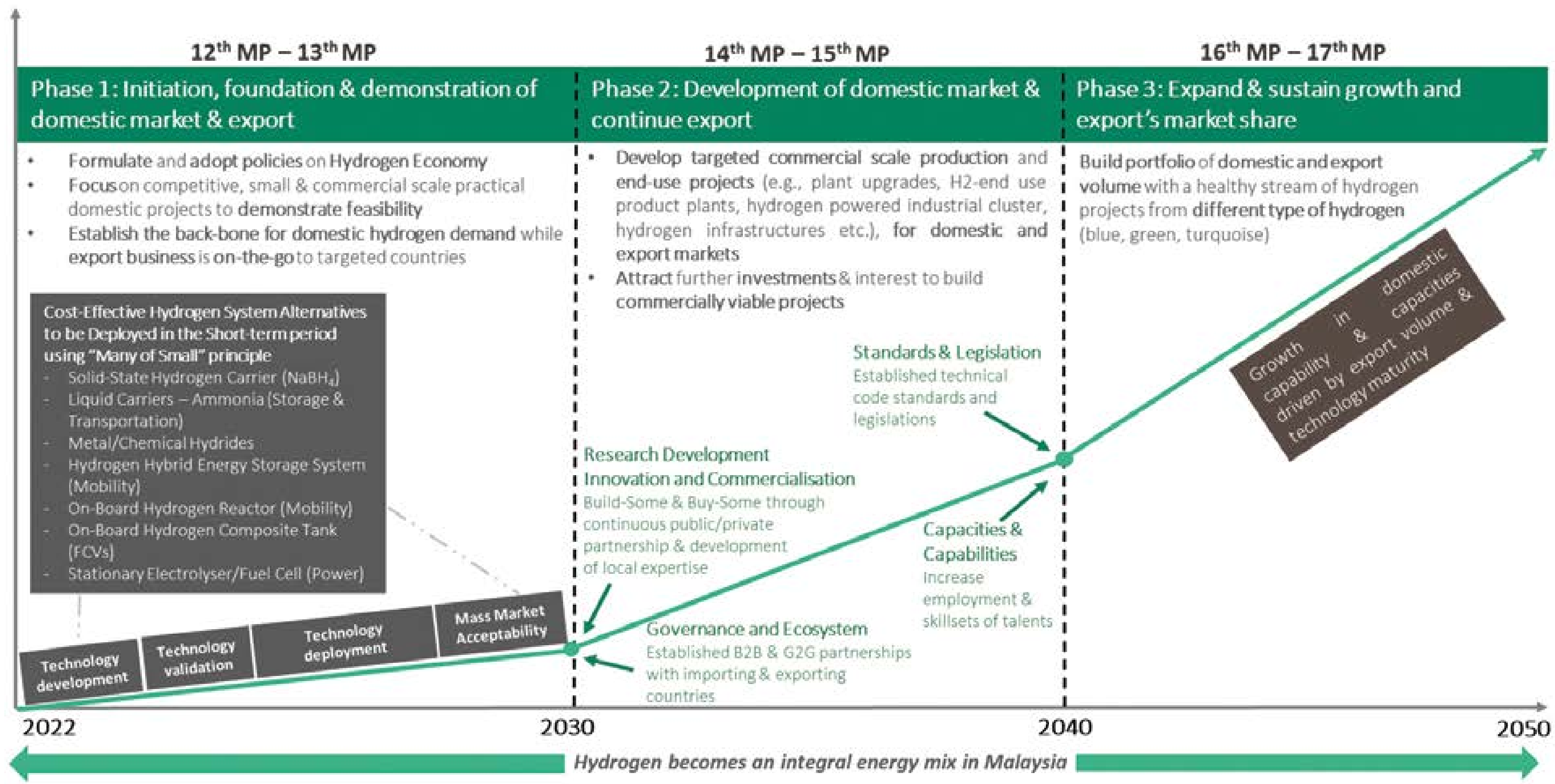
In line with the transition from current state to a state where hydrogen economy is adopted by the domestic sectors and for export, this Hydrogen Economy and Technology Roadmap (HETR) has outlined the agenda and initiatives to be achieved in the short, mid, and long-term. Beginning with the hydrogen production cost, the grey hydrogen will be phased out in short term, blue hydrogen price increases due to the price of natural gas and its limited availability. The long-term strategic approach to utilise green hydrogen by making it price-competitive by increasing the targeted conversion efficiency of the technologies across the hydrogen value chain in mid-term. Hence in the long-term, green hydrogen price reduces gradually.

The environmental contribution from hydrogen economy results in GHG reduction in which significant reduction is from the emission-driven scenario. Meanwhile in term of the revenue generation, the economy benefits increase significantly along the short to medium and finally to the long-term with the adoption of hydrogen into more domestic sectors and progressive export operation beginning with capturing 10% of the hydrogen demand with revenue of RM 20 billion and finally positioning Malaysia to be a major exported in APAC with revenue of RM 409 billion. All these revenues, reflects benefit on the development of infrastructure for export, utilisation in domestic sectors and opens a new platform for job creations.

CHAPTER

STRATEGIES AND ACTION PLANS

4.1 Phases of Malaysia Hydrogen Economy and Technology Development



The execution of short, mid, and long-term plan of the Hydrogen Economy and Technology Roadmap (HETR) are separated into three phases according to the timeline of short, mid, and long-term in which the short term covers 12th and 13th Malaysia Plan from 2022 – 2030, mid-term involves the 14th and 15th Malaysia Plan from 2031 – 2040 and long-term covers on the 16th and 17th Malaysia Plan from 2041 – 2050. To achieve the growth in domestic capability to meet the IRENA Levelised Cost of Hydrogen of USD $1 – $1.5 by 2050, the execution of the phases will be a continuous process beginning from initiation, foundation and demonstration of domestic market and export.

During Phase 1, the focus will be on establishing a back-bone for domestic hydrogen demand and initiate the export business to the targeted countries. The initiatives involved from technology development to technology deployment under the Build-Some and Buy-Some approach has been further deliberated under Strategic Thrust 3. Besides that, the home-grown technology development will take place and targeted to achieve its mass market acceptability by 2030. The cost-effective hydrogen systems to be deployed in the short-term period using 'Many of Small' principle that is listed under Phase 1 are currently on the development stage. These hydrogen technologies will be analysed under the competitive, small, and commercial scale practical domestic projects to demonstrate feasibility for mass deployment. Besides technology development, the growth in economy will take place during this phase by putting a priority in capturing the market share of imported hydrogen by exporting hydrogen produced domestically in Malaysia (of up to 0.5 – 1 MTPA by 2030) while local Hydrogen Economy is being developed.

As a continuation from Phase 1, the aim of Phase 2 will be looking at the development of domestic market with the continuation of export. By the end of short-term, under the Governance and Ecosystem and Research, Development, Innovation and Commercialisation strategic thrusts are targeted to have established Business-to-Business (B2B) and Government-to-Government (G2G) partnerships with importing and exporting countries and initiate the build-some and buy-some, respectively. In Phase 2, the focus will be to develop targeted commercial scale production and end-use projects to attract further investments for mass productions of commercially viable projects. It is aimed that by the end of the mid-term period, relevant technical code standards and legislations will be established to position Malaysia firmly in the international market.

Concurrent with the domestic market development, the employment and skillsets of talent will begin to increase. Increase in capacities and capabilities to supporting the developing Hydrogen Economy is also the pathway to achieve a knowledge-based economy (k-economy) for Malaysia to reach developed nation status. Upon initiating and achieving the key action plan under the 4-core strategic thrusts, the 3rd Phase looks at expanding and sustaining domestic growth and exports market share. This focused initiative will be to build portfolio of domestic and export volume with a healthy stream of hydrogen projects from different type of hydrogen. This will ensure growth in domestic capability and capacities driven by export volume and technology maturity throughout the long-term.

4.2 The Roadmap and Strategy

The Hydrogen Economy and Technology Roadmap (HETR) outlines 5 strategic thrusts, 8 strategies and 29 action plans towards providing strategic direction and strengthening national hydrogen economy of the country.

4.2.1 Strategic Thrust 1: Strengthening Governance System, Institutional Framework, and Regulatory Mechanism.

Strategies	Action Plan	Targets	Timeline			Players
			ST 2022 - 2030	MT 2031 - 2040	LT 2041 - 2050	
1.1 Institutionalising 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.	Q4 2023 (1st Steering Committee Meeting			Lead: MOSTI Supported by: Ministry of Economy, NRECC, MITI, ST, SEDA, PETRONAS/Gentari, Sarawak Energy, and other relevant ministries & agencies.
		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).	Q2 2023			Lead: MOSTI Supported by: Ministry of Economy, NRECC, MITI, ST, SEDA, and other relevant ministries & agencies.
		Incentivisation or permit for local manufacturers to be part of the hydrogen export supply chain.	Q1 2024 (A list of customised incentives for local manufacturers of components or hydrogen technology)			Lead: MITI Supported by: Ministry of Economy, KPDN, MATRADE, PETRONAS/ Gentari, MPRC, MIDA, SMECorp and other relevant ministries & agencies
		Standard operational procedure across the hydrogen supply value chain according to different energy and raw material sources.	Q2 2025 (One guideline document established and certification issued according to the hydrogen classification system)			

Strategies	Action Plan	Targets	Timeline ST 2022 - 2030	Timeline MT 2031 - 2040	Timeline LT 2041 - 2050	Players
	1.1.2 Develop and establish collaborative platform(s) to form a 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 mechanism 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.	Q3 2024			Lead: MITI Supported by: Ministry of Economy, MOSTI, NRECC, KPDN, MOHE, JPPKK, MIDA, Khazanah Nasional, PETRONAS/ Gentari, SEB, SEDC Energy and other relevant ministries & agencies
		Develop framework and mechanism for export of hydrogen to the targeted countries (Singapore, South Korea, and Japan).	Q4 2024			
		Build a strategic partnership network with hydrogen-producing countries to produce Malaysian graduates who are skilled in hydrogen field to improve knowledge of hydrogen technology in the TVET program while also producing graduates who meet the latest industry and technology requirements.	Q1 2024			
	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.	Q2 2024			Lead: MITI Supported by: MOSTI, NRECC, KPDN, Khazanah Nasional, MIDA, PETRONAS/ Gentari, Ministry of Economy and other relevant ministries & agencies.
		Malaysia – Singapore, China.	Q3 2024			
		Malaysia – Importing countries (e.g., Australia, Chile).	Q1 2025			
		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 local hydrogen economy is being developed.	Q1 2027 (First shipment of hydrogen)			
	1.1.4 A centralised database & impact tracking system which include monitoring & evaluation component (M&E) on TRL and status of technology development across the hydrogen value chain in Malaysia.	A centralised database & impact tracking system which include monitoring & evaluation component (M&E) on TRL and status of technology development across the hydrogen value chain in Malaysia.	Q4 2024 (One (1) online database or platform for tracking system is operational)			
		Study on the feasibility and Identify technologies under pilot study for demonstration projects/scale-up.	Q4 2025 (Two (2) feasibility studies completed)			
		Develop framework for each technology across the hydrogen value chain from development to deployment phase.	Q1 2025 (One (1) framework for technology mapping established and announced)	Q3 2031 (Five (5) demo projects completed and scaled- up)		Lead: MOSTI Supported by: Ministry of Economy, NRECC, MGTC, NMB and other relevant ministries & agencies.

4.2.1.1 Strategy 1.1: Institutionalising and Strengthening the National Hydrogen Governance and Ecosystem

A centralised National Committee named as National HETR Steering Committee is proposed to be established under the purview of the Ministry of Science, Technology & Innovation (MOSTI). The National HETR Steering Committee, chaired by MOSTI, will be tasked to oversee, and regulate the implementation of the HETR National Strategy and Action Plans in accordance with Malaysia's transition towards clean energy initiatives (i.e., energy, carbon, RE, and hydrogen-related initiatives).

The steering committee will be tasked to oversee implementation of energy-carbon-RE-and-hydrogen-related-initiatives with an authority to regulate across respective clusters which will lead different segments of the supply chain. The detailed roles and responsibilities of the committee is described in the action plan to deliver the dynamic needs required as the steering body for the national hydrogen agenda.

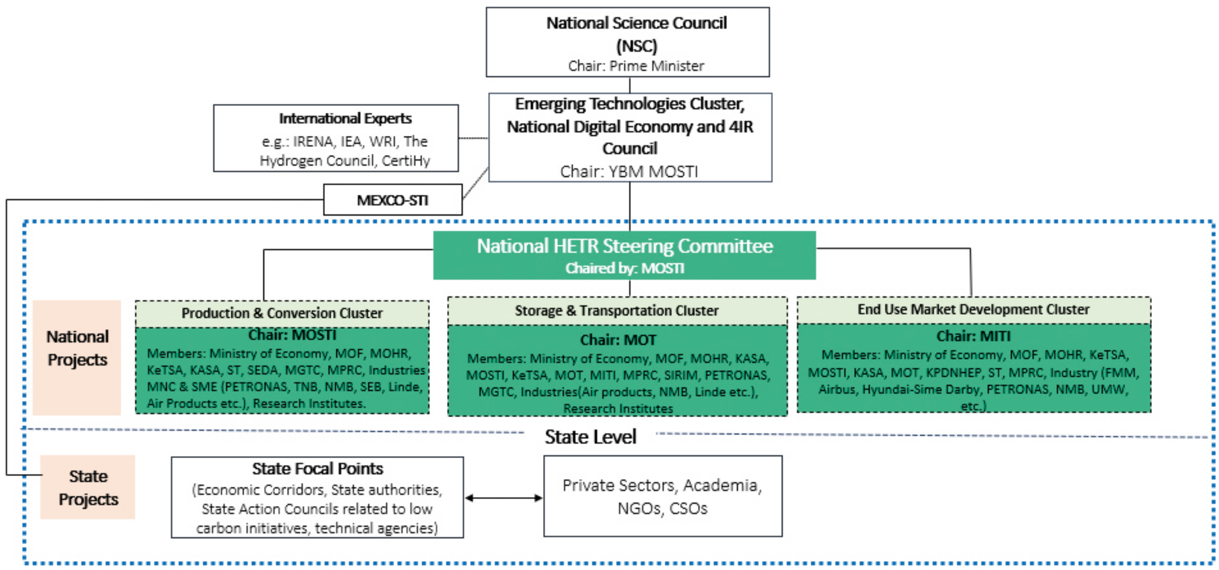


Figure 30: Proposed governance structure of National Hydrogen Economy and Technology Roadmap (HETR) Steering Committee

The Emerging Technologies Cluster, National Digital Economy and 4IR Council (*Kluster Teknologi Baru Muncul, Majlis Ekonomi Digital dan 4IR Negara*), provides strategic direction on the emerging hydrogen technology that have the potential to be developed in Malaysia and also oversee the policy and act as enabler that drives the implementation of action plans and development of technology under the HETR. The council will be advised by International Advisory Panel on emission reduction strategy and emerging technologies.

The governance and planning of the hydrogen sector are very complex and include diverse aspects as energy related decision making covers a wide scope and nature across sectors. Hence, the members of the National HETR Coordination Committee cuts across the Hydrogen Economy value chain clusters in which the members of the committee are grouped according to three main clusters led by the following respective ministries:

Cluster 1: Production and Conversion to be led by Ministry of Science, Technology and Innovation (MOSTI)
Cluster 2: Storage and Transportation to be led by the Ministry of Transport (MOT)
Cluster 3: End-Use Market Development to be led by the Ministry of Investment, Trade and Industry (MITI)

Each cluster will be led by different ministries according to the nature of respective cluster that matches with their core functions. Energy supply and demand consisting of various energy sources such as natural gas and RE also requires cooperation across a wide range of sectors with stakeholders related to industries, natural resources, and environment.

Each cluster need to plan and coordinate the research development, talent growth, funding/investment, legislation, supply chain and logistics, technology commercialisation accelerator, and incentivisation/tax/subsidy for technology mass deployment.

Under this proposed structure, state projects related to hydrogen economy will be overseen by respective State focal points. *Mesyuarat Menteri-Menteri Dan Ahli-Ahli Majlis Mesyuarat Kerajaan Negeri Yang Bertanggungjawab Mengenai STI (MEXCO-STI)*, will serve as a platform to harmonise the Federal Government and State Governments' direction and initiatives. Through this structure the visibility of respective ministries and their roles are enhanced.

Strategies	Action Plan	Targets	Timeline			Players
			ST 2022 - 2030	MT 2031 - 2040	LT 2041 - 2050	
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.	Q4 2024			Lead: MOSTI Supported by: NRECC, MITI, MGTC, SEDA, ST, PETRONAS/Gentari, industry players and other relevant ministries & agencies
	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.	Q1 2026			Lead: Energy Commission (ST) Supported by: Ministry of Economy, Sarawak State Government, Sabah State Government, Standards Malaysia, PETRONAS/ Gentari, and other relevant ministries & agencies
		Development of guideline for verifiable certification system and guarantees of origin scheme that allow end-users to know the origin, quality (purity) and life cycle GHG emissions of hydrogen.		Q2 2035		Lead: Standards Malaysia Supported by: NRECC, SIRIM, MGTC, SEDA, PETRONAS/Gentari and other relevant ministries & agencies
		Study and develop guideline as well as monitor on the safety aspects implementation along the hydrogen economy value chain.	Q1 2026			Lead: DOSH/JKKP Supported by: MOHR, Standards Malaysia, SIRIM, PETRONAS/ Gentari, SEB, SEDC Energy and other relevant ministries & agencies
	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 has not been tapped for hydrogen production as energy storage medium.		Q1 2031 (One (1) study)		Lead: NRECC/Energy Commission (ST) Supported by: MoF, Ministry of Economy, ST, SEDA, MGTC, TNB, PETRONAS/Gentari, NMB and other relevant ministries & agencies

Strategies	Action Plan	Targets	Timeline ST 2022 - 2030	Timeline MT 2031 - 2040	Timeline LT 2041 - 2050	Players
		Study on the allocation of special tariff for electricity generation from hydrogen using the Green Electricity Tariff (GET) programme for the hydrogen production using the allocated hydropower capacity business model.		Q1 2035 (One (1) study)		
		Study and analyse on 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 private sector.		Q1 2032 (One (1) business model)		
		Roll out feasible and cost-effective technologies related to hydrogen for energy storage solutions.	Q1 2028 (One (1) pilot project)			
		Study on blending of up to 20% hydrogen in Combined Cycle Gas Turbine Power Plant (consideration for initial 1% blending of hydrogen in retrofitted or retired CCGT power plant).		Q1 2035 (One (1) study)		Lead: NRECC/Energy Commission (ST) Supported by: Ministry of Economy, TNB, ST, PETRONAS/Gentari, and other relevant ministries & agencies
		Detailed technical economic feasibility studies to set parameters for hydrogen blending with natural gas in existing pipeline according to the pipeline conditions (e.g.: internal pipe wall protection, ancillaries' equipment stability).	Q1 2026 (One (1) study			Lead: Energy Commission (ST) Supported by: Ministry of Economy, NRECC, TNB, PETRONAS/ Gentari, and other relevant ministries & agencies.
	1.2.4 Adopt and harmonise hydrogen taxonomy, technical code, and safety standards. (Supporting NEP Action Plan B8)	Study and adopt the relevant standards that is applicable across the hydrogen economy value chain to facilitate future flow or trade of hydrogen.	Q3 2025 (One (1) study on industry standard for hydrogen)			Lead: Standards Malaysia Supported by: MoF, MOSTI, MITI, NRECC, Ministry of Economy, ST, SEDA, MGTC, and other relevant ministries & agencies.

4.2.1.2 Strategy 1.2: Strengthen Regulatory Framework, Existing Policies/ Act, and Legislation

Implementation of a new operation at the upstream and downstream requires a top-down approach which includes legislation, public policies and regulation to be strengthened through the implementation of low carbon hydrogen projects which indirectly contributes to the National Carbon Emissions Reduction. Adoption of hydrogen for Combined Cycle Gas Turbine (CCGT) plant requires technical and economic feasibility studies prior to be included in the Malaysian Gas Supply Act. As the regulatory scope of the hydrogen economy is wider than the scope of the Gas Supply Act, a detailed study needs to be conducted for the proposed regulation amendments that addresses the usage, licensing, tariffs, safety, and standards for hydrogen in the Gas Supply Act.

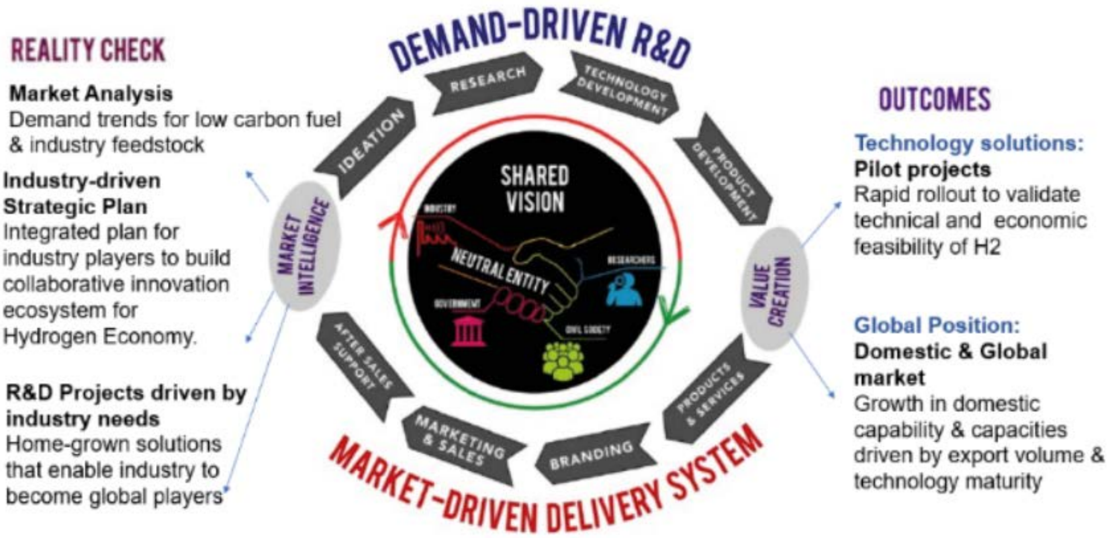
The production and consumption of hydrogen in power sector also brings forward an opportunity for power generation industrial sectors to leverage on their potential to use hydrogen as co-blend with natural gas or coal. Technical and economic feasibility studies need to be conducted to study the percentage of hydrogen blending with natural gas in the existing gas pipelines. Malaysia Renewable Energy Roadmap has highlighted that, at 30% solar penetration level in relatively low demand days such as on weekends, excess solar PV generation may cause some baseload plants to shut down and result in frequency stability issues.

Hence, it was proposed to adopt cost competitive storage solutions in the short term and explore initiatives to develop storage technologies, e.g., green hydrogen in the long term. This has been detailed out as part of the target to be achieved under the mechanism to facilitate hydrogen production and consumption in the power sector. For example, the electrolyser could be turned on during periods of excess solar energy production to store the renewable energy as hydrogen. Then, during periods of high demand, data centres could start up the hydrogen fuel cells to generate electricity. The conversion of energy from electricity to hydrogen and back to electricity in a power station is deemed to be inefficient as it involves a lot of energy loss. Therefore, the use of hydrogen as a renewable energy source for electricity generation are proposed to be limited to generators in rural areas where there is no grid connection. It is important to note that, any planning which affects the supply of Electricity and Renewable Energy in the Peninsula and Sabah must be in line with the Planning and Generation Development Plan approved under the Electricity and Tariff Development Implementation Planning Committee (JPPPET). This is because the supply of electricity in the Peninsular and Sabah is under the jurisdiction of the Minister of Energy, in accordance with the Electricity Supply Act 1990 [Act 447]. Therefore, any form of project proposal involving the generation of electricity using hydrogen needs to be studied, discussed, and an approval obtained from the Ministry of Natural Resources, Environment and Climate Change (NRECC) prior to implementation.

While the national niche areas provide strategic focus, the translation on the ground cannot happen effectively unless there is a collaborative platform that brings together key players to spearhead concerted action. The collaborative platform provides a more holistic solution and effective implementation of strategies, policies, and programmes. To develop a conducive Hydrogen Economy and Technology ecosystem, we need the 8 clusters (capacity builders, connectors, producers and manufacturers, technology providers, financing providers, standards setters and regulators, supply chain and logistics providers and market access providers) to come together.

This collaborative platform will be able to promote the Business-to-Business (B2B) and Business-to-Consumers (B2C) collaboration for further hydrogen initiatives implementation. Figure 31 presents the Hydrogen Economy and Technology clusters that need to come together in building the platform, whereas Figure 32 shows the iConnect collaborative platform as supportive mechanism for local technology commercialisation to bridge the local technology innovation chasm.

Figure 31: The 8 clusters of the Hydrogen Economy Ecosystem



Source: ASM New Economic Opportunities in STI-based Industries to Serve Emerging Markets, 2017

Figure 32: iConnect collaborative platform between researchers (Academia) and local industries in creating the demand-driven R&D and market-driven delivery system.

4.2.2 Strategic Thrust 2: Facilitating Enabling Environment and Economic Instruments.

Strategies	Action Plan	Targets	Timeline			Players
			ST 2022 - 2030	MT 2031 - 2040	LT 2041 - 2050	
2.1 Acceleration of hydrogen economy adoption by local industry sector	2.1.1 Subsidise and incentivise 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 subsidy for diesel vehicles by stages and reallocate to subsidise hydrogen fuel for Commercial and Heavy Vehicles by stages to support the transition from fossil fuels to greener energy for long-term investment.		Q2 2031 (One (1) mechanism to phase-out fossil fuel subsidy)		Lead: MoF Supported by: Ministry of Economy, KPDN, MOT, and other relevant ministries & agencies.
	2.1.2 Dedicated funding and allocation from focused area budget/ grants as a stimulus to support hydrogen initiatives. (Supporting NEP Action Plan E2)	Strengthening international networking to facilitate provision of international funding and green hydrogen investment projects to spearhead green economy based on hydrogen.	Q2 2026 (One (1) pilot project activated under international fund)			Lead by: NRECC Supported by: MoF and Ministry of Economy
		Allocate and review incentives and source from funding agencies (including GITA/GITE and e-dana) to support the hydrogen technologies innovation demonstration & early commercialisation projects. Example of incentives are: i. i.Purchase subsidy, Exemption of Sales Tax, Excise Duty, Import Duty, and Road tax for FCEV; ii. ii.Green Investment Tax Allowance and Green Income Tax Exemption for Projects and Purchase of Hydrogen Technologies as Assets. iii. iii.Pioneer status and import duty exemption for investment on relevant manufacturing activities	Q1 2026			Lead: MoF Supported by: Ministry of Economy, NRECC, MITI, MOSTI, MGTC, NMB, MAVCAP, Khazanah Nasional and other relevant ministries & agencies.

Strategies	Action Plan	Targets	Timeline			Players
			ST 2022 - 2030	MT 2031 - 2040	LT 2041 - 2050	
	2.1.3 National Hydrogen Fund for hydrogen-related projects and technology at R&D and Commercialisation phase from dedicated funding and allocation under focused area budget. (Supporting NEP Action Plan B8)	Green financial instruments with attractive rates to develop local hydrogen ecosystem and project and nurture the sustainability of green hydrogen economy.	Q1 2025 (One (1) business model study on green financial instruments deployed by MOF)			Lead: MOSTI Supported by: NRECC, NMB, MGTC, MAVCAP, Khazanah Nasional, and other relevant ministries & agencies.
		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).	Q1 2027 (One (1) funding programme for TRL 6 and above)			
		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.	Q2 2026 (Two (2) joint feasibility studies with local/ foreign partners to commercial large-scale projects)			
	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 & supply side.	Q2 2025 (One (1) mapping of the renewable energy resources for hydrogen generation)			Lead: MPIC Supported by: NRECC, KPDN, ST, SEDA, KASA, PETRONAS/Gentari, MGTC, MITI, MIDA, MPOB, MIGHT, and other relevant ministries & agencies.
		Agreement with focused industry sectors for raw material sourcing for hydrogen demonstration projects.	Q1 2026 (One (1) business matching platform)			
		Study and analyse on the staggered or incentives pricing for biomass feedstock.	Q1 2028 (One (1) joint feasibility study)			

Strategies	Action Plan	Targets	Timeline			Players
			ST 2022 - 2030	MT 2031 - 2040	LT 2041 - 2050	
	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 CO_2 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)	Q1 2027 (One (1) study)			Lead: Ministry of Economy Supported by: PETRONAS/Gentari, SEDC, MIDA, Khazanah Nasional and other relevant ministries & agencies.
		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.	Q1 2027 (One (1) demonstration project from petrochemical industry)			
	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.	Q1 2025 (One (1) joint feasibility study on the implementation)			Lead: MOT Supported by: MOSTI, Ministry of Economy, MARii, APAD, State Governments and other relevant ministries & agencies.
		Encourage pilots into various future powertrains (e.g., hydrogen trucks / light duty commercial vehicles) in the Peninsular, Sarawak and Sabah.		Q1 2031 (One (1) joint feasibility study on the implementation and one (1) commercialised H2 powertrains		
	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.	Q1 2030 (One (1) demo projects on hydrogen as fuel for marine)			Lead: MOT Supported by: Marine Department Malaysia (MDM), PETRONAS/ Gentari and other relevant ministries & agencies.

Strategies	Action Plan	Targets	Timeline			Players
			ST 2022 - 2030	MT 2031 - 2040	LT 2041 - 2050	
	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).		Q2 2031 (One (1) joint feasibility study on implementation)		Lead: MOT Supported by: MOSTI, Malaysia Aviation Commission, Civil Aviation Authority Malaysia (CAAM), Aerospace Malaysia Innovation Centre (AMIC), PETRONAS/ Gentari and other relevant ministries & agencies.
		Initiate studies to culminate into commercial projects to capture the emerging clean fuels for aviation.		Q1 2032 (One (1) joint feasibility study on implementation)		
		Decarbonisation of aerospace sector by developing a sustainable ecosystem that involve hydrogen technology through industrial programme.		Q1 2035 (One (1) joint feasibility study on implementation)		

4.2.2.1 Strategy 2.1: Acceleration of Hydrogen Economy Adoption by Local Industry Sector

The Hydrogen Economy in Malaysia is still at a nascent stage, competitive supply-chain is not yet established, and current cost structure is still expensive which requires a lot of policy push, governmental and financial support, investments (projects and R&D), and cross collaboration/ partnership. This means that funding needs to be sustainably sourced. An incentive schemes supported by hydrogen policies and targets needs to be in-place to promote the creation of domestic & export hydrogen economy. The review of the incentive schemes includes tax breaks, hydrogen tax credits, special pioneer status incentives and custom duties exemption for clean hydrogen projects, including hydrogen-related assets to be considered as part of the Green Investment Tax Allowance (GITA) and Green Income Tax Exemption (GITE). The phase-out of fossil fuel subsidies will support the shift from fossil fuels to greener raw materials for long-term investment. As such, the government should focus on reducing fossil fuel subsidies over time and introduce subsidies for renewable technologies.

The initial cost of building a complete hydrogen infrastructure for the transportation and power sectors that encompasses production, purification, distribution, and storage is very high. Through the National Investment Aspirations (NIA) developed by MITI, we will be able to strengthen the international networking to facilitate provision of international funding and green hydrogen as NIA act as a key guiding principle for our New Investment Policy to ensure an accelerated and holistic national growth. A key priority for the New Investment Policy involves introducing initiatives targeted at strengthening Malaysia's foundations in adopting enhanced ESG standards, in-line with global megatrends such as achieving Net Zero earliest by 2050. This includes incentivising companies to embed ESG practices within their business. Development of the strategic hydrogen assets under the National Hydrogen Fund shall introduce benefits for hydrogen project and infrastructure development at selected locations to position them as hydrogen clusters.

Feasibility studies must be carried out with substantial collaborations from all stakeholders in terms of time, effort, and investment. The feasibility studies that need to be commissioned are as follows:

- Commission a specific study on the resources available to produce hydrogen (supply-side study) and the domestic supply/demand/export balance to spur the hydrogen economy and ecosystem;
- Commission a specific study for ammonia supply chain
- Commission a specific study on Hydrogen + Natural Gas co-combustion in CCGT vs. CCS at the point of use
- Commission a specific study for potential hydrogen industrial cluster
- Commission a specific study for hydrogen for land mobility

Commitment to cost-share must also be put in place to relieve the early adopters of this burden. The subsidies and incentives will boost up the transition to low-carbon projects to be deployed for large scale utilisation. Hence, as a start project that have proof-of-concept that has passed Technology Readiness Level 4 (TRL 4) and above, need to have a feasibility study conducted by relevant ministries together with industries for a demonstration level deployment at a strategic location.

This also includes development of portfolio on the stream of feedstock availability from oil palm sectors, and their steady supply for hydrogen production. In line with the Twelfth Malaysia Plan (RMK-12) in promoting private sector investments in driving industrial growth, government need to identify and prioritise specific segments for a targeted investment in the infrastructure for adoption at the end-use sectors. Based on the economic values that is generated through the chosen least-cost pathway in the techno-economic modelling, the total investment needed are shown in Table 13. The breakdown of the subsidy, incentives and dedicated fundings that is required to reduce cost and accelerate growth of hydrogen economy in term of research, commercialisation and deployment at end-use sectors is tabulated in Figure 33.

Table 13: Cumulative investment (RM Million) for BAU and EDS

Scenario / Timeline	Cumulative Investment (RM Million)	Revenue Generation (RM Million)	GDP Contribution (RM Million)	Job Creation
Business As Usual Scenario (BAU)				
2025-2030	2,381	3,427 (Domestic) 6,671 (Export)	6,036	
2031-2040	26,034	32,099 (Domestic) 62,411 (Export)	80,656	168,000
2041-2050	53,580	86,669 (Domestic) 120,252 (Export)	187,858	
Emissions Driven Scenario				
2025-2030	6,055	9,567 (Domestic) 6,671 (Export)	13,644	
2031-2040	59,716	66,876 (Domestic) 62,411 (Export)	136,376	211,680
2041-2050	124,726	208,725 (Domestic) 120,252 (Export)	338,841	

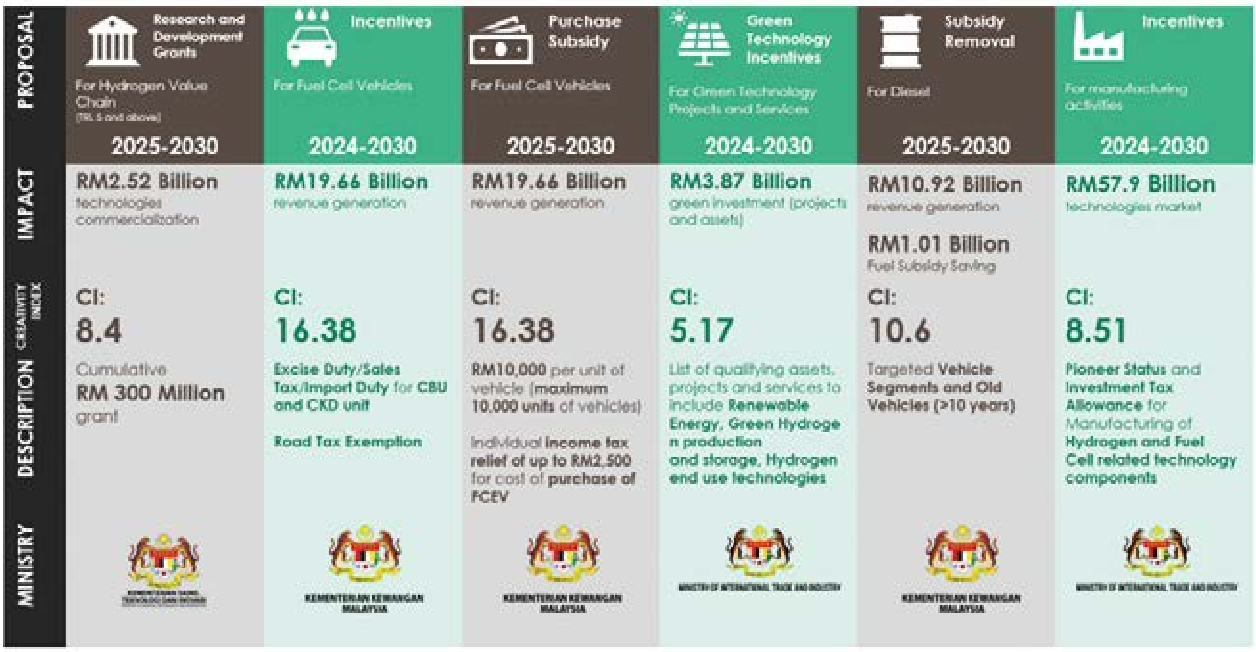


Figure 33: Proposed breakdown of grant/subsidy/incentives from respective ministries to accelerate Hydrogen Economy and the economic returns.

Strategies	Action Plan	Targets	Timeline			Players
			ST 2022 - 2030	MT 2031 - 2040	LT 2041 - 2050	
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.	Q1 2024 (Cost benefit analysis proven for adoption of the technology by at least two industries)			Lead: MOSTI Supported by: Ministry of Economy, NRECC, MITI, KPKT, MIDA, MPIC, PETRONAS/Gentari and other relevant ministries & agencies.
		Hydrogen Economy to be part of the circular bioeconomy for industries that produce biowaste.	Q1 2026 (Two (2) collaboration initiatives with agriculture and forestry industry players to add-value to the waste)			

4.2.2.2 Strategy 2.2: Accelerating Transition to the Circular Economy

The Twelfth Malaysia Plan (RMK-12) has positioned the Circular Economy model for economic sectors that is mainly from manufacturing sectors applicable to all type of products toward transition into low carbon economy. The concept of low carbon economy involves recycling, reusing, remanufacturing, and maintaining existing processes. The Circular Economy model will determine the linkages between economic growth and the use of natural resources as well as environmental impact, which will be a key reference for policymaking. This is crucial in boosting resource efficiency and maintaining environmental ecosystem resilience.

Coming to the context of Hydrogen Economy, waste-based hydrogen production through circular bioeconomy realises the pathway for hydrogen production from POME and domestic waste or municipal solid waste. A waste biorefinery–circular bioeconomy strategy represents a low carbon economy by reducing greenhouse gases footprint and holds greater prospects for a sustainable and greener world. The targeted sectors that may adopt the circular bioeconomy are oil palm mill, domestic waste industries such as sewage, producer of fertiliser and other bio-based products.

Strategies	Action Plan	Targets	Timeline			Players
			ST 2022 - 2030	MT 2031 - 2040	LT 2041 - 2050	
2.3 Low Carbon Hydrogen contributing to GHG mitigation strategies	2.3.1 Implementation of Low Carbon Hydrogen projects that contributes 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.	Q4 2027 (One (1) assessment study)			Lead: NRECC Supported by: MGTC, SEDA, ST, PETRONAS/Gentari, Bursa Malaysia, and other relevant ministries & agencies.
		Assessment of methodology on Low Carbon Hydrogen to be adopted under the international carbon market mechanism.	Q4 2028 (One (1) assessment study)			

4.2.2.3 Strategy 2.3: Low Carbon Hydrogen Contributing to GHG Mitigation Strategies

Malaysia aspires to achieve net zero greenhouse gas (GHG) emissions as early as 2050. Malaysia has recently updated its Nationally Determined Contributions (NDC) target stating its intention to reduce economywide carbon intensity (against GDP) of 45% compared to 2005 levels.The National Energy Policy 2022- 2040 has strategically roll-out strategies and action plan to enable the country to effectively navigate challenges and capture large opportunities associated with energy transition and other global megatrends, towards achieving Low Carbon Nation Aspiration 2040. Following the pledge that Malaysia has made under the UNFCCC and Paris Agreement, the Ministry of Natural Resources, Environment and Climate Change (NRECC) (formerly known as the Ministry of Environment and Water- KASA) is developing a Long-Term Low Emissions Development Strategies (LT-LEDS).

In this regard, there is a need to assess low carbon hydrogen initiatives as a potential mitigation action to contribute towards the achievement of Malaysia's Nationally Determined Contributions (NDC) and LT-LEDS.

On the other hand, the Government also need to assess the potential of Low Carbon Hydrogen projects to be adopted under the international carbon market mechanism including the standards and methodology.

4.2.3 Strategic Thrust 3: Accelerate Commercialisation of Technology to Enable Export and Domestic Uptake.

Strategies	Action Plan	Targets	Timeline			Players
			ST 2022 - 2030	MT 2031 - 2040	LT 2041 - 2050	
3.1 Advancing Research Development Innovation Commercialisation 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.	One (1) electrolyser demonstrator plant (Q4 2024) – PEM Electrolyser One (1) biomass-based demonstrator plant (Q1 2026) AWE electrolyser demonstrator plant at SEB to be further validated for large scale commissioning (Q1 2028)	One (1) MSW demonstrator plant (Q1 2032) One (1) biogas-based demonstrator plant (Q1 2034)		Lead: MOSTI Supported by: Ministry of Economy, NRECC, MITI, MGTCSEB, SEDA, PETRONAS/Gentari, NMB and other relevant ministries & agencies.
		Industrial scale project (by local and international players) to be deployed and start commission at potential location that supports export and domestic consumption.		Q2 2035 (One (1) industrial scale project commissioned)		Lead: MITI Supported by: MOSTI, NRECC, MGTC, SEDA, NMB and other relevant ministries & agencies.

Strategies	Action Plan	Targets	Timeline			Players
			ST 2022 - 2030	MT 2031 - 2040	LT 2041 - 2050	
	3.1.2 Development of localised 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	Q1 2025 (One (1) joint feasibility study on the implementation)			Lead: MITI Supported by: Ministry of Economy, NRECC, MIDA, MIGHT, SEDA, ST, PETRONAS/Gentari, and other relevant ministries & agencies.
		Participation of local services providers (e.g., services providers of logistic, engineering, construction, O&M) in the development of local projects by international and local hydrogen players.	Q3 2025 (10% of local service providers in hydrogen development project)			
		Deployment of hydrogen fuel-cell truck as the mode to transport hydrogen by truck for decentralised hydrogen production.	Q3 2030 (Five (5) FCEV trucks)			
		Decentralised hydrogen production in the early deployment stages of the Hydrogen Economy.	Q2 2027 (One (1) decentralised project)			
		Large-scale centralised hydrogen production plants.	Q1 2030 (One (1) centralised project)			

Strategies	Action Plan	Targets	Timeline			Players
			ST 2022 - 2030	MT 2031 - 2040	LT 2041 - 2050	
	3.1.3 Technology penetration into market through the Build-Some and Buy-Some approach. (Supporting NEP Action Plan E2)	Analyse the economic viability for technology that has proof-of-concept.	Q1 2024 (E-learning tools or software on economic modelling analysis to capture and analyse data to verify technology commercial value)			Lead: MOSTI Supported by: MoF, MITI, NRECC, MOHE, MOT, Technology Depository Agency (TDA), , MGTC, NMB, , TPM, MIDA, MARii, RIs, Industries and other relevant ministries & Agencies.
		Develop infrastructure for projects that is at pilot scale with proven proof-of-concept for hydrogen storage and delivery.	Q1 2025 (One (1) Green hydrogen refuelling station demo project)			
		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.	Q2 2024 (Five (5) public-private partnership established)			
		Industry to provide facilitation (testing facility) and government to provide fundamental and matching grant according to the TRL of the research/ project	Q1 2024 (One (1) testing facility)			
		Incentives for hydrogen pre-commercialisation scale project	Q1 2026			

Strategies	Action Plan	Targets	Timeline			Players
			ST 2022 - 2030	MT 2031 - 2040	LT 2041 - 2050	
	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 port(s) in Malaysia. (Supporting NEP Action Plan B8)	Q1 2027 (Three (3) potential terminal port for hydrogen export)			Lead: MITI Supported by: Ministry of Economy, NRECC, MOT, MATRADE, ST, MPIC, Standards Malaysia, PETRONAS/Gentari, MCMC, KKLW and other relevant ministries & agencies.
		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)		Q1 2031 Two (2) state governments and (2) economic corridors to implement the project		
		Transportation sector networks which include hydrogen pump stations, related infrastructure, and dedicated hydrogen corridors with strategic depots. (Supporting NEP Action Plan B2)		Q1 2035 (2% - 5% of the Low Carbon Zone have establish hydrogen transportation networks)		
		Identify new or existing industrial clusters to be further developed with demonstration and / or commercialised 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)	Q2 2027			

4.2.3.1 Advancing Research Development Innovation Commercialisation and Economy through Build-Some and Buy-Some Strategy

The technologies that have been analysed and considered for the Hydrogen Economy and Technology Roadmap (HETR) has been projected from commercialisation to mass market acceptability across the 30-year horizon. Given the current lack of infrastructure for domestic use, centralised production and distribution would require immense investment as well as governmental push and support. Meanwhile the decentralised system would lead to sporadic use of hydrogen, without creating the necessary national-level demand uptake and impact that would pull more investment. Hence, in the short to medium term, a decentralised production and distribution of hydrogen is more technically and commercially viable until the domestic market is created, and infrastructures are ready. The decentralised system covers on the demonstration project that will be carried out based on on-site off-grid RE power generation. A centralised hydrogen system could be effective for large captive hydrogen-based industrial hubs.

Prior to the technology development using the Build-Some and Buy-Some approach, it is important to identify and prioritise specific segments and value chain to be promoted as main domestic hydrogen sector. Build-Some and Buy-Some approach will develop intellectual capabilities of local talent and develop an expedited Hydrogen Economy initiative. The distinctive differences between these approaches are:

a. Costing required from planning to scale-up for deployment. As Build-Some begins from initial development to continuous maintenance, the incurred cash flow is higher than Buy-Some in which businesses can bypass initial development costs and only spend on operational and maintenance costs.

b. Time to Market: When technology is procured, the readiness of the said technology to be integrated with minimal technical resources or risks can be achieved in a relatively shorter period. Developing a new technology or solution in-house can take months, even years, to implement and has a timeline that is largely unpredictable.

The choice between Build-Some (in-house development) or Buy-Some (outsourced technology) comes up often in the world of technology commercialisation. The strategy behind deciding whether to build or buy a solution is multifaceted – spanning across the business and affecting the timeline. On that note, the qualifying criteria for technologies under Build-Some and Buy-Some are as follows:

(a) Build-Some

- Proven proof-of-concept that's been validated with a prototype.
- Available infrastructure for pilot-scale testing;
- Readiness of collaborators to deploy the technology.
- Efficiency of the technology/process for a life-time usage once it has been scaled-up.

(b) Buy-Some

- Proven Return on Investment (ROI);
- Certified in terms of safety and technical standards to be complied with;
- Able to be customised according to the end-user or client requirement;
- Cost competitiveness over the 30-year horizon.

The technologies that have been analysed and considered for the HETR has been projected from commercialisation to mass market acceptability across the 30-year horizon as shown in Figure 34. Some of these technologies are already being developed such as the SMR-CCUS, ammonia production, liquid organic hydrogen carrier (MCH), and alkaline water electrolyser. However, the mass market deployment of the technology is still at its pre-mature phase, hence it is included in the mapping as well. It is recommended for the National HETR Steering Committee or Technology Taskforce to scan for niche domestic areas / technology unique for Malaysia (or where clear leader has not emerged yet) prior to deciding on moving forward with the Build-some or Buy-Some approach. The commercialisation and mass market deployment of this technology is subjected to regulation, policies, standards creation, and industry readiness assuming the timeline it takes for the technology to be into the commercialisation stage as follows:

a. Technology that is at TRL 3 – 5: 6 – 9 years
b. Technology that is at TRL 5 – 7: 4 – 8 years
c. Technology that is at TRL 7 – 9: 2 – 6 years

As the technology development phase are on-going, an integrated low carbon and hydrogen industrial cluster and hubs need to be further developed and established at the production and end-use sector for further expansion. Upon commissioning and gaining revenue, the low carbon / hydrogen industrial clusters need to be established as special economic zone equipped with supportive incentives such as the development of Drone and Robotics Zone (DRZ) Iskandar that is solely meant for drone and robotics eco-system. Besides gaining revenue from export operation, hydrogen can also be used as a fuel in fuel cell systems for buildings, backup power, or distributed generation. Hydrogen used in power via fuel cell is one of the end-use technology applications under the power sector for the Emission Driven Scenario (EDS).

Renewable hydrogen will enable deployment of Variable Renewable Energy (VRE) such as wind and solar and will be a game changer by breaking the integrated traditional power systems. The power can be supplied using the stationary fuel-cell applications and portable fuel-cell applications. Hydrogen backup power utilise the Proton-Electron Membrane (PEM) technology to support DC power. Hence, it provides a promising future for the data/ telecommunication industry. For mid-term (2031-2040) the hydrogen demand for this technology accounts for 36 TWh, meanwhile for long-term (2041-2050) the hydrogen demand is 162 TWh.

Proton-exchange membrane fuel cells (PEMFC), also known as Polymer Electrolyte Membrane (PEM) fuel cells was built and advanced materials for polymer composite bipolar plates were developed in 1995. Domestic PEMFC technology in Malaysia has currently reached the design and fabrication stage from 200 W, 1 kW, and up to 5 kW maximum power (Fuel Cell Industries in Malaysia, 2017).

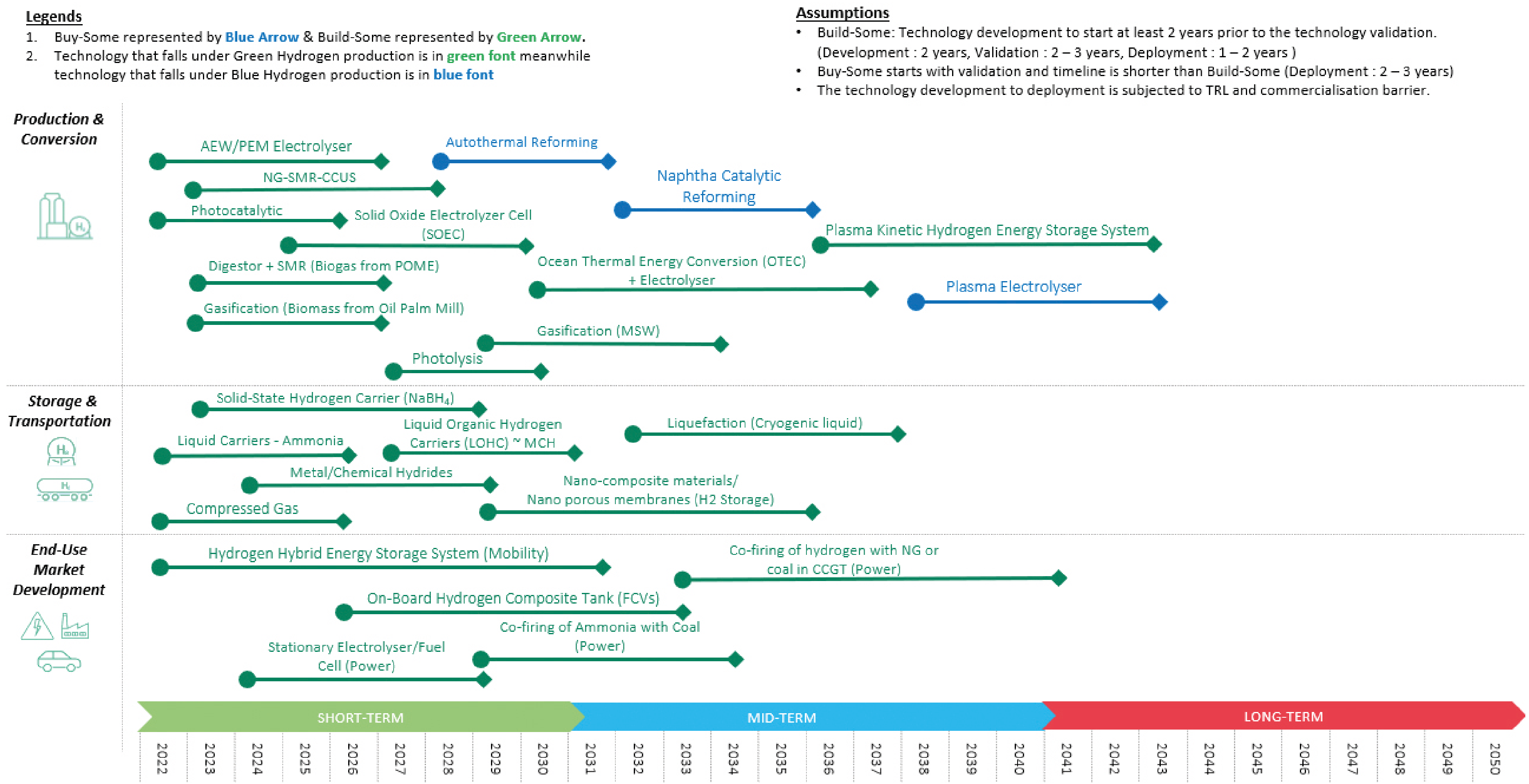


Figure 34: Technology to build and buy across the 30-year horizon (List is not exhaustive & technology mapping need to be revised every 3 to 5 years)

Based on the technologies that has been categorised according to Buy-some and Build-some, the path that would serve as guideline to commercialise the technologies begins from (a) Technology Development: Product Development and Scale-Up Projects, (b) Technology Validation: Venture Building and (c) Technology Deployment: Ecosystem Growth and Expansion are shown below in Figure 35:

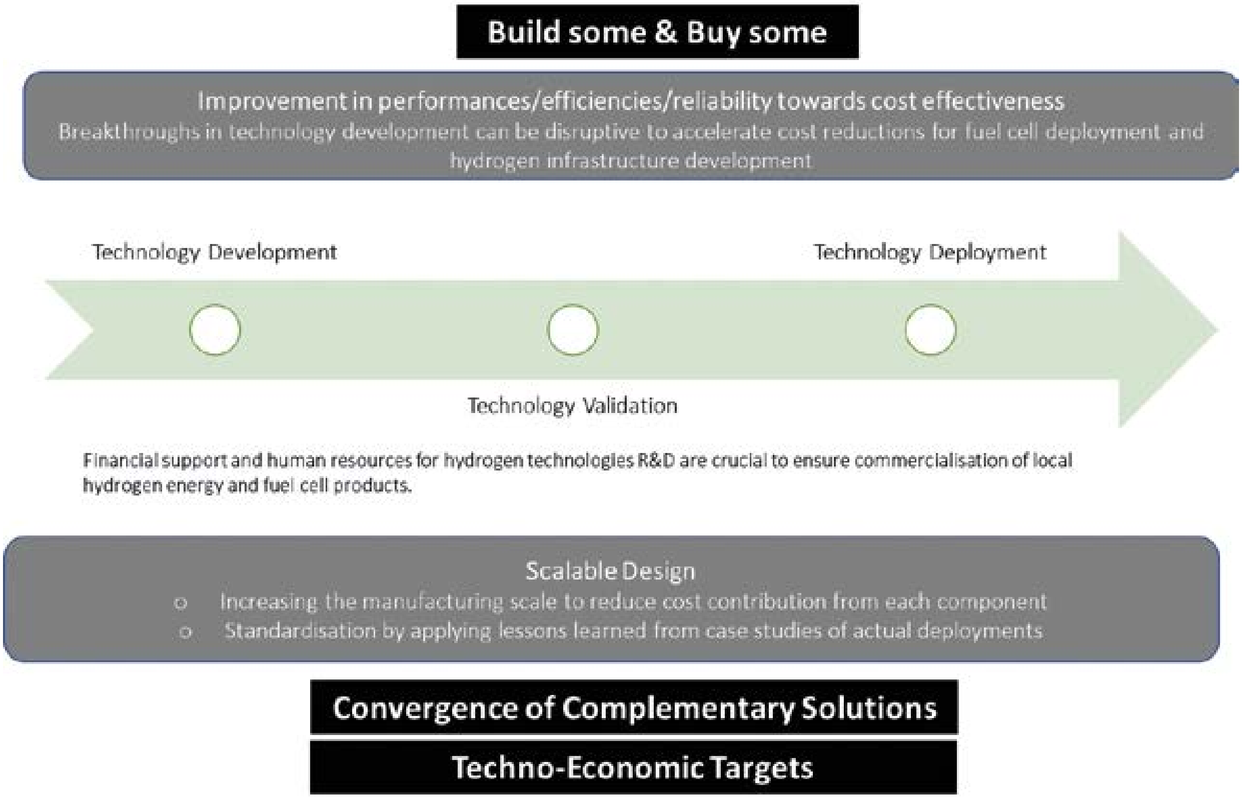
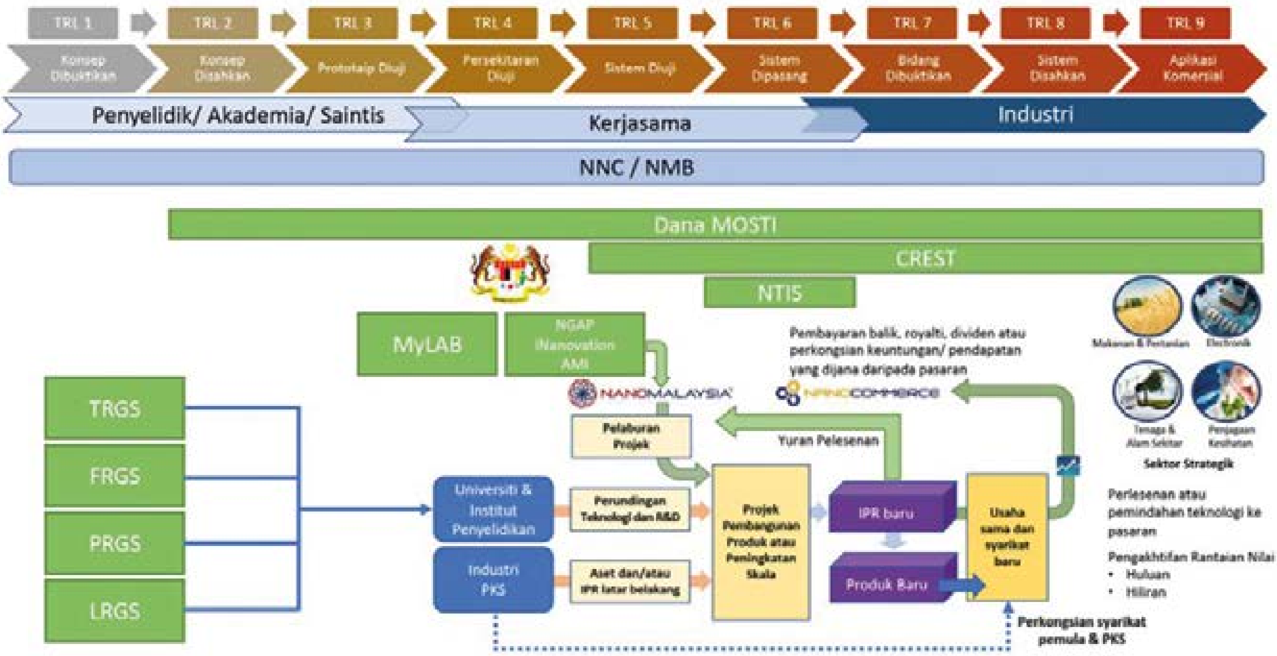


Figure 35: Technology development to technology deployment for Build-Some and Buy-Some

Key technology focus area for Malaysia would be technology scanning, development and adoption of green hydrogen production and transportation technologies. Technology development is the phase where the technologies must go through proof-of-concept and set the criteria such as efficiency, power requirement, and output for a pilot-scale deployment. Technology validation requires on-site validation based on the set of prerequisites apart from analysing the cost, efficiency, and requirements for lifetime operation. Finally, technology deployment which takes a longer timeline due to ecosystem development and infrastructure readiness for a centralised production. Meanwhile the technology partnerships and technology transfer from international players will be critical on a range of topics including electrolyser technologies, export terminal technologies, and hydrogen transport technologies between production sites and export terminals. Technology transfer into the country will be able to build-up capability and capacity to adopt, adapt and innovate. Under the hydrogen technologies, the sub-focus areas that will be prioritised investigates reducing electrolyser capital costs, increasing electrolyser conversion efficiency and utilisation potential. End-to-end hydrogen value chain competitiveness will be further enhanced through technologies that studies the enhancement of safety and reduce operational costs such as terminal handling costs. Despite already has a proven technology that is ready to be commercialise through the Buy-Some approach, the mass market acceptability needs to go through the technology demonstration phase so that it is viable to be deployed at targeted sectors across the hydrogen economy value chain. The elements under Buy-Some (foreign technologies) and Build-Some (local technologies) are as follows:

a. Buy-Some: Smart Partnerships (Regional and Global), Quick Wins, Complementing local systems (techs) and Foreign Direct Investments (FDIs).
b. Build-Some: Lab-to-Market, Start-Ups, Sandbox, Scale-Ups, Commercialisation, Venture Building, Ecosystem Development.

In relation to that, when translated into an ecosystem that would bring together the industries and academia with the support of financial providers (government grants/ incentives), the technology development phase that is involved in the Build-Some can be adapted through the existing technology commercialisation model that has been developed by NanoMalaysia Berhad (NMB) as shown in Figure 36. It is worth to consider that development of SMEs can also be realised through this model.



Source: NanoMalaysia Berhad (NMB)

Figure 36: Exemplary Research Development Innovation Commercialisation and Economy model for Build-Some technology commercialisation, the agency co-ideates and co-creates the innovation and the business entity required as well as develop corresponding ecosystem to successfully commercialise the end-product.

4.2.4 Strategic Thrust 4: Capacity Development and Capability Enhancement

Strategies	Action Plan	Targets	Timeline			Players
			ST 2022 - 2030	MT 2031 - 2040	LT 2041 - 2050	
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 programme including the Technical and Vocational Education and Training (TVET) on hydrogen technologies.	Q1 2024 (Inclusion of hydrogen technologies in all relevant TVET programmes)			Lead: KBS Supported by: MOHE, JPK, JPPKK, HRDCorp, MQA and other relevant ministries & agencies.
		Include performance specification/skills required under National Occupational Skills Standards (NOSS).	Q2 2026 (Develop skills required according to the hydrogen clusters)			Lead: MOHR Supported by: JPK, JPPKK, industry players and other relevant ministries & agencies.
		Development of green job guideline to increase awareness among graduates from IHLs including TVET.	Q1 2025 (One (1) green job guideline approved by MOHR)			Lead: MOHR Supported by: MOSTI, NRECC, MOHE, JPK, JPPKK and other relevant ministries & Agencies.
		Professional courses on building the hard-core skills for the unemployed and low-income group.	Q1 2025 (One (1) green job professional courses approved by MOHR)			Lead: MOHR Supported by: JPK, JPPKK, HRDCorp and other relevant ministries & agencies.
		Certification of competent personnel for hydrogen job under ISO 17024 – Accredited Personnel Certification.	Q2 2029 (One (1) certification of personnel one (1) scheme developed)			Lead: MOHR Supported by: JPK, Standards Malaysia, MQA and other relevant ministries & agencies.

Strategies	Action Plan	Targets	Timeline			Players
			ST 2022 - 2030	MT 2031 - 2040	LT 2041 - 2050	
4.2 Strengthen knowledge for the continuous enhancement of skills for future needs	4.2.2 Develop and introduce a dedicated continuous development programme (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.	25	50	75	Lead: MOHR Supported by: MOSTI, NRECC, MOHE, JPT, JPPKK, MOE, MQA, MBOT and other relevant ministries & agencies.
		150 Experts from RIs.	25	50	75	
		225 Experts from industry.	50	75	100	
	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.	Q1 2026			Lead: MOE Supported by: MOHR, HRDCorp and other relevant ministries & agencies.
	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.	Q2 2028			Lead: MOE Supported by: MOHR, HRDCorp and other relevant ministries & agencies.
		Prioritise specific segments and value chain to develop the capability of SMEs.	Q1 2027			Lead: MITI Supported by: MOSTI, MIDA, NMB, MGTC and other relevant ministries & agencies.

4.2.4.1 Building a Competent and Adaptive Talent

With the development of the Hydrogen Economy, increased job opportunities in the market will take place concurrently. Therefore, we need to invest in building a competent and adaptive talent to be part of the workforce. In line with the spirit of Malaysia MADANI, the action plans that has been crafted addresses the social aspect that will benefit and strengthen the community especially the hardcore poor, B40 and vulnerable groups. With the substantial amount of job that will be created, community from different categories of income level will be able to go through skill courses and trainings. Talent development starts from cradle to career to nurture interest and expose younger generation to have a solid understanding of Science, Technology and Innovation (STI).

Malaysia has moved up to the 26th position out of 88 countries in the Global Talent Competitiveness Index 2020 (GTCI 2020), which is two spots higher than its 28th ranking in 2019.However, efforts need to be ramp-up in building an agile and resilient talents in meeting the criteria of having a market-ready talents. Emphasis needs to be placed on the educational ecosystem, especially technical and vocational education, so that learning is in line with the needs of the industry, which creates a wide-ranging impact on students, society, industry, and the country.

In the context of hydrogen economy, the action plan that has been aligned merges both talent and technology development which would collectively enhance the capacity and capability. Based on the techno-economic model, the modelled result shows hydrogen production from 2025 onwards which means the year 2022 to 2024 are the significant years to build capability and capacity for smaller scale production and pilot end-use projects. Hence, we may begin by developing the local capacities and transfer of capability, technology, and knowledge through strategic alliance and technology transfer between research community and industries.

4.2.5 Strategic Thrust 5: Communication, Education, Public and Awareness

Strategies	Action Plan	Targets	Timeline			Players
			ST 2022 - 2030	MT 2031 - 2040	LT 2041 - 2050	
5.1 Enculturation and Acculturation of Hydrogen Economy	5.1.1 Create awareness to the consumers through 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.	Q1 2026 (Hydrogen FCEV included in the business plan of MOT strategic plan for people and goods movement)			Lead: MOT Supported by: MITI, MARii, MIDA, NMB, UMW, Sime-Darby Hyundai and other relevant ministries & agencies.
		Public transport powered by hydrogen fuel cell to be deployed in the Federal Territory.		Q1 2038 (Hydrogen FCEV considered as low carbon mobility initiatives in three (3) states and economic corridors)		
	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 course in Technical and Vocational Education and Training (TVET) programme.	Q1 2027 (Five (5) Upskilling programmes implemented)			Lead: MOHE Supported by: MOE, JPT, JPPKK and other relevant ministries & agencies.
		Collaboration between local companies and training institutions to have a National Dual Training System (SLDN) on hydrogen-related job scope.	Q2 2026 (20 on job trainings at MNCs and GLCs)			
		Enculturation and acculturation programmes to inculcate understanding on hydrogen economy from primary to tertiary level.	Q2 2026 (Six (6) programmes implemented)			

Strategies	Action Plan	Targets	Timeline			Players
			ST 2022 - 2030	MT 2031 - 2040	LT 2041 - 2050	
	5.1.3 Develop understanding through Science Communication on the application of hydrogen. (Supporting NEP Action Plan E3)	Learning through factsheets and other interactive platform that could have substantial outreach to public.	Q1 2025 (Annual outreach programmes on hydrogen application e.g.: Conference, Exhibition, and Technology Demo)			Lead: MOSTI Supported by: MOHE, MOE, JPT, JPPKK, ASM, Pusat Sains Negara, NMB and other relevant ministries & agencies.

5.0 CONCLUSION

To realise the vision for Malaysia to be a leading nation in Hydrogen Economy by 2050, the Hydrogen Economy and Technology Roadmap (HETR) outlines three goals as follows:

a. Hydrogen to be the cornerstone for new energy economy in Malaysia and take lead among ASEAN countries and establish a strong global presence on hydrogen supply chain and shift from moderate to high significant trade, we shall focus on the exports of hydrogen to the Asia Pacific region for the short-, medium and long-term period with a cumulative revenue of RM 648 billion.

b. Malaysia to achieve a sustainable energy mix through diversification of energy types or sources and increase cleaner energy shares in Malaysia's energy mix by the means of promoting on the use of hydrogen in energy storage and as a fuel in CCGT, creating a hydrogen demand of 68.2 TWh/year in the long-term period.

c. Malaysia to invest in hydrogen technologies to address domestic consumption, stability, security of energy, sustaining international energy trading and decarbonise emissions. A wider ecosystem shall be developed the mobility sector, creating a hydrogen demand of 30.5 TWh/year in the long-term period.

To achieve the goals, a holistic approach has been outlined in the HETR consisting of 5 strategic thrusts, 9 strategies, 29 action plans involving various ministries, agencies, research institutions and stakeholders to create a robust and competitive hydrogen ecosystem to untap a potential revenue of RM 89 billion by 2050.

The realisation of the targets outlined in the HETR will contribute to each dimension of the energy trilemma in the National Energy Policy 2022-2040 by providing a secure, affordable, and sustainable alternative fuel source.


H2
HYDROGEN
HYDROGEN
H2 Station

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APPENDICES FOR FURTHER READING

Table A: The installed capacity of hydropower stations in Malaysia as of 31 December 2016 (Source: Malaysia Energy Statistics)

Station	Installed capacity (MW)	Total (MW)
1. Terengganu		
Stesen Janakuasa Sultan Mahmud Kenyir	4 × 100	400
2. Perak		
Stesen Janakuasa Temenggor	4 × 87	348
Stesen Janakuasa Bersia	3 × 24	72
Stesen Janakuasa Kenering	3 × 40	120
Chenderoh	3 × 10.7 + 1 × 8.4	40
Sungai Piah Upper Power Station		14.6
Sungai Piah Lower Power Station		54
3. Pahang		
Stesen Janakuasa Sultan Yussuf, Jor	4 × 25	100
Stesen Janakuasa Sultan Idris II, Woh	3 × 50	150
Cameron Highland Scheme		11.9
4. Kelantan		
Pergau	4 × 50	600
Kenerong Upper	2 × 6	12
Kenerong Lower	2 × 4	8
5. Sabah		
Tenom Pangi	3 × 22	66
6. Sarawak		
Batang Ai	4 × 23.5	94
Murum HEP	4 x 236	944
Bakun HEP	8 x 300	2400
Total		5434.5

Table B: Hydrogen demand (MTPA Hydrogen) by different countries for 2030 and 2050
Source: Demand and Supply Potential of Hydrogen Energy in East Asia (2019) and IEA (2022), Hydrogen, IEA, Paris

No	Country	Demand (MTPA H_2)	
		2030	2050
1	Japan	3	20
2	South Korea	2	11
3	China	35	60
4	Singapore	0.3	1
5	India	8	26
6	Germany	3	11
7	Europe	20	68
8	USA	17	63
9	Canada	4	20
10	Malaysia	TBC	TBC

** Data is non-exhaustive

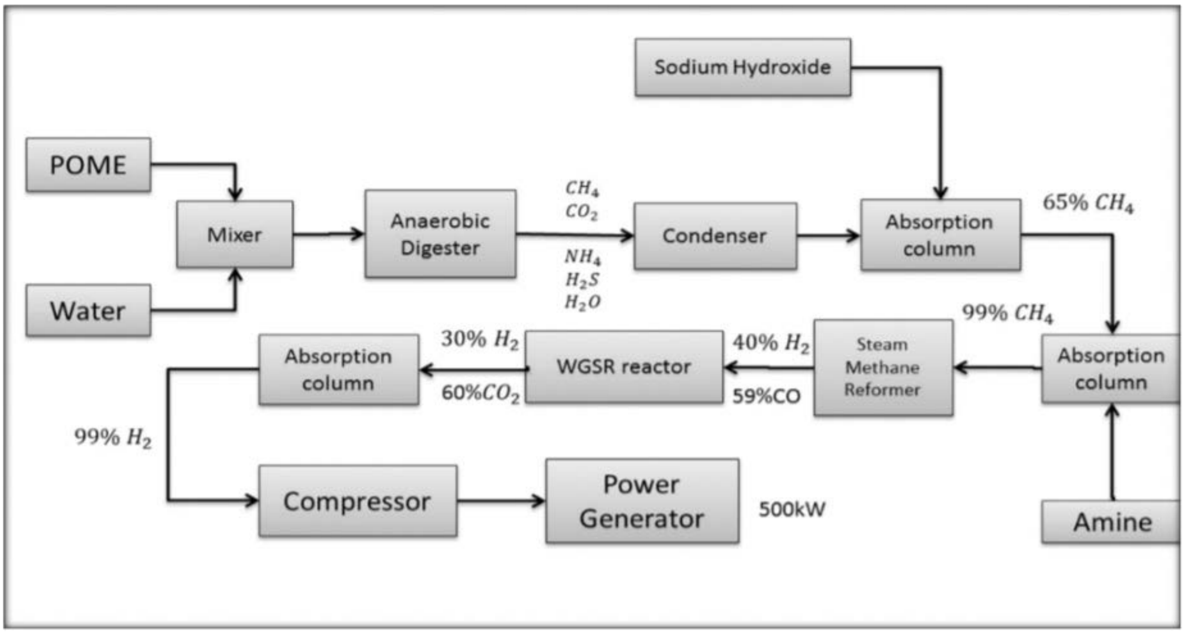

Figure A: Schematic diagram that shows pathway for Green Hydrogen production from Biogas (POME) – Digestor + SMR
(Source: Simulation Study of Bio-Methane Conversion into Hydrogen for Generating 500 kW of Power)

Technologies To Be Considered

Hydrogen Economy Value Chain	Technology	To build	To buy
Production	**Blue Hydrogen [produced from natural gas with applied carbon capture and storage (CCUS) technologies]**		
	• Natural Gas-SMR-CCUS **	X	
	• Membrane and pressure swing adsorption (PSA) – CO_2 capture technology from onshore process gas stream		**X**
	• Autothermal Reforming (ATR) technologies– Steam Methane Reforming and partial oxidation in a single reactor.		**X**
	• Shell gas partial oxidation (SGP) and ADIP ULTRA – proven solvent technology for capturing CO_2 from high-pressure process streams.		**X**
	Turquoise Hydrogen		
	• Cracking of bio-methane to produce hydrogen and carbon black • Natural gas pyrolysis**	**X**	
	Green Hydrogen		
	• Vertical windmill – able to harness wind energy in varying conditions, suitable for city use**	**X**	
	• Plasma Electrolysis Technology – greatly increases the rate of hydrogen production		**X**
	• Electrolyzer: Polymer electrolyte membrane, Alkaline water electrolysis (AWE), Solid Oxide Electrolyzer Cell (SOEC), laser-based electrolyzer**	**X**	
	• Photolysis - Direct solar water splitting, or photolytic, processes use light energy to split water into hydrogen and oxygen.	**X**	
	• Ocean Thermal Energy Conversion (OTEC) – hydrogen production from ocean thermal energy**	**X**	
Conversion	**Green Hydrogen**		
	• Thermochemical conversion - the most advanced technology for hydrogen production from biomass**	**X**	
Storage and Transportation	• Ammonia	**X**	
	• Solid-State Hydrogen Carrier: Sodium Borohydride (NaBH4)**		**X**
	• LOHC: Methylcyclohexane**	**X**	
Re-Conversion	• Catalytic dehydrogenation of MCH**	**X**	
	• NaBH4 hydrolysis**	**X**	
End-Use Application	• Fuel cell for mobility: Lightweight composite high-pressure tank technology for light-duty FCEVs**	**X**	
	• Hydrogen turbine technology for power generation		**X**

GAMS
General Algebraic Modeling Language

How the model works ?

- A **series of mathematical equations** relating all parts of the bottom-up **hydrogen supply chain network outlined in the superstructure**
- **Cost Minimization** or **Profit Maximization** as an economic objective function.
- Identify the **cost-optimal technologies** and **cost-optimal energy carriers flows** in each technological module across the hydrogen supply chain which translates into the **least-cost hydrogen pathway**

What can the model generate?

- Modelling of **energy supply and demand balancing**, covers the main parts of energy systems (i.e., power, industry, mobility, export) for hydrogen penetration.
- Model selected least cost technology options to reach the targeted production volume.
- **Economic, Energy, Transportation** and **Environmental/Emission** variables to drive hydrogen production
- **Example:** Annual investments, operational costs, annual systems cost, annual subsidy, annual GHG emission reduction, GHG emissions from each of the specific supply chain activities, hydrogen deployment in each end-use sector, scale of hydrogen transportation fleet, transportation, transmission and export trade flows, etc.

Limitations

- Only **technologies with available techno-economic information** in the **literature/industrial estimates** are **included in the model.**
- Subjected to the following constraints: **Resource availability, hydrogen/energy/export demand, GHG emission, technological capacities, & capacity investment/retirement.**

Figure B: Model and Limitations of GAMS software for Hydrogen Economy Techno-Economic Modelling

The derivation of Levelised Cost of Energy from Levelised Cost of Hydrogen

Levelized Cost of Hydrogen (LCOH)

$$LCOH\left(\frac{USD}{kg_{delivered}}\right) = \frac{H2\ Production\ \left(\frac{USD}{kg_{produced}}\right)}{(1 - ProcessLoss_{delivery})\left(\frac{kg_{delivered}}{kg_{produced}}\right)} + \text{H2 Delivery}\left(\frac{\text{USD}}{kg_{delivered}}\right) + \text{H2 End Use}\left(\frac{\text{USD}}{kg_{delivered}}\right)$$

Levelized Cost of Energy (LCOE)

$$LCOE\left(\frac{USD}{kWh_{enduse}}\right) = \frac{LCOH\ \left(\frac{USD}{kg_{delivered}}\right)}{Efficiency_{enduse}\left(\frac{kWh_{enduse}}{kWh_{delivered}}\right) x\ 33.3\ \left(\frac{kWh_{delivered}}{kg_{delivered}}\right)}$$

Example Calculation of LCOH and LCOE for Power Sector

Pathway:
Year: 2025
Hydrogen Production: NG-SMR
Hydrogen Delivery: GH2-Pipeline-Power
Hydrogen End Use: CCGT (Co-firing)

Levelized Cost of Hydrogen (LCOH)

$$LCOH\left(\frac{USD}{kg_{delivered}}\right) = \frac{1.893\left(\frac{USD}{kg_{produced}}\right)}{(1-0.005)\left(\frac{kg_{delivered}}{kg_{produced}}\right)} + 0.622\left(\frac{USD}{kg_{delivered}}\right) + 0.090\left(\frac{USD}{kg_{delivered}}\right) = \mathbf{2.615}\left(\frac{\mathbf{USD}}{\mathbf{kg_{delivered}}}\right)$$

Levelized Cost of Energy (LCOE)

$$LCOE\left(\frac{USD}{kWh_{enduse}}\right) = \frac{2.615\left(\frac{USD}{kg_{delivered}}\right)}{0.5\left(\frac{kWh_{enduse}}{kWh_{delivered}}\right) x\ 33.3\left(\frac{kWh_{delivered}}{kg_{delivered}}\right)} = \mathbf{0.157\ USD/kWh_{enduse}}$$

KEMENTERIAN SAINS, TEKNOLOGI DAN INOVASI
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