AKADEMI SAINS MALAYSIA

POSITION PAPER ON HYDROGEN ECONOMY

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Position Paper on Hydrogen Economy

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ISBN 978-983-2915-83-6

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Executive Summary

Intergovernmental Panel on Climate Change (IPCC) in 2012 predicted that emissions of carbon due to continued usage of fossil energy will increase the global temperature by 2 to 6° Celsius by the year 2100. Countries around the world are now committed to addressing this global issue by reducing their carbon emission intensity. In the COP 21 in Paris 2015, Malaysia has committed itself to reducing carbon emission intensity by 45% based on the 2005 level in 2030. To meet this commitment, Malaysia has started diversifying the energy mix to include renewable energy as the fifth energy source in the total energy mix since 2001. Despite the various initiatives to increase renewable energy share in the total energy mix to 20% since the 8^{th} Malaysia Plan, it is still not enough to meet Malaysia's commitment to reduce carbon emission intensity.

Hydrogen energy is zero-emission energy that can bridge the gap to fulfil Malaysia's commitment to this reduction. Hydrogen energy can be produced from carbon-free sources such as water splitting by renewable energy and carbon-neutral/low-carbon sources, such as biomass gasification. Hydrogen economy is a type of circular economy where hydrogen is produced from renewable sources and used in transportation and electricity generation, where water is produced and recycled as a source of hydrogen that completes the cycle in the hydrogen economy.

The main challenges in building a hydrogen economy are negative public perception of hydrogen safety, lack of national policy on hydrogen economy and high cost of hydrogen energy and fuel cell deployment. Nevertheless, Malaysia has both the strength in scientific know-how on hydrogen energy and fuel cell, and industrial strength to further pursue the development of hydrogen economy. Despite the challenges, there is a growing trend of universities and industries collaborating to develop hydrogen economy in Malaysia. Two of the largest Malaysian companies have invested in hydrogen and fuel cell research and development in collaboration with local universities. With a firm national policy on hydrogen energy, Malaysia could be a leading player in the region.

Recommendations and action plans have been crafted in this position paper to help establish hydrogen economy in the 12^{th} Malaysia Plan and beyond. The three main areas of developing the hydrogen economy, namely hydrogen infrastructure, fuel cell applications and emerging fuel cell technologies, will be addressed by looking at four different aspects of governance, public and market acceptance, technology & human capital readiness and finance readiness.

It is recommended that the 12th Malaysia Plan should focus on utilising the country's available renewable energy sources to produce hydrogen. Demonstration projects are critical to test the technical viability of new methodology and technology in producing hydrogen, as well as to promote its application in various sectors. In order to promote the adoption of hydrogen energy, hydrogen needs to be introduced as the sixth energy source in the total national energy mix. Guidelines, regulations and standards need to be developed to help deploy hydrogen energy safely. In terms of investment, investment related to hydrogen technology should be included in the current green technology incentive schemes. That also includes revision of Feed-in Tariff scheme, where electricity generation from hydrogen and solar energy are included. Lastly, the public needs to be well-informed of the national targets as well as all safety measures related to the hydrogen economy.

For the 13th and 14th Malaysia Plans (2026-2035), the action plan focuses on securing continuous financial support from relevant stakeholders while building the complete local hydrogen and fuel cell supply chain. Hydrogen and fuel cell applications are expected to be diversified and maturing at this stage. This also requires a stronger development of human resources to support the supply chain. Champions should be selected among the investing companies to champion different hydrogen and fuel cell technologies.

For the 15th, 16th, 17th and 18th Malaysia Plans (2036-2050), the action plan focuses on becoming a global hydrogen supplier and regional market leader with industrial projects for hydrogen and fuel cell applications. It includes establishing efficient hydrogen infrastructure for high-capacity storage system facilities, purification, production, distribution, and refuelling. It also includes organising awareness campaigns with stakeholders to raise a positive local and global profile for the hydrogen and fuel cell industry and technology in Malaysia.

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List of Acronym

AEL	Alkaline Electrolysis
AEMEL	Anionic Exchange Membrane Electrolyser
APUs	Auxiliary Power Units
BIPV	Building Integrated Photovoltaics
BOP	Balance of Plant
BR	Boudouard Reaction
CCS	Carbon Capture and Storage
CCU	Carbon Capture and Utilisation
CNG	Compressed Natural Gas
COP	Conference of the Parties
CPO	Crude Palm Oil
CR	Combustion Reactions
CSP	Concentrated Solar Power
DEFCs	Direct Ethanol Fuel Cells
DLFC	Direct Liquid Fuel Cell
DMFC	Direct Methanol Fuel Cells
DOSH	Department Of Occupational Safety and Health
EFB	Empty Fruit Bunch
EOR	Enhanced Oil Recovery

EP	European Parliament
EPU	Economic Planning Unit
FCC	Fluidized Catalytic Cracker
FCEV	Fuel Cell Electric Vehicle
FCI	Fuel Cell Institute
FCVs	Fuel Cell Vehicles
FiT	Feed-in Tariff
GEF	Global Environmental Facility
GGE	Gasoline Equivalent
GHG	Greenhouse Gases
INDC	Intended Nationally Determined Contribution
INDCs	Intended Nationally Determined Contributions
IRPA	Intensification Of Research in Priority Areas
KASA	Ministry of Environment and Water
KeTSA	Ministry of Energy and Natural Resources and
LCOE	Levelized Cost of Electricity
LFG	Land Fill Gas
LNG	Liquified Natural Gas
LOHC	Liquid Organic Hydrogen Carrier
LPG	Liquefied Petroleum Gas
LSS	Large Scale Solar
MAHE	Malaysian Association of Hydrogen Energy
MBIPV	Malaysian Building Integrated Photovoltaics
mCHP	micro Combined Heat And Power
MEC	Microbial Electrolysis Cell
MFC	Microbial Fuel Cells
MFC	Microbial Fuel Cell
MGTC	Malaysian Green Technology and Climate Change Centre
MIDA	Malaysian Investment Development Authority
MITI	Ministry of International Trade and Industry
MOE	Ministy of Education
MOHR	Ministry of Human Resources
MOT	Ministry of Transportation
MR	Methanation Reaction

MSW	Municipal Solid Waste
Mtc	Million tonnes carbon
MTDC	Malaysian Technology Development Corporation
MyIPO	Intellectual Property Corporation of Malaysia
NEM	Net Energy Metering
NETL	National Energy Technology Laboratory
NG	Natural Gas
NGCC	Natural Gas Combined Cycle
NGO	Non-Governmental Organization
NGV	Natural Gas Vehicles
NIOSH	National Institute of Occupational Safety and Health
OPEC	Organization of the Petroleum Exporting Countries
OTEC	Ocean Thermal Energy Conversion
PEC	Photoelectrochemical
PEM	Proton Exchange Membrane
PEMEL	Polymer Electrolyte Membrane
PEMFC	Proton Exchange Membrane Fuel Cell
PIC	Pengerang Integrated Complex
PNS	Purple Nonsulfur
POME	Palm Oil Mill Effluent
PS	Photosystem
PSA	Pressure Swing Adsorber
PV	Photovoltaics
RAPID	Refinery and Petrochemical Integrated Development
RE	Renewable Energy
RETR	Renewable Energy Transition Roadmap
ROG	Refinery Off Gases
SEDA	Sustainable Energy Development Authority
SMR	Steam Methane Reforming
SOEL	Solid Oxide
SOFC	Solid Oxide Fuel Cells
SREP	Small Renewable Energy Program
TPM	Technology Park Malaysia
TRL	Technology Readiness Level

TVET	Pendidikan Teknikal dan Latihan Vokasional
UITM	University Technology MARA
UKM	Universiti Kebangsaan Malaysia
UM	University Malaya
UNDP	United Nation Development Program
UPS	Uninterruptible Power Supplies
UTM	University of Technology Malaysia
WGR	Water-Gas Reaction
WGSR	Water-Gas Shift Reaction

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Preface

Hydrogen Economy (HE) is the circular economy associated with hydrogen energy production from water splitting by renewable energy (RE) sources. Hydrogen is utilised as a source of energy for electricity generation and transportation, and as feedstock for the chemical industry. The process produces only water as end product, making it a low- or zero-carbon emission cycle.

Hydrogen energy is a sustainable low or zero-emission energy of the future. It is clean, safe, reliable and affordable. It can also be a secure energy carrier if produced from locally available renewable energy (RE). Leveraging on Malaysia's strength, there is enormous potential to build a new sustainable industry and green technology associated with hydrogen. The establishment of HE could provide energy security, as well as to prevent the onset of climate change that would affect our economy negatively. Moving towards clean hydrogen energy would also contribute to the health and prosperity of the nation.

At the threshold of the 21st century, Malaysia was heavily dependent on imported fossil fuels to power its economic growth. This exposes Malaysia to global risks and uncertainties in securing fossil fuel resources. Although Malaysia had developed its own oil and gas industry since the late 70s, Malaysia is now still a net oil importer mainly for transportation because most of its natural gas (NG) and low sulphur oil are exported. Energy security concern was addressed by using NG as the fourth fuel in the diversification of fuels for electricity generation and as compressed NG (CNG) fuel for cars to wean Malaysia off imported oil.

To fight climate change, Malaysia has adopted RE such as solar energy (SE), biofuel (BF) and biomass (BM) as the fifth fuel for electricity generation in the 8th Malaysia plan (2001-2005). This has enhanced energy security using locally sourced RE. However, since the utilisation of RE alone will not be enough to reduce carbon emission to meet Malaysia's target, hydrogen energy as a low to zero-emission energy needs to be considered by the Malaysian Government to drive the change.

In January 2006, the Ministry of Energy, Communications and Multimedia (MECM) published the first national Solar, Hydrogen and Fuel Cells Roadmap for Malaysia (SHFCRM) for research, development and utilisation of SE, HE and fuel cell technologies in Malaysia. It was implemented under the 9th Malaysia Plan, but was abandoned in subsequent Malaysia Plans because it was superseded by the RE Transformation Roadmap where RE was given much emphasis through the Feed-in-Tariff (FiT) scheme.

In 2017, the Academy of Science Malaysia (ASM) published The Blueprint for Fuel Cell & Hydrogen Industries in Malaysia (BFCHIM), a study on the fuel cell and hydrogen energy industry in Malaysia. The BFCHIM updated the HE and fuel cells part of the original 2006 SHFCRM and proposed a new hydrogen energy and fuel cells roadmap for the industry in Malaysia.

This position paper on the hydrogen economy commissioned by the ASM in 2020 takes the case for hydrogen economy in the BFCHIM, and further study the global and regional energy scenarios in adopting hydrogen economy. It also explores the global, regional and national efforts to thwart climate change following the 2015 COP21, by reducing carbon emissions from fossil fuel and by replacing it with green hydrogen energy produced from RE sources. Producing green hydrogen energy through locally available RE sources such as solar, hydro, biomass and ocean thermal energy also addresses some of the concerns in the provision of energy security for Malaysia. The position paper proposes an updated blueprint for the coordinated, short, medium and long-term development plan of the hydrogen economy in Malaysia.

The writing of this report could not have been completed as successfully as it had, if not for the enthusiastic support of the ASM management, the dedication of the ASM fellows who are members of the Special Interest Group of Hydrogen Economy (SIG HE), and the excellent work of ASM analysts team. Other members of the SIG HE from the Government, research institutions, non-governmental organisations, academia and industry also contributed immensely to the writing of the paper.

I would like to offer many thanks to ASM President and Professor Emerita Datuk Dr Asma Ismail FASc and ASM CEO Pn Hazami Habib for their undivided support, ASM Academician Tengku Datuk Dr Mohd Azzman Shariffadeen FASc, ASM Fellows Prof Datuk Dr Abu Bakar Jaafar FASc, Prof. Dr Mahendhiran Sanggaran Nair FASc and Allahyarham Prof. Dr Hamdani Saidi FASc for their many invaluable thoughts that had helped in making the position paper better and more wholistic in approach.

I would also like to offer many thanks to Prof Dr Mohammad Kassim, Deputy Vice Chancellor of UKM and Secretary General of the Malaysian Association of Hydrogen Energy, Prof. Dr Arshad Ahmad, Former Director of Institute of Hydrogen Economy UKM & Deputy President of MAHE, Prof Madya Dr Mohd Shahbudin Mastar, Deputy Director of Fuel Cell Institute UKM & Member of the MAHE, Prof. Madya Dr Edy Herianto Majlan, Senior Research Fellow of Fuel Cell Institute UKM & Member of MAHE, Dr Umi Azmah Hasran, Senior Research Fellow Fuel Cell Institute UKM & Assistant Secretary General of MAHE and En Wan Mohd Hafizi Wan Hassin, Researcher at Malaysia Autmotive Robotics and IoT Institute (MARII).

I would like to offer many thanks to Mr Colin Patrick, Head of Innovation and Future Positioning (Hydrogen) of Petronas, Ir Noraziah Muda Head of Renewable Energy & Green Technology, TNB Research Sdn Bhd, En Wong Tin Song, Undersecretary Energy Efficiency, Ministry of Energy and Natural Resources (KETSA), Last but not least, I would like to thank Pn Nitia Samuel, STI Strategic Studies Unit and ASM Analysts Pn Joy Rayappan, En Mohd Ikhwan Abdullah and Pn Teng Yu He.

ASM hopes that this position paper will form the basis for the drafting of a National Hydrogen Economy and Technology Roadmap for Malaysia. Let us hope that the Hydrogen Economy will be one of the game-changers that the Malaysian economy needs to recover from the Pandemic.

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1. INTRODUCTION

1 Introduction

Malaysia's initial discovery of oil and gas reserves in its waters in the late 60s and early 70s. Its strategic geographical position along important trade routes for seaborne energy trade had increased Malaysia's global competitiveness in the energy industry. Oil and gas have contributed up to 20% of Malaysia's total GDP and have since become a significant industry in Malaysia and Southeast Asia. Malaysia is the third-largest oil producer and has the third-highest reserves in Southeast Asia.

Although oil is still profitable to produce in Malaysia, there has been a gradual decline in oil production at major producing oil fields in the last decade. Natural gas is currently the largest contributor to Malaysia's energy industry and accounted for about half of the country's total supply and electricity generation.

Malaysia, along with the rest of the world, is fighting the threat of climate change due to global warming as a result of greenhouse gases (GHG)/carbon emissions from man-made sources, primarily from the utilisation of fossil fuels such as oil and gas. As an oil and gas producing country, Malaysia contributes directly to the global emissions of carbon through the utilisation of its oil and gas domestically, Malaysia also contributes indirectly to global carbon emission, albeit to a lower degree, through the export of its oil and gas to other countries.

Since the widespread utilisation of fossil fuels in the world constitutes the largest contribution to global carbon emissions, there is cause for concern that the continuous use of oil and gas without adequate mitigations would continue to emit carbon for some time, eventually causing a worldwide climate disaster.

Renewable energy (RE) other than hydropower, such as biomass, biodiesel, biogas, solar and wind energy, could replace some of the fossil fuels in Malaysia's fuel diversification plan. RE was added as the fifth fuel to the four-fuel mix for electricity generation in 2001, transforming the latter into the present five-fuel mix. The RE target of 5% of the total electricity generation by 2005 was not met. Only small-scale biomass and biogas power stations were deployed.

However, since RE target could not be reached due to high cost, capacity and seasonal changes issues, as well as market uncertainties of solar energy, a Feed-in Tariff scheme for RE was implemented by Malaysia in 2011. This was done to attract RE investment by offering higher tariffs in the early years in order to pay back the capital investment quickly before the tariff dropped to prevailing industry rates. RE deployment was further accelerated in 2016 with the deployment of large-scale solar farms that also helped drop the costs of solar PV panels significantly.

To mitigate the large contribution of transportation to carbon emissions, biodiesel from palm oil was added to the transportation fuel mix in the form of 5% , 7% and 10% biodiesel blends with petroleum diesel, B5, B7 and B10 in 2010. However, its deployment is still relatively small because of the increased price of palm oil.

Despite all the schemes being employed to accelerate the replacement of fossil fuels with RE in the last 5 years, Malaysia still far short of the target of carbon emission intensity reduction of 45% from 2005 level as committed at the COP21 Paris 2015. Alternative zero-emission nuclear energy is now no longer viable because of strong public opposition. However, Malaysia has a golden opportunity to deploy another zero-emission energy, called hydrogen energy, for which Malaysia has developed significant technical expertise from extensive R&D programmes related to hydrogen energy, funded by MOSTI and MOHE in the last 25 years to the tune of RM50 million. This could provide the answer for the drastic cuts needed in carbon emission by 2035.

It is therefore vital for Malaysia to start deploying greener and cleaner energy that has low or zero-carbon emissions like hydrogen, alongside conventional and renewable energy sources. Hydrogen energy, which was produced at a low cost through steam reforming of natural gas with low carbon emission can now be produced at a cheaper rate by using RE sources such as large-scale solar farms to split water by electrolysis, making it a truly zero-emission energy. Hydrogen energy is not just an energy carrier; it is also an economy called the hydrogen economy that encompasses the whole hydrogen energy supply chain from production, storage and distribution to applications in transportation, electricity generation, industry/commerce and the home that closes the hydrogen cycle driven by primary RE.

Although hydrogen had been touted to be one of the energy carriers in the latter half of the 21st Century (Ibrahim Dincer, 2008), it would not replace fossil energy altogether in the near and middle terms because of the enormous current, and future energy demand far outstrips planned hydrogen production capacities. In addition, the slow pace of construction of hydrogen production and supply network infrastructure further delays its deployment. Instead, hydrogen will complement the Malaysian energy mix as the sixth fuel to the five primary energy sources, i.e. natural gas, fuel oil, coal, hydropower and RE in the near and middle terms. Various types of fuel cells, which are highly efficient electrochemical devices, could be used to convert hydrogen energy into electrical energy without emitting any GHG or carbon. The hydrogen fuel cells could be used in various applications, especially for transportation, electric power generation, industry/commercial power and distributed power for the home.

The main objective of the present proposal is to update the hydrogen energy and fuel cell roadmaps envisioned in both the original Solar, Fuel Cell and Hydrogen Energy Roadmap 2006 and the recently updated Blueprint for Development of the Fuel Cell Industry 2017. Besides that, it also aims to develop a sustainable programme for the hydrogen economy to be implemented in the 12th Malaysia Plan (2021-2025) and beyond. The strategy developed for the transition to Malaysia's Hydrogen Economic will also considered the recommendations made in the Report of the Hydrogen Council (2020) for global investment commercial deployment of the hydrogen economy.

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2. ENERGY SECURITY AND CARBON EMISSION

World Energy Security
Carbon Emission, Global Warming and Climate Change
Energy Security in Malaysia
Carbon Emission in Malaysia

2 Energy Security and Carbon Emission

Energy is an essential factor in contemporary civilisation, without which the world as we know it today could collapse and the human civilisation would end. It is therefore important to know about the world energy scenario, the trends and future directions of the global energy industry. This would provide a background of relevancy that would keep the national energy scenario in synchronization with the rest of the world.

The world total primary energy supply was 584.980 EJ (13,972 Mtoe) in 2017, as shown in Figure 1 (Anon, 2019). About 81% of it was from fossil fuels, 14% from renewable energy (hydro 2%, biofuels 10% others 2%) and 5% from nuclear. The World total final energy consumption was 406.83 EJ (9,717 Mtoe) in 2017, as shown in Figure 2 (Anon, 2019). About 87% was used for industry (37%), transport (29%) and residential areas (21%).

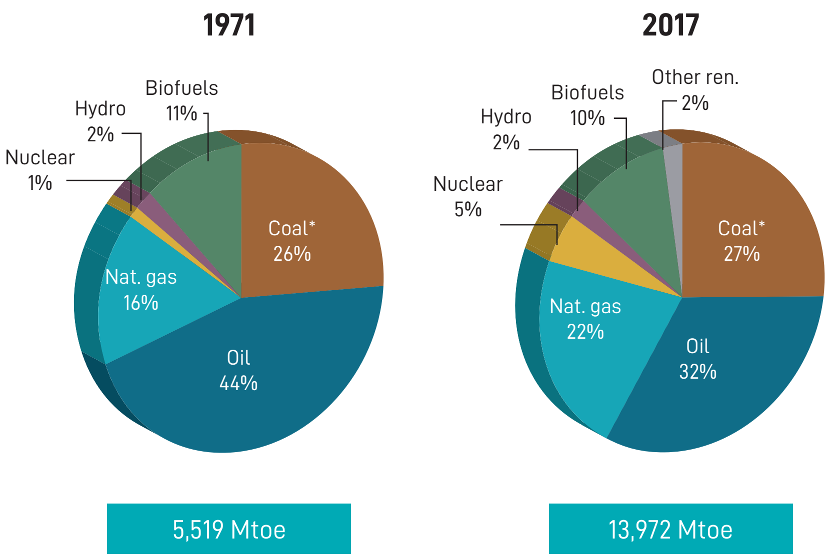

Figure 1: World Total Primary Energy Supply by Fuel
Source: World Energy Balance 2018 IEA

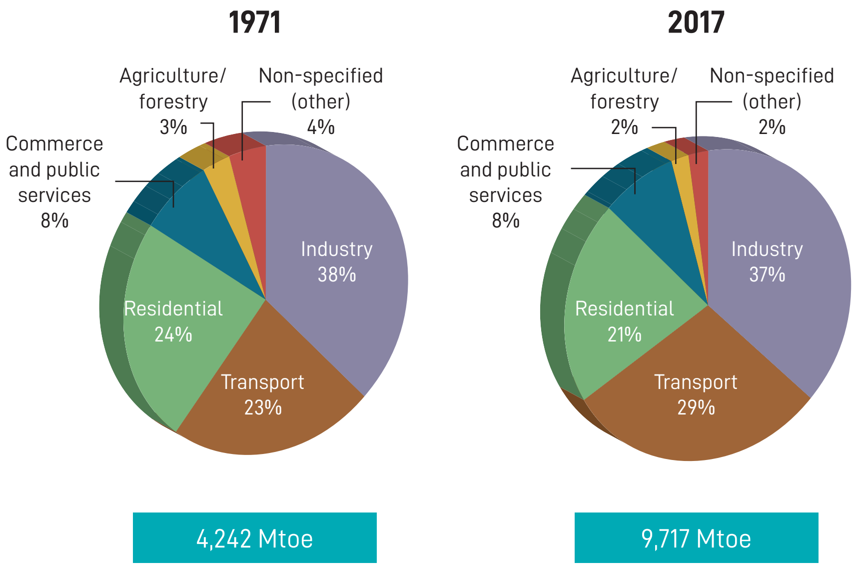

Figure 2:
World Total Final Consumption by Sector
Source: World Energy Balance 2018 IEA

2.1. World Energy Security

Fossil fuels are finite resources. If they are consumed for long enough, global fossil fuel reserves will eventually run out. In 1956, Hubbert suggested fossil oil production follows a bell curve; first increasing, peaking in 1970 and then declining when reserves are gradually depleted (Cavallo, 2004). Peak oil production did occur around 1970, with production declining until 2010 (Figure 3). However, as new reserves were discovered and exploited, especially shale oil and Canadian oil sands that are cheaper to produce than deep well oil, production of fossil fuels rose rapidly after 2010.

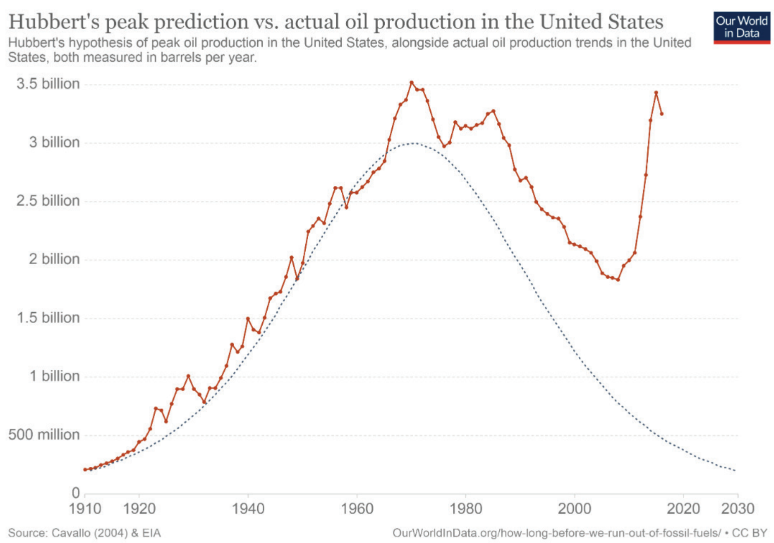

Figure 3:
Peak Oil Prediction
Source: Cavallo 2004 and IEA

Oil prices tumbled to USD 40 per barrel when Saudi increased their oil production in response to cheaper oil production from shale and oil sands in 2014 (Figure 4). Oil prices recovered to above USD 60 per barrel after Saudi agreed to limit production. Although economic sanctions against Iran initiated by the United States, the United Kingdom and European Union over alleged non-compliance to a nuclear deal should have increased the oil price, but over production and the global Covid-19 crisis contributed to the present declining oil prices.

2.2 Carbon Emission, Global Warming and Climate Change

Carbon emission from human activities such as electricity power generation, industries and transportation has been proven, beyond doubt, to be the main cause of global warming and climate change. The Kyoto Protocol 2005 is an international treaty to fight global warming and climate change that commit countries to reduce GHG/carbon emissions and concentrations in the atmosphere that would prevent dangerous anthropogenic interference with the climate system. However, continuing the pledges of the Kyoto Protocol would not reduce carbon emission fast enough to stabilise atmospheric concentrations of GHG to prevent the onset of climate change (Figure 5).

Since the expiry of the commitments of the Kyoto Protocol in 2012, a new global agreement, the COP21 Paris Agreement 2015, was negotiated to limit global warming to below 2°C compared to pre-industrial levels so that zero net anthropogenic greenhouse gas emissions could be reached during the second half of the 21st century 2050-2070 (Figure 5). It is also committed to pursuing efforts to limit the temperature rise to 1.5°C to prevent earlier inundation of islands and coastlines. Each country agreed to determine its intended nationally determined contributions (INDCs) that it should make to achieve them.

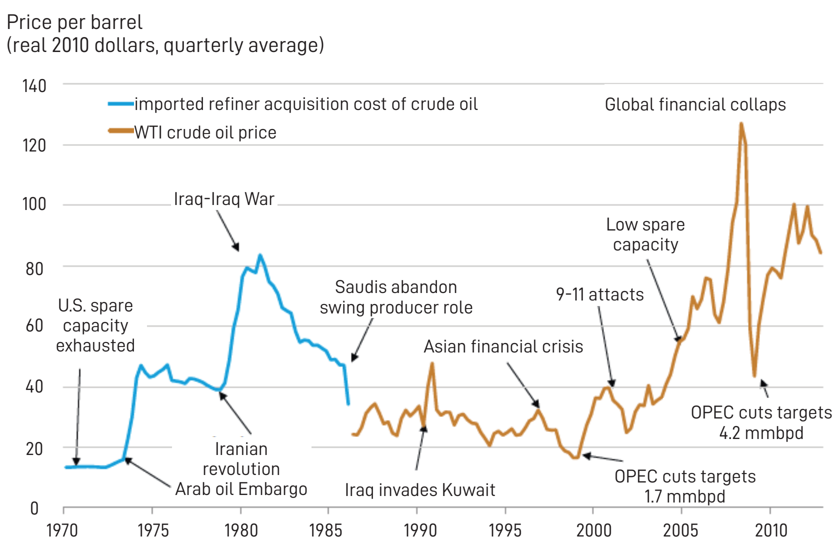

Figure 4:
World Crude Oil Prices Driven by World
Source: U.S. EIA, 2017

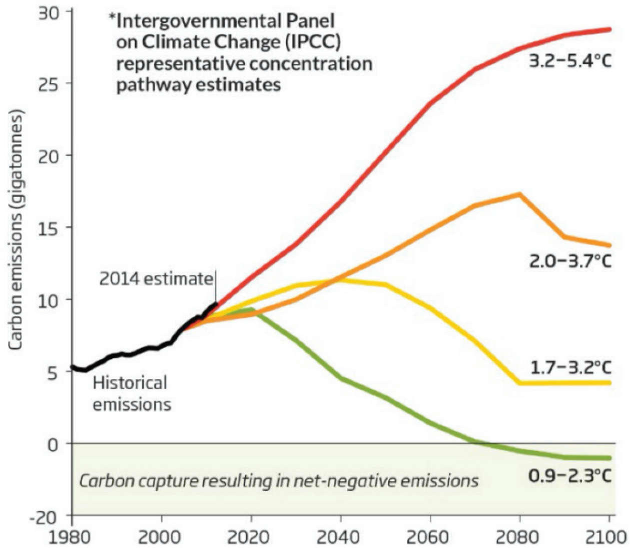

Figure 5:
Global CO_2 Emissions for Four IPCC Concentration Pathways
Source: Peters et al. 2012, Global Carbon Project 2013

Most countries including Malaysia responded by diversifying energy resources for electricity generation by replacing oil and nuclear in the energy mix with renewable energy like hydro, biomass, biofuel, solar energy and wind energy (Figure 6 & 7). They also explored low carbon and zero-emission hydrogen energy by developing sustainable national hydrogen economy roadmaps from 2015 to 2050. Hydrogen economy roadmaps for Malaysia had been developed twice in 2006 and 2017, but its implementation is fraught with barriers. The present document will suggest the way forward for Malaysia.

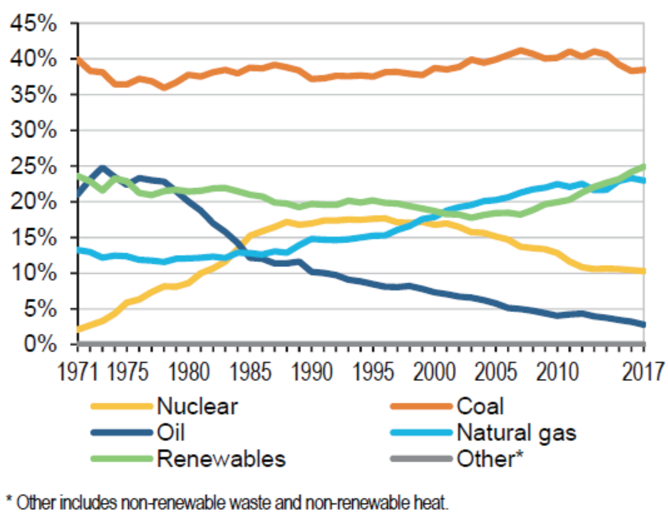

Figure 6:
Energy Mix for Global Electrical Generation
Source: World Energy Balance 2018 IEA

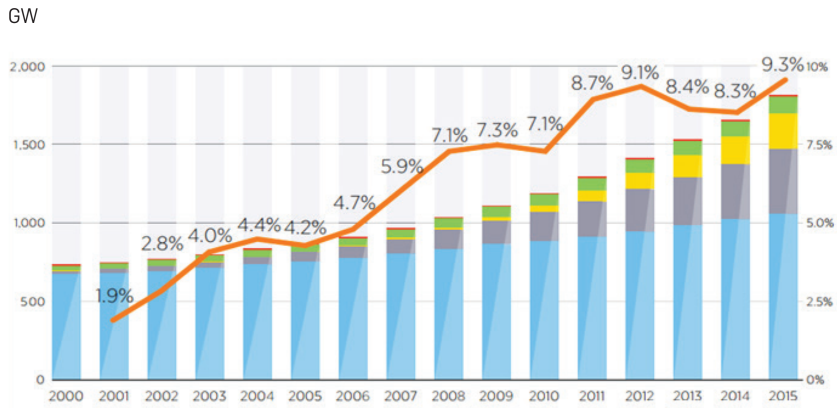

Figure 7:
World Electrical Generation Capacity from Renewable Energy
Source: IRENA 2016

2.3 Energy Security in Malaysia

2.3.1 Energy Policy in Malaysia

Before the formation of Malaysia, the first Royal Dutch Shell oil well was drilled in 1910 in Miri, Sarawak (Sorkhabi, 2015). After Malaysia was formed in 1963, it approved the Petroleum Mining Act which gave Exxon and Shell the rights to explore for oil and pay oil royalties and tax to the Malaysian. In the late 1960s, Esso and Continental Oil were given concessions to explore oil offshore of the east coast of Peninsular Malaysia. By 1974, Malaysia's crude oil output stood at about 4.48–4.93 Mtoe per year (Bank Pembangunan Malaysia, 2011).

In 1974, Malaysia approved the Petroleum Development Act and incorporated PETRONAS on 17 August 1974. In tandem with the Act, the National Petroleum Policy was developed in 1975 in response to the World oil crisis when Arab members of OPEC decided to embargo oil to America after the Arab-Israeli War 1973. It was also designed to help PETRONAS exercise majority control in the management and operation of the industry and to guide and regulate it. By April 1975, all concessions of foreign oil companies like Exxon and Shell were surrendered to PETRONAS. By 1976, PETRONAS finally had total control of all oil and gas reserves in Malaysia when all oil-producing states in Malaysia signed the petroleum agreement including Sabah and Sarawak. PETRONAS operates over 1000 petrol service stations in Malaysia and is the single largest contributor to the country's revenue at nearly 45% of it, in the form of taxes and dividends.

However, since both the Act and the Policy did not cover the electricity sector, the National Energy Policy was formulated in 1979 to ensure efficient, secure and environmentally sustainable energy supplies, including electricity. The National Depletion Policy was introduced in 1980 to safeguard the exploitation of crude oil reserves to prevent overproduction because of the rapid growth in the production of crude oil. In addition, the Four Fuel Diversification

Policy for electricity generation was introduced in 1981 to ensure energy reliability and security by preventing over-dependence on oil as the main energy resource by adding three more primary energy resources i.e. gas, hydropower and coal to the energy supply mix. Energy efficiency was also encouraged to prevent Malaysia from becoming a net energy importer which will affect her economic growth.

2.3.2 Renewable Energy Policy in Malaysia

In 2001, in the light of increasing concern for global warming due to carbon emission from fossil fuels that ultimately would lead to climate change, the Four Fuel Policy was amended to become the Five Fuel Policy where renewable energy (RE) was added as the fifth fuel in the energy supply mix. The less than 10 MW grid-connected Small Renewable Energy Program (SREP) was implemented in the 8th Malaysia Plan to fulfil the 5% renewable energy target for electricity by 2005.

In order to create a conducive ecosystem that encourages the deployment of renewable energy in Malaysia, two United Nation Development Program (UNDP)-Global Environmental Facility (GEF) funded demonstration programmes were conducted. The first programme is the Biomass Generation & Co-generation in the Malaysian Palm Oil Mill (BioGen) (2002-2010) that converted palm oil biomass waste such as POME and EFB into biogas and syngas, respectively, for electrical energy. The second programme is the Malaysian Building Integrated Photovoltaics (MBIPV) (2005-2011) that increased the utilisation of BIPV in Malaysia, reduced the long-term cost of BIPV technology and reduced GHG and carbon emissions from the electricity sector.

Since the transportation sector's contribution to GHG and carbon emission is significantly as much as the emission from the electricity generation's, there was also an urgent need to substitute fossil fuel with renewable fuel such as biofuel. The National Biofuel Policy was approved in 2006, and the Biofuel Industry Act was passed in 2007. The biofuel is palm oil-based biodiesel blends with petroleum diesel at 5%, 7%, and 10% biodiesel content (B5, B7 and B10) to be deployed in the 9th and 10th Malaysia Plans (2008-2014).

Both UNIDO-GEF projects created an ecosystem where there was greater acceptance of renewable energy by Malaysian stakeholders. Malaysia approved the National Renewable Energy Policy and Action Plan (RE Roadmap) in April 2010, followed by the Renewable Energy Act, which established the Feed-in Tariff (FiT) scheme for renewable energy that is administered by the Sustainable Energy Development Authority (SEDA), which was established under the Sustainable Energy Development Authority Act 2011.

After quotas of FiT were oversubscribed in 2016 and could not continue without increasing RE levy, the Energy Commission introduced the Net Energy Metering (NEM) scheme for solar PV of up to 500 MW and the Large Scale Solar (LSS) for Peninsular Malaysia and Sabah in the 11th (2016-2020) and 12th Malaysia Plans (2021-2025).

2.3.3 Malaysia's Current Energy Scenario

Malaysia's total primary energy supply was 4.15 PJ (98,298 Ktoe) in 2017 (Figure 9). About 92.9% of it was from fossil-fuels and 7.1% from renewable energy (hydro 6.35%, solar 0.38%, biofuels 0.63%) (Figure 10). Malaysia's total energy demand was 2.6 PJ (62,490 Ktoe) in 2017 (Figure 11). About 98% was used for industry (45.8%), transport (43.2%) and residence (9.8%). About 20.17% is for electricity generation. Malaysia's final energy consumption is shown in Figure 12. Fossil fuels constitute 75% of it.

Fuel oil and diesel have been phased out of the fuel mix for electricity generation (Figure 13). The utilisation of coal, coke and natural gas for electric power generation has increased dramatically in the past five years to increase their share to 48.38% and 37.51%, respectively. Hydropower had also increased sharply to take 12.4% of the energy mix. Other REs such as biodiesel, biogas and solar is only 0.47% of the total energy mix.

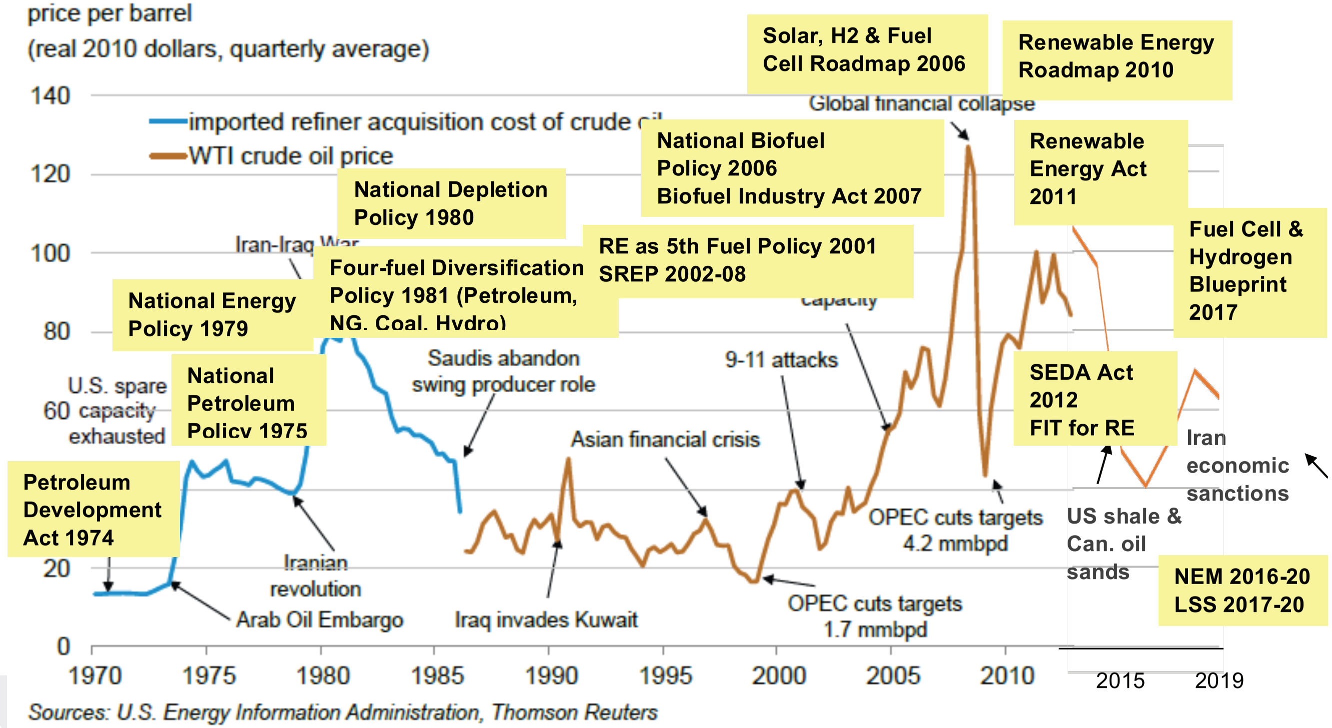

Figure 8: Evolution of Malaysian Energy Policy

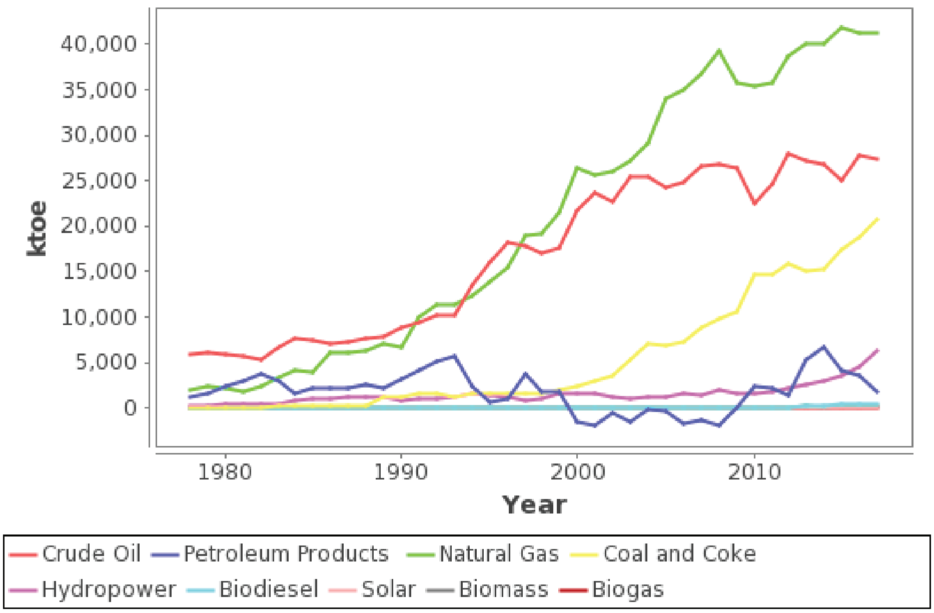

Figure 9:
Malaysian Primary Energy Supply
Source: Malaysia Energy Balance 2018.

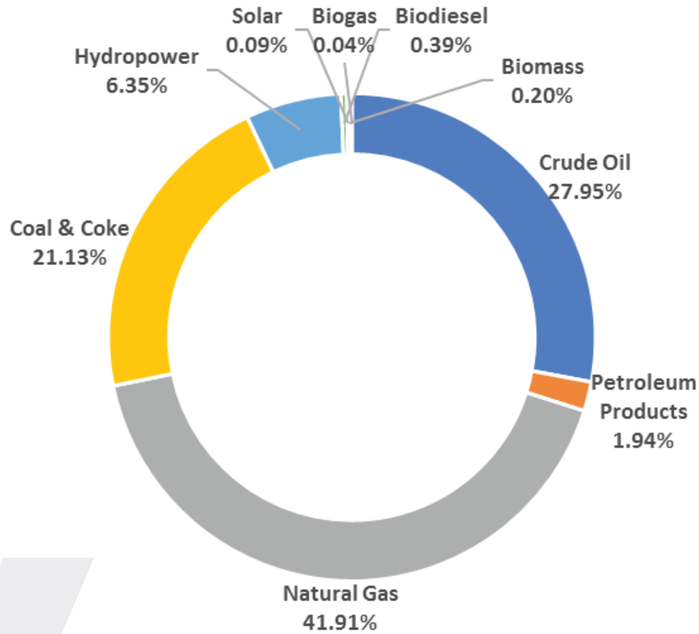

Figure 10:
Malaysian Primary Energy Supply 2017
Source: Malaysia Energy Balance 2018

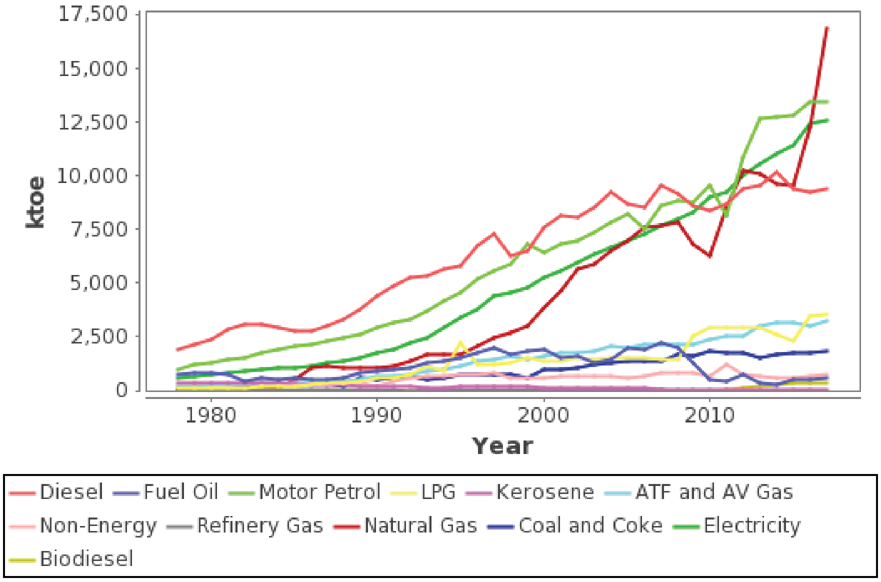

Figure 11:
Malaysian Final Energy Demand
Source: Malaysia Energy Balance 2018.

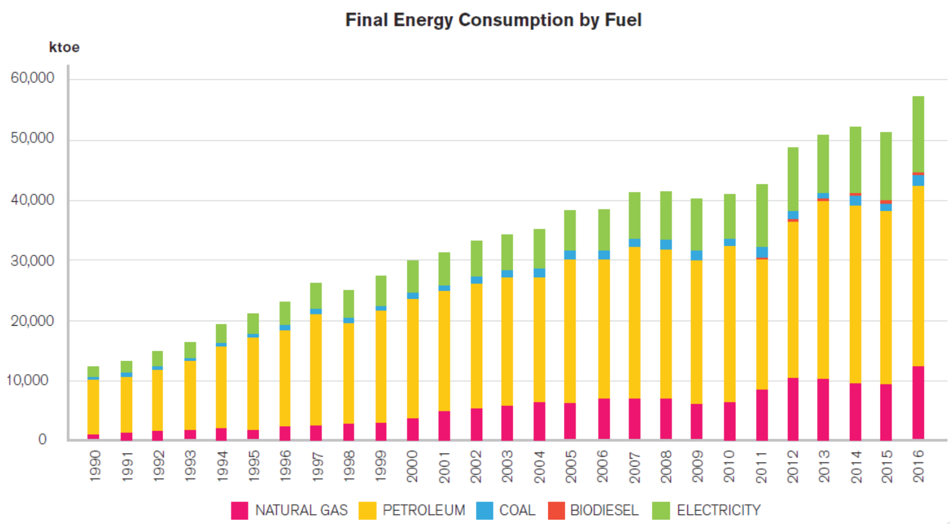

Figure 12:
Malaysian Final Energy Consumption by Fuel
Source: Malaysia Energy Balance 2018

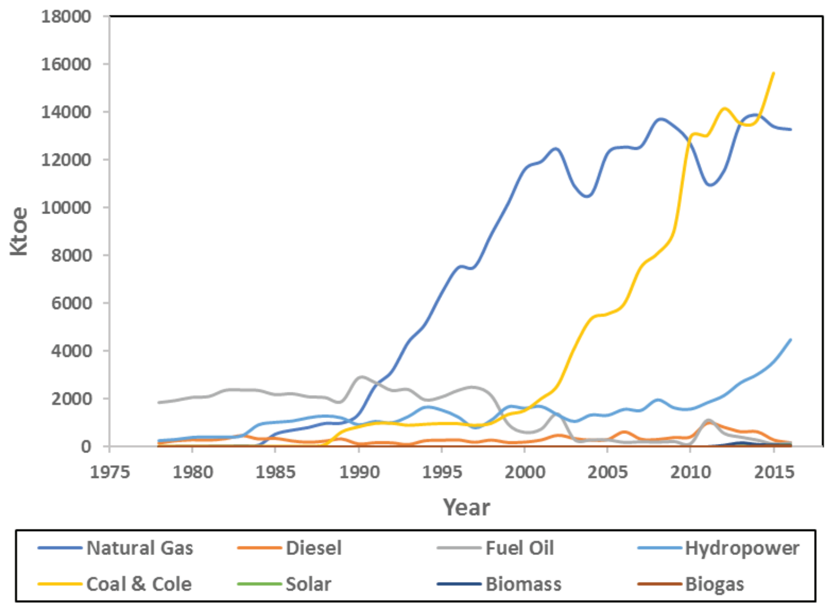

Figure 13:
Electricity Generation According to Fuel Malaysia Energy Balance 2018

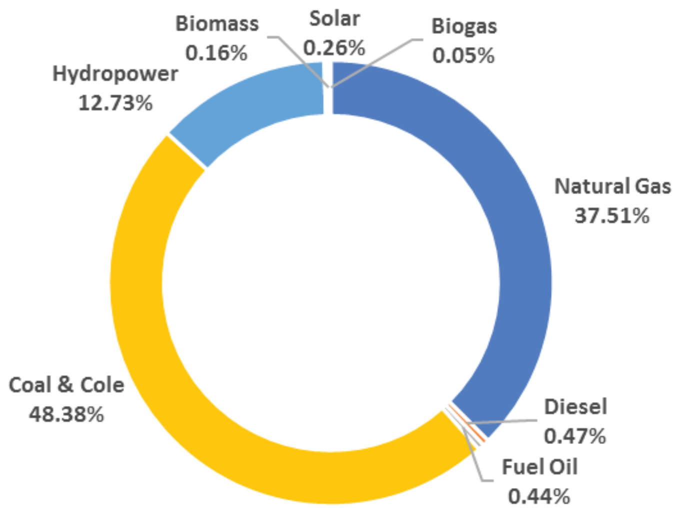

Figure 14:
Electricity Generation According to Fuel 2016
Source: Malaysia Energy Balance 2018

Oil

Malaysia is the third-largest holder of oil reserves in Southeast Asia after Indonesia and Vietnam (Figure 15). It is also the third-largest oil producer in Southeast Asia after Indonesia and Vietnam (Figure 16 & 17). Malaysia exports crude oil mostly to the Asia Pacific region, namely Australia, India, Thailand, and Japan (U.S. EIA 2017).

Rapid rise in demands for crude oil and oil products in regional and domestic markets and gradual production decline at major producing oil fields for the last decade have forced Malaysia to take the following steps (Figure 18):

- Investing in enhanced oil recovery and deep water marginal discoveries
  - Tapis EOR project off Terengganu in a 25-year production-sharing since 2010
  - Baram Delta and North Sabah EOR off Sarawak and Sabah since 2011
- Increasing the capacity of oil refining and storage in preparation to become the region's oil trading and storage hub
  - Pengerang Integrated Complex (PIC) in Pengerang Johor and Refinery and Petrochemical Integrated Development (RAPID) to start-up in 2019
- Enhancing oil exploration in existing deep water areas by investing in new major upstream and downstream oil projects
  - Kikeh, Kakap and Malikel off Sabah deep water oil field

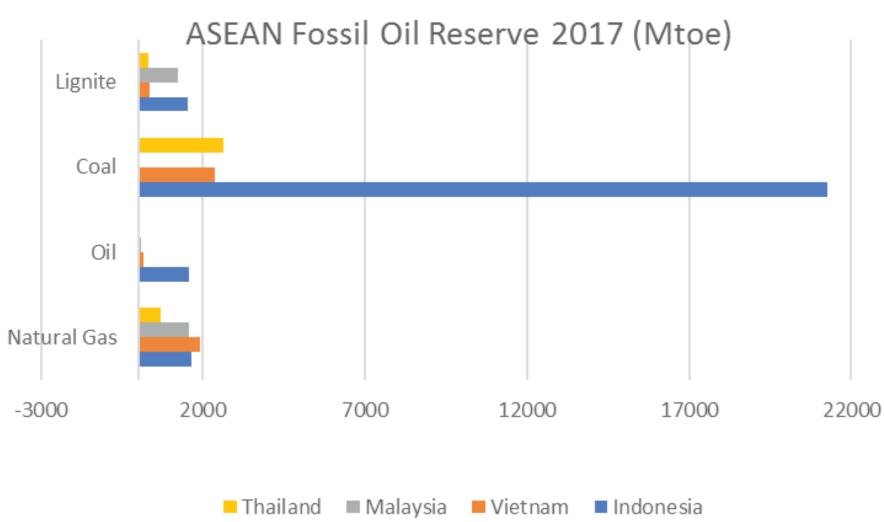

Figure 15:
ASEAN Fossil Oil Reserve 2017 (Mtoe)
Source: ASEAN Power Cooperation Report 2017

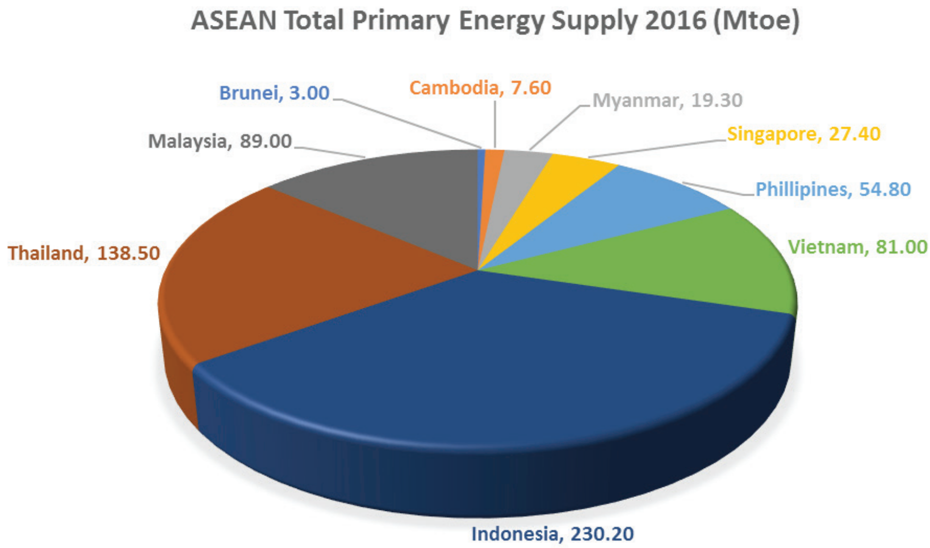

Figure 16:
ASEAN Total Primary Energy Supply 2017 (Mtoe)

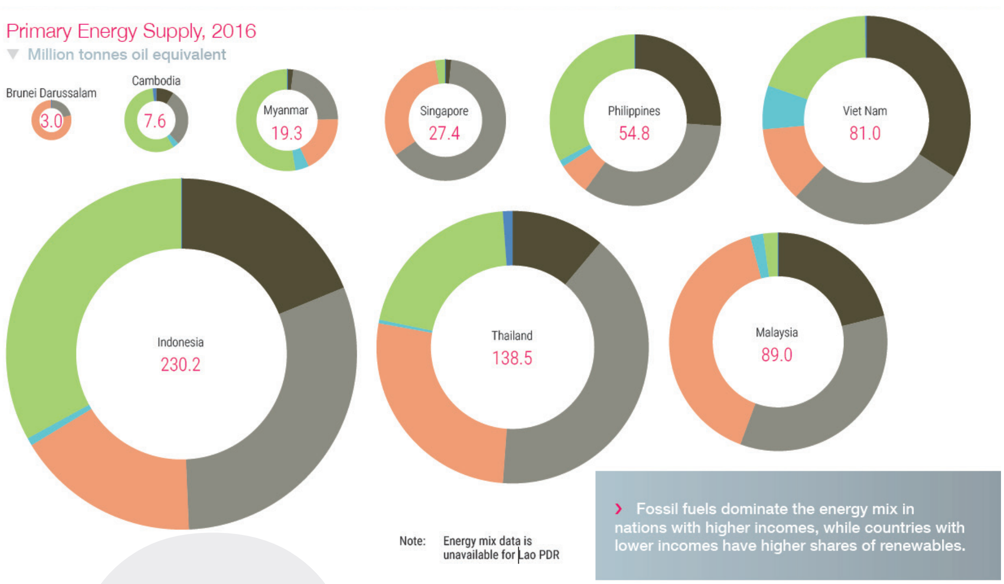

Figure 17:
Primary Energy Mix of ASEAN

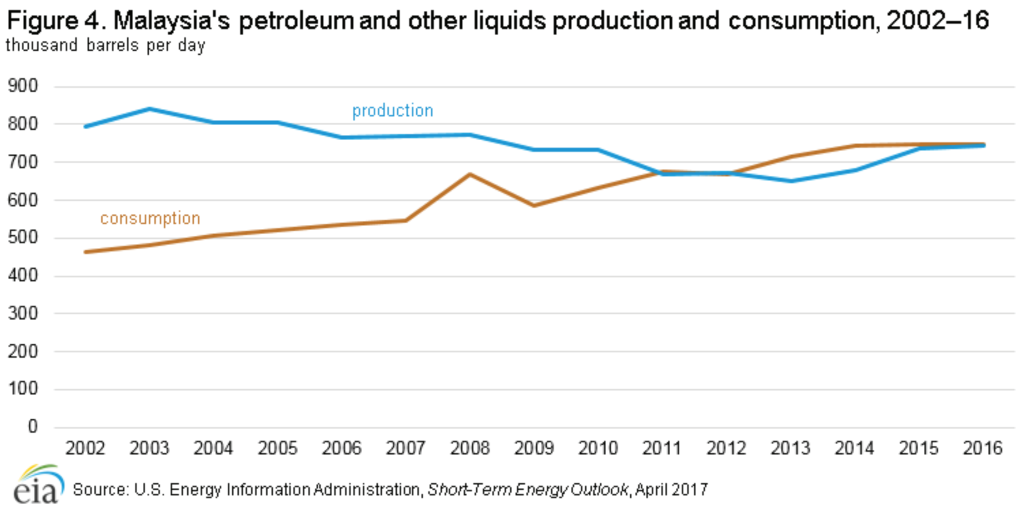

Figure 18:
Malaysia's Petroleum Production and Consumption 2002-1016 (thousand barrels per day)
Source: U.S. EIA, 2017

Gas

Malaysia is the third-largest holder of gas reserves in Southeast Asia after Indonesia and Vietnam (Figure 15). It is also the third-largest gas producer in Southeast Asia after Indonesia and Vietnam (Figure 16 & 17). Natural gas accounted for about 41.9% of the country's total supply (Figure 10) and about 37.5% of the electricity generation in 2016 (Figure 14) (Malaysia Energy Balance 2018).

The PETRONAS LNG Complex in Bintulu, Sarawak, is the world's largest production facility of liquified natural gas (LNG) at a single location and produces 23 million metric tonnes per year (Malaysia Productivity Corporation 2014). However, domestic consumption is mostly in Peninsular Malaysia, where the main demand is from electric power generation of about 58%. With the current average daily production rate of around 6 bscd, Malaysia's natural gas resources should last for more than a couple of decades. Figure 19 shows a comparison between the natural gas resources and consumption by region (Enerdata.net 2015; Malaysiangas.com 2014).

Natural gas production and import have increased due to demands from domestic and export. Malaysia is the second-largest natural gas producer after Indonesia in Southeast Asia and the World 16th largest natural gas reserves with a capacity of about 85 tscf. It is also the second-largest exporter of LNG, after Qatar, in the world.

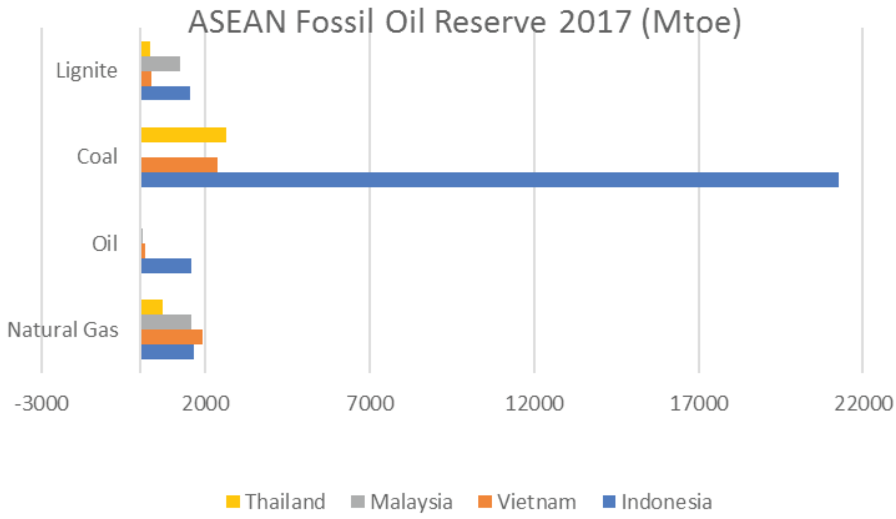

Figure 19: **Natural Gas Resources and Consumption by Region, 2013**

Renewable Energy in Malaysia

The less than 10 MW grid-connected Small Renewable Energy Project (SREP) scheme that was implemented in the 8th Malaysia Plan (2001-2005) to fulfil the 5% target share of RE in the Five Fuel Policy was off-target because only two SREP projects utilising oil palm biomass (10MW) and landfill biogas (2MW) were successfully built and operated. The target of 5% of RE was revised to 350MW in the 9th Malaysia Plan where 245MW is from biomass (Oil palm 193MW, municipal solid waste (MSW) 35MW, land fill gas (LFG) 7MW, and rice husk 10MW) and 105MW from minihydro.

RE contribution to electricity generation was only 12 MW in 2005. The 9th Malaysia Plan's target of 300 MW in Peninsular Malaysia and 50 MW in Sabah was not met, as only 41.5 MW was contributed by the end of the year. In the 10th Malaysia Plan, a new RE target was set at 985 MW by 2015, which is 5.5% of the total mix for Malaysia (Economic Planning Unit 2001, 2006, 2011).

The BioGen funded by UNIDO-GEF in the 8th and 9th Malaysia Plans (2001- 2010) had successfully built two full-scale demonstration models: a 10MW biogas from POME power plant and a 13 MW biomass from the EFB power plant. The MBIPV funded by UNIDO-GEF in the 9th Malaysia Plan (2005 – 2011) had increased the utilisation of BIPV up to 1.5 MWp.

In the FiT programme administered by SEDA, only 421 MW out of the approved 1349 MW of RE had achieved commercial operation by 2016 (Figure 20). All of the projects except for solar PV (individual) were scaled up from SREP. Only 30% of the approved FiT project reached commercial operation. Solar PV was commercialised very quickly but biomass, biogas and small hydro were very slow to commercialised (Figure 21).

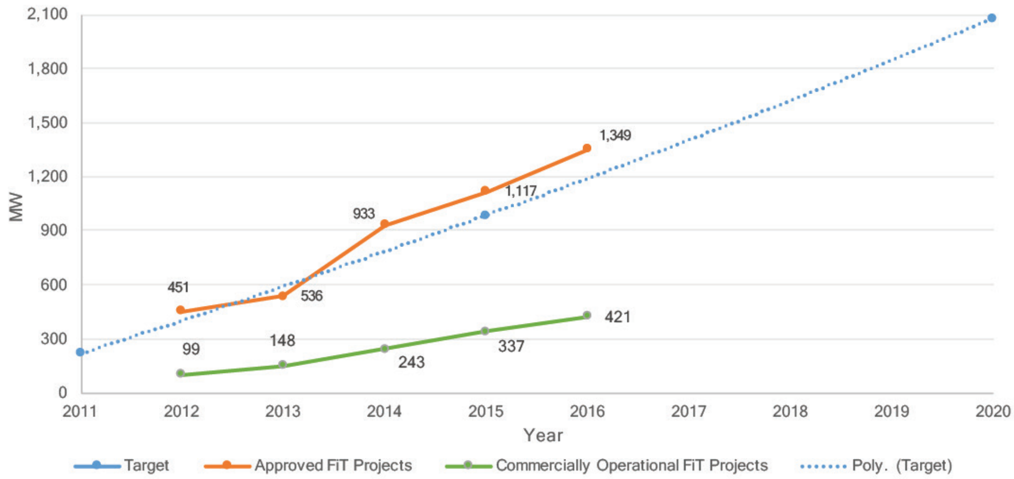

Figure 20: Commercialised FiT Projects Compared to Approved Projects

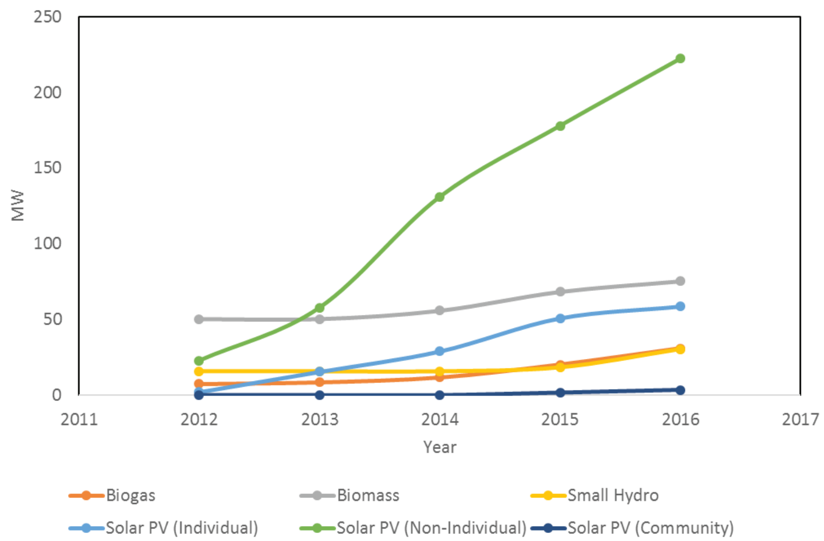

Figure 21: Commercialised FiT Projects by RE Types

The NEM policy's 500 MW target is distributed equally over 5 years (2016-2020) 100 MW per year (Peninsula Malaysia 90MW, Sabah 10MW). The capacity is further divided into residential 24MW, commercial 39MW and industrial 37MW per year. However, between 2016 and 2018, only 4.5% (or 13.56 MW) of the available 300MW capacity for the NEM scheme has been taken up (Figure 22). The take up in Sabah is almost non-existent. The failure is due to inadequate incentives, forfeiture of accumulated credits and high installation costs.

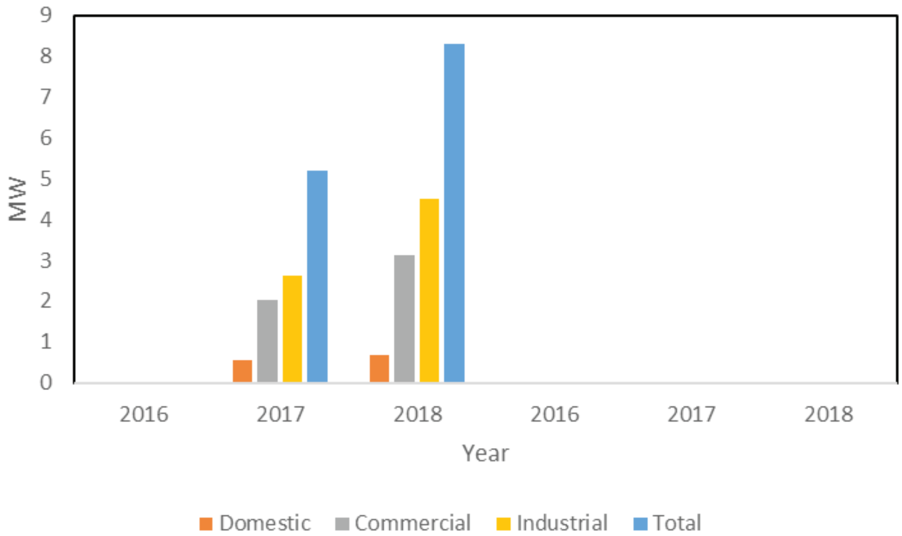

Figure 22:
Net Energy Metering (NEM) by Region

The biodiesel 5% blend B5 was only fully implemented nationally 6 years after the passage of the Biofuel Industry Act in 2014. The biodiesel content in the biodiesel blend was increased to 7% for B7 in 2015 because of growing CPO stocks and declining CPO prices. There was a push to increase the blend to 15% in the 11th Malaysia Plan (2016-2020), but it was shelved because of strong objections from the industry.

Biodiesel production in 2018 was 1.22 billion litres, and the amount exported in the same year was 570 million litres (Figure 23). In early 2018, the European Parliament (EP) wanted to ban the use of palm oil in biofuels by 2020 but retracted it in June 2018, after objection, and agreed to cap at the 2019 level until 2023 and then subsequently reduced to zero by 2030.

In 2019, SEDA developed the Renewable Energy Transition Roadmap (RETR) 2035 which includes the strategic roadmap to support Malaysia's target in achieving 20% RE in the national installed energy mix for electricity generation by 2025 (excluding large hydro of more than 100MW) as well as to determine the future of the electricity scenarios at 2035. The RETR will start to be implemented in the 12th Malaysia Plan (2021-2025).

In compliance with the RETR, the Energy Commission is now counting on LSS and NEM to increase the RE of the fuel mix including off-grid up to 20% in the 12th Malaysia Plan (2019-2025) (Figure 24). Calls for open tender by Energy Commission on LSS for up to 250MW in 2016 yielded an award of 450MW that would begin commercial operation in 2017-2018. A second LSS2 tender for up to 460MW in 2017 received bids totalling 1,632MW but was awarded 562 MW that would begin commercial operation in 2019 - 2020. Up to April 2018, four LSS projects had commenced operations with a total capacity of 34.5MW, representing only 7.65% of the total approved capacity. At the time this report was written the LSS scheme was still suffering from a slow commercialisation rate. On 29th May 2020, the Energy Commission called for a third tender on LSS for up to 500 MW to be operational in 2021.

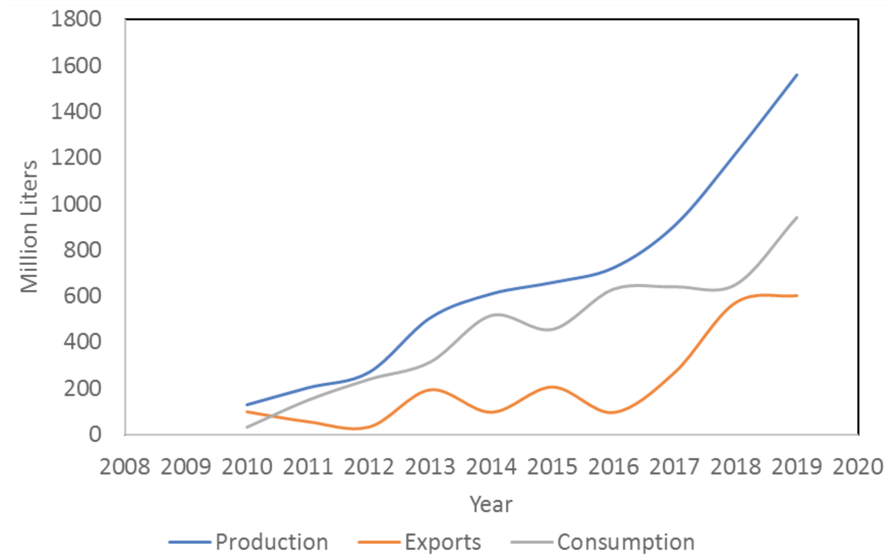

Figure 23:
Biodiesel Production, Export and Consumption in Malaysia

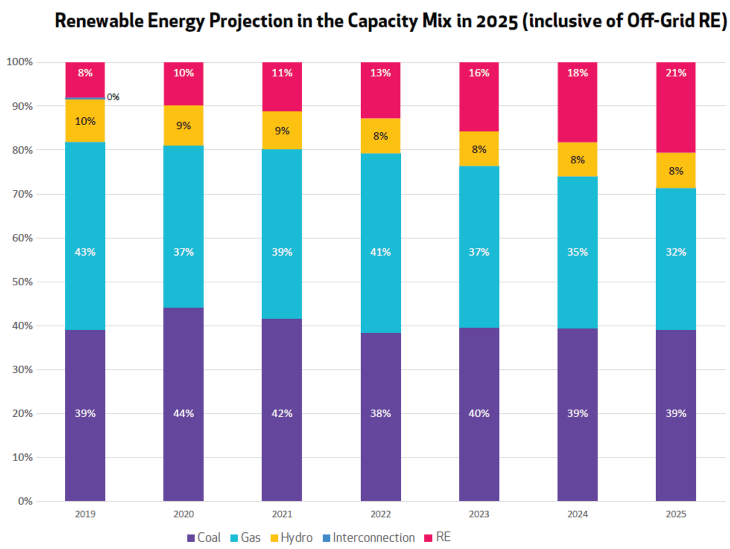

Figure 24:
RE Projection in the Capacity Mix Including Off-Grid (2019-2025)

In 2019, SEDA conducted a study on decarbonising the electricity sector to further strengthen and spur the growth of clean energy. Malaysia's Renewable Energy Transition Roadmap (RETR) 2035 includes the strategic roadmap to support the current government's aspiration in achieving 20% RE target in the national installed capacity mix by 2025 (excluding large hydro of more than 100MW) as well as to determine the future of the electricity scenarios at 2035. The outcome of the roadmap is to be part of the 12th Malaysia Plan (2021-2025).

Nuclear Energy in Malaysia

Malaysia has been operating 1 MW TRIGA Mark II research nuclear reactor at the Agensi Nuklear Malaysia in Bangi, Selangor, since 1982 (Ahmad & Abdul-Ghani 2011). In 2010, Malaysia planned to build two 1000 MWe nuclear power reactors to be operational by 2021 provided that the public accepts the project, the relevant international treaties are ratified, the regulatory framework is put in place and approvals of the site is obtained from local authorities and residents. However, enthusiastic support for nuclear energy in Malaysia declined after the Fukushima Daichi nuclear accident in 2011, where an earthquake and a tsunami knocked out the coolant pumps resulting in severe loss of coolant circulation, reactor meltdown and hydrogen explosions that released radioactive wastes into the atmosphere and the sea. On 20 November 2019, the Minister of MESTECC had decided that Malaysia will not build a nuclear power station.

Hydrogen Energy in Malaysia

Hydrogen energy and fuel cells in Malaysia began with the award of an RM4 million project from the Intensification of Research in Priority Areas (IRPA) fund at the Ministry of Science, Technology and Environment Malaysia (MOSTE) (1996-2000) on the development of a commercially competitive proton exchange membrane fuel cell (PEMFC), which was shared equally by UKM and UTM. The research was not only mainly on the PEMFC and its components but also on hydrogen production from various primary fuels like natural gas and methanol and solar energy through electrolysis and photoelectrochemical (PEC) water splitting.

A much larger grant of RM30 million was awarded from the PR-IRPA fund at the Ministry of Science, Technology and Innovation (MOSTI) to the same teams in UKM and UTM (2002-2007). The main objective of the research was to develop a PEMFC prototype for commercial applications in portable generators, motorcycles and golf carts. The project also included the development of new types of fuel cells; solid oxide fuel cells (SOFC), direct methanol fuel cells (DMFC) and microbial fuel cells (MFC) as well hydrogen production from glycerol and solar energy using PEC water splitting.

The fund made it possible for UKM to form the Fuel Cell Institute at UKM in January 2007 as the first research institute in Malaysia to carry out research and development in the field of fuel cells and hydrogen energy.

The Institute was awarded again with a grant of RM 7 million from the Ministry of Higher Education (2013-2018), which is shared with UTM, UM, UITM and UNITEN. The objective of the project was to develop a 5 kW PEMFC prototype to power a fuel cell vehicle with Proton. The UKM Institute also collaborated with a local company to develop a new type of Proton Exchange Membrane (PEM) Electrolyzer to produce hydrogen from solar energy for off-grid schools in remote areas using an RM3 million Technofund grant from MOSTI.

Recently, Petronas Research Sdn Bhd was 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 Malaysian fuel cell and hydrogen energy R&D community, mainly based in UKM and UTM but has since spread to UM, UITM and UNITEN, has to date garnered research funding of over RM 40 million from MOSTI and MOHE and over RM 11 million from the industry.

It has also published over 450 world-renowned scientific articles on fuel cells and hydrogen energy in high impact international journals. The community has also produced more than 50 PhD and MSc graduates in fuel cells and hydrogen energy. Malaysia's fuel cell experts have also delivered international keynote lectures and international invited lectures in various countries including Australia, Iceland, India, Indonesia, Iran, Japan, South Korea, Philippines, Russia, Singapore, Spain, and

Thailand. More than 50 patents in fuel cells technology and hydrogen energy have been filed and granted. The Malaysian fuel cell and hydrogen energy community has also garnered numerous international and invention awards in the fuel cells and hydrogen energy categories. Recently the community had finally formed the Malaysian Association of Hydrogen Energy (MAHE) in 2018.

The solar, hydrogen and fuel cells roadmap for Malaysia was approved in 2006 and incorporated in the 9th Malaysia Plan but was superseded by the RE policy. A second updated hydrogen economy roadmap, The Blueprint for the Fuel Cell Industry was commissioned by The Academy of Science Malaysia in 2017.

In May 2019, the Sarawak government launched Southeast Asia's first Integrated Hydrogen Production Plant and refuelling station in Kuching and the introduction of Sarawak's first hydrogen-powered vehicles. This shows that there are local industry players that have started venturing into Hydrogen technology. However, we still need to increase the numbers of industry players to pick up and commercialize new research and technologies from the Universities, such as fuel cell and hydrogen energy technologies.

2.4 Carbon Emission in Malaysia

Carbon dioxide emissions are calculated from the burning of fossil fuels and cement manufacture , which are the main contributors. They include carbon dioxide produced during the consumption of solid, liquid, and gas fuels and gas flaring. In 2018, carbon emissions for Malaysia were 257.8 million tonnes carbon (Mtc). Malaysia's carbon emissions increased from 122.9 Mtc in 1999 to 257.8 Mtc in 2018 growing at an average annual rate of 4.09% (Figure 25).

Malaysian INDC proposal to UNFCCC (2015) calls for a reduction in per capita carbon emissions by 45% by 2030 based on the level in 2005 with 35% from domestic initiatives and the remaining 10% from climate finance, technology transfer and capacity building from the developed countries (UNFCCC, 2015). The economic impact of the proposed Malaysian Intended Nationally Determined Contribution (INDC) initiative was found to be the best compared to two other policy prescriptions for climate change mitigation in Malaysia (Rasiah et al. 2016).

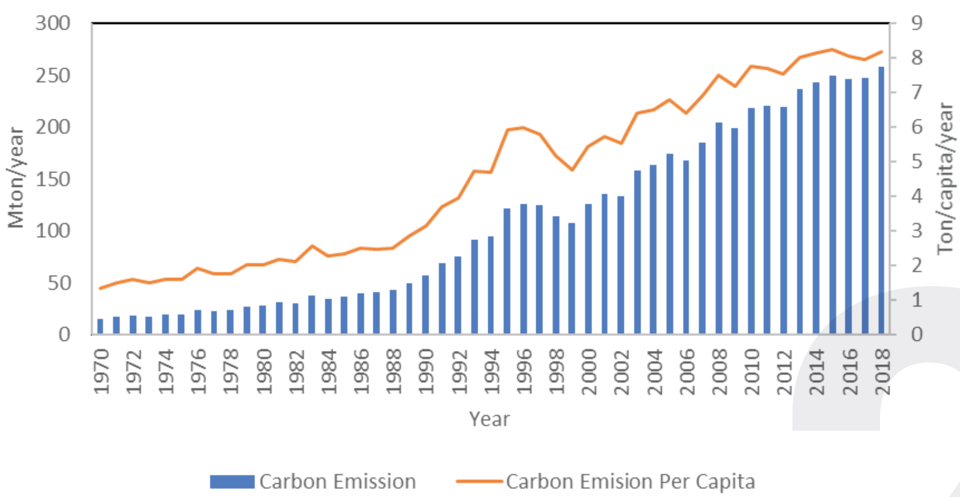

Figure 25:
Carbon Emission and Carbon Emission per capita for Malaysia

Malaysia plans to fulfil part of its INDC commitments by increasing its low-carbon energy supply over 2020-2050. The National Renewable Energy and Action Plan (RE Roadmap) aims to gradually increase the RE installed capacity from 985 to 4,000 MW by 2030 and 21.4 GW by 2050. RE electricity would be 5%, 9% and 12% of the total electricity generation in 2015, 2020 and 2030 respectively. Malaysia targets to have 24% of its total energy mix from RE by 2050 that will enable it to avoid carbon emissions of more than 500 Mtc. Since RE from biomass, biogas, mini-hydro and solid waste is limited by the availability of non-solar energy resources by 2020, large scale solar (LSS) energy and alternative energy such as hydrogen energy could be viable sources of energy to fill up the shortfall in RE from the other sources beyond 2020.

If Malaysia' s INDC is implemented, its carbon emission will be reduced by 160 Mtc in 2020, 120 Mtc in 2030 and 500 Mtc in 2050 (Rasiah et al. 2017) (Figure 26). However, although the CO2 concentration in the atmosphere would reduce slightly or remain the same up to 2030, it will rise thereafter to 570 ppm by 2060 (Figure 27) (Rasiah et al. 2017). It will not reduce any more unless more low-carbon or zero-emission technologies like hydrogen energy are deployed. Temperature rise limit of 2°C agreed upon at COP 2015 will be reached in 2060 (Figure 28) (Rasiah et al. 2017).

According to Rasiah et al. 2018, Malaysia's INDC proposal for COP21 is the most attractive since the cumulative cost of climate damage over the period 2010-2110 using this proposal will come to RM 5.264 trillion, which is significantly less than the RM 40.128 trillion projected under the baseline scenario. Although the Stern and Nordhaus proposals have also improved both emission levels and economic output, they were inferior to Malaysia's INDC.

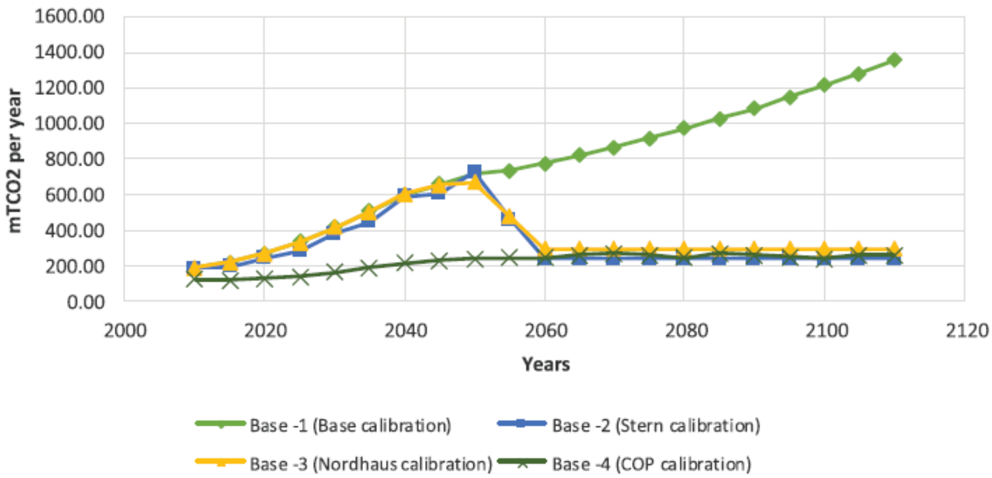

Figure 26:
Industrial Emission Projections, Malaysia, 2010-2110
Source: Rasiah et al. 2016

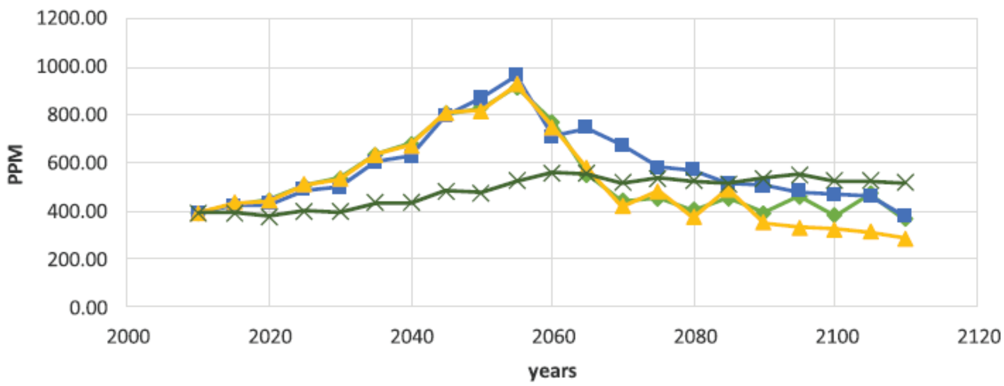

Figure 27:
Atmospheric Concentration, Malaysia, 2010-2110
Source: Rasiah et al. 2016

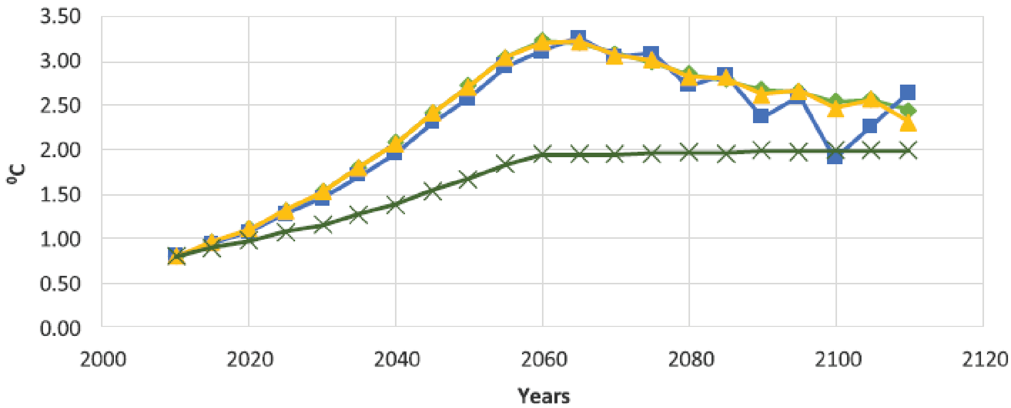

Figure 28:
Atmospheric Temperature, Malaysia, 2010-2110
Source: Rasiah et al. 2016.

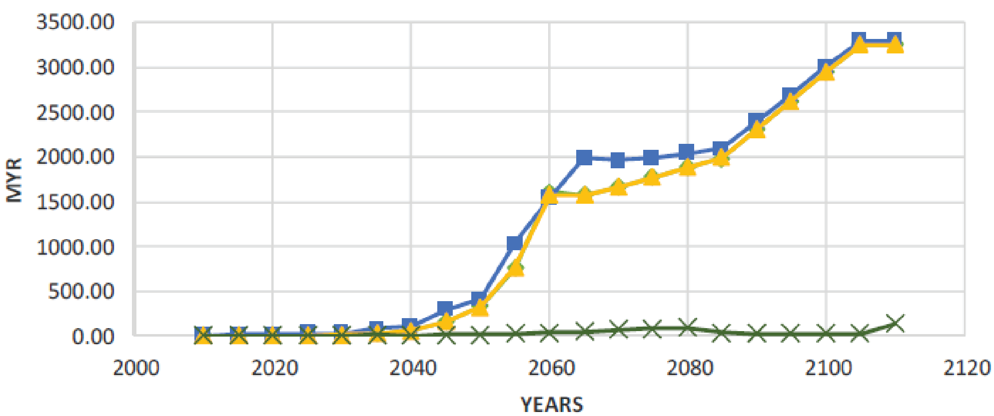

Figure 29:
Abatement Costs, Malaysia, 2010-2110
Source: Rasiah et al. 2016.


Danger
Explosive atmosphere
EX
H2


H_2
H_2
H_2
H_2
H_2
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3. THE HYDROGEN ECONOMY

Hydrogen Energy
Hydrogen Production and Storage Technology
Utilization of Hydrogen Energy in Fuel Cells for Electricity Generation
Hydrogen Supply Chain
Initiatives in Malaysia

3 The Hydrogen Economy Carbon Emission

The idea behind the development of the hydrogen economy was first broached in the 1960s (Bockris, 2013). In the beginning, hydrogen was thought of as an intensive energy carrier that could transmit energy more cost-efficiently by pipeline than electricity by copper wires. It was not until the late 1970s when air pollution by combustion of fossil fuels became a health hazard that hydrogen began to be thought of as an ideal form of clean fuel that produced only water after combustion.

Later on in the late 1980s, when the world was facing serious air pollution and global warming crisis as a result of excessive CO_2 emissions from fossil fuel combustion, hydrogen was thought of as an ideal form of energy storage and carrier that could be integrated with the electrical energy from primary renewable energy sources, which is expected to replace fossil fuel combustion to generate energy.

Sustainable development in the energy sector is a transformation from a fossil fuel based energy system that uses mainly oil for transport and natural gas and coal for electrical power generation without carbon capture and storage and reuse and with very little renewable energy resources, into a renewable electricity-hydrogen energy system where most electricity is produced from renewable energy (solar, wind, hydro and biomass) with carbon capture and storage and reuse for biomass. Hydrogen energy produced by renewable energy along with electricity are used for most of the transport, in place of oil and natural gas, with very little use of oil, natural gas and coal in electricity generation.

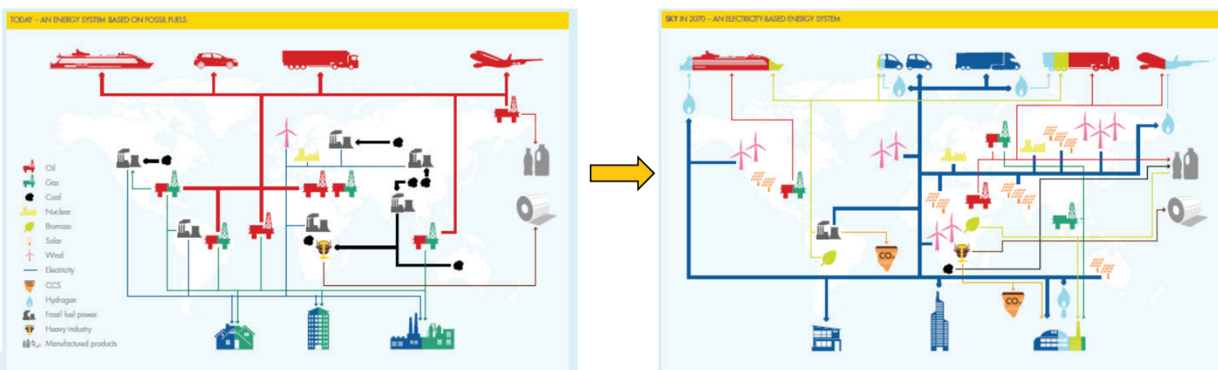

Figure 30:
Transformation of Fossil Fuels Based Economy to Renewable-Hydrogen Based Economy

Hydrogen economy is a type of circular economy where hydrogen is produced from carbon-free sources such as water and renewable energy and is used as an alternative fuel for transport and electrical power generation (Liu et al., 2012). Water vapour produced from the hydrogen energy conversion returns to the atmosphere and condenses as water to be reused in the hydrogen economy. The hydrogen economy is driven by the input of renewable energy in hydrogen production.

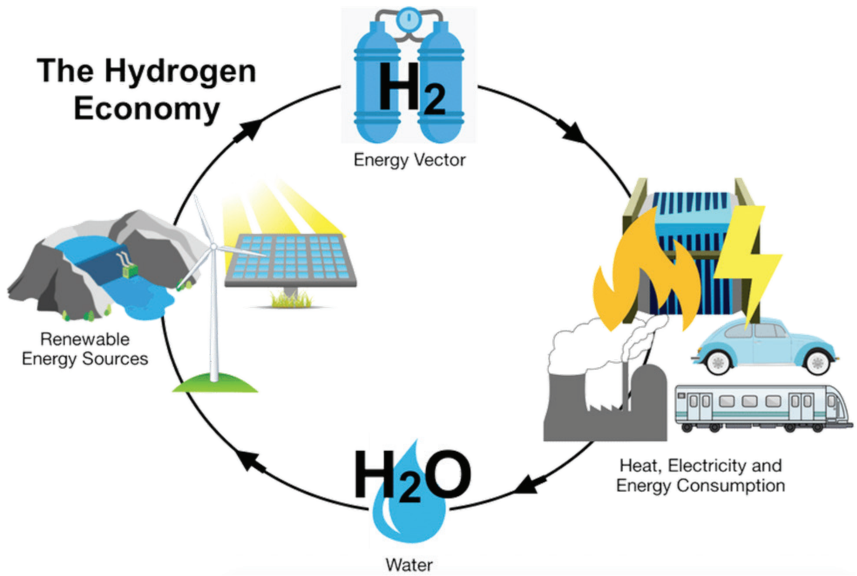

Figure 31:
The Hydrogen Economy

In the hydrogen economy, hydrogen energy is now widely accepted as a promising energy carrier for decarbonizing transport and electricity generation, mitigating the emission of greenhouse gases (GHG)/carbon that causes global warming and climate change, and enhancing security of the energy supply.

Many countries are currently embarking on a transition to the hydrogen economy. They have published technology roadmaps of hydrogen economy that will make the transition possible (Ajanovic, 2008, Agnolucci and McDowall, 2013; Kontogianni et al., 2013, McDowall and Eames, 2006, Stiller et al., 2008, Mcdowall, 2012, Lee, 2013).

3.1 Hydrogen Energy

Hydrogen is an odourless and colourless gas at ambient temperature and pressure. Like electricity, it is not a primary energy source but an energy carrier. It could be used to store and deliver energy that could later be converted into other forms of energy, especially electrical energy. It is a clean energy carrier with zero or low carbon emission depending on the method of its production and the primary fuel or energy used to produce it.

Hydrogen offers Malaysia a very viable means to store and deliver energy from abundant, domestically available renewable resources such as biomass, solar energy, hydropower, organic wastewater and water. Hydrogen can also help in reducing Malaysia's carbon footprint to fulfil its commitment to reduce carbon emission intensity based on the 2005 level by 45% in 2030 at the COP21 Paris Agreement in 2015. It can protect Malaysia from energy insecurity as a result of uncertainties in the world oil supply because of war.

Table 1: Advantages and Disadvantages of Hydrogen Energy

Advantages	Disadvantages
The lightest and most abundant element in the universe	Rarely found in nature by itself due to its strong tendency to combine with other elements like oxygen to form water
Contains more energy per mass compared to other energy carriers	Has relatively much less energy by volume unless at high pressures
Can be produced from a variety of energy resources using various methods. Hence it can be produced on a large scale	Hydrogen produced from fossil fuels requires carbon capture and storage or reuse to reduce carbon emissions
Can be easily transported to users from the production plants	Normally transported by road due to the lack of pipeline infrastructure for hydrogen delivery
Can be stored as a high-pressure gas, a liquid at atmospheric pressure and very low temperature or via advanced physical and chemical storage	Energy losses can occur due to storage and distribution and storage technology improvements can incur additional costs

Hydrogen offers sustainable solutions to Malaysia's energy and climate challenges:

- Energy security:
    - Hydrogen utilisation as a fuel to power fuel cell vehicles and power generators for residential, commercial and industrial sectors could significantly reduce Malaysia's sole dependence on fossil fuels.
- Energy sustainability:
    - Hydrogen could be produced sustainably from renewable energy sources such as biomass by gasification-syngas reforming, solar and wind energy-water electrolysis and solar energy-photoelectrochemical water splitting.
- Carbon capture and reuse:
    - Hydrogen could convert captured greenhouse gas CO_2 from CO_2-rich oil and gas wells, flue gases from furnaces and off-gases from production units to produce methanol, methane (CH_4) or formic acid (CO_2H_2) which could be used as alternative fuels to gasoline. This will help Malaysia meet its commitment to reduce 45% of carbon emission intensity by 2030 based on the 2005 level sustainably at a lower cost.
- Climate change mitigation:
    - Hydrogen from renewable resources which is used as a fuel to power fuel cell vehicles and power generators for residential, commercial and industrial sectors emit near-zero carbon. This will help Malaysia meet its commitment to reduce 45% of carbon emission intensity by 2030 based on the 2005 level.
- Urban air quality:
    - Hydrogen emits only water when it is used as a fuel in fuel cells. This could reduce the emissions of air pollutants such as hydrocarbons, carbon monoxide and nitrogen oxides and improve urban air quality.
- Economic viability:
    - Hydrogen produced from Malaysia's abundant resources of natural gas and renewable energy such as hydropower could secure Malaysia a share of the rapidly developing global hydrogen energy markets in developed countries by leading the research, development and commercialisation of hydrogen energy and fuel cell technology.

Public perception on safety of hydrogen transport and storage remains an obstacle despite being vouched for by safety professionals as safer than the liquefied petroleum gas (LPG) used in the kitchen and gasoline or petrol used in cars in terms of the risk of explosion and fire from a leakage. If the hydrogen leaks from the high-pressure tank, the leak is a buoyant high velocity jet that mixes with the air some distance from the tank or vehicle before catching fire if there is an ignition source.

Hydrogen energy deployment is unfortunately also constrained by its high cost of production from renewable resources and the high cost and low durability of fuel cells, the main energy conversion device for hydrogen that does not involve combustion. It could be used as fuel for transportation or for electricity generation using fuel cells.

3.2 Hydrogen Production and Storage Technology

3.1.1 Raw Material or Feedstock for Hydrogen Production

Hydrogen is commonly produced by steam methane reforming followed by water-gas shift reaction, gasification of coal followed by water-gas shift reaction, electrolytic water splitting, dark fermentation and photofermentation of wastewater. The common feedstocks for hydrogen production are natural gas, coal, biomass, wastewater and water.

Hydrogen from fossil fuels such as natural gas and coal without carbon capture and storage (CCS) or utilisation (CCU) are called grey hydrogen. Hydrogen from natural gas and coal with CCS and CCU are called blue hydrogen. Hydrogen from biomass or wastewater and water splitting by renewable energy with low or zero carbon emission is called green hydrogen.

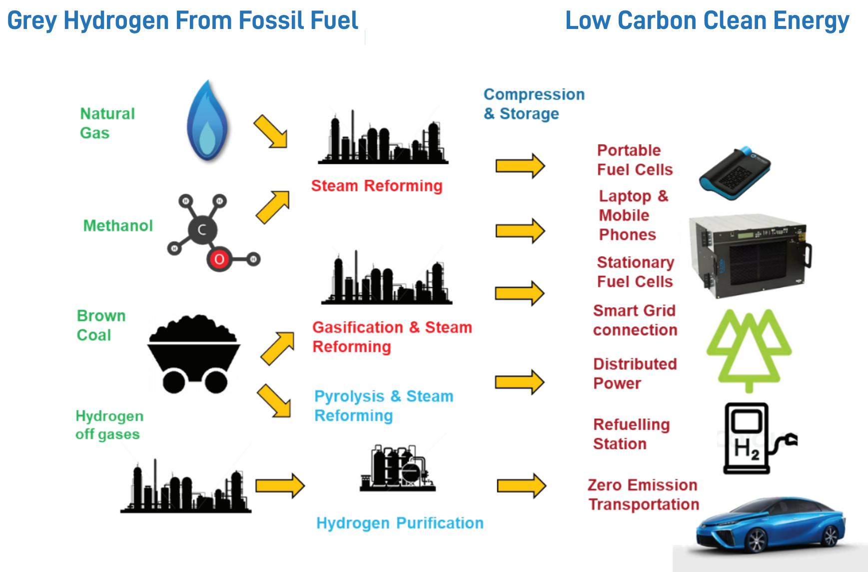

Figure 32:
Grey Hydrogen Supply Chain

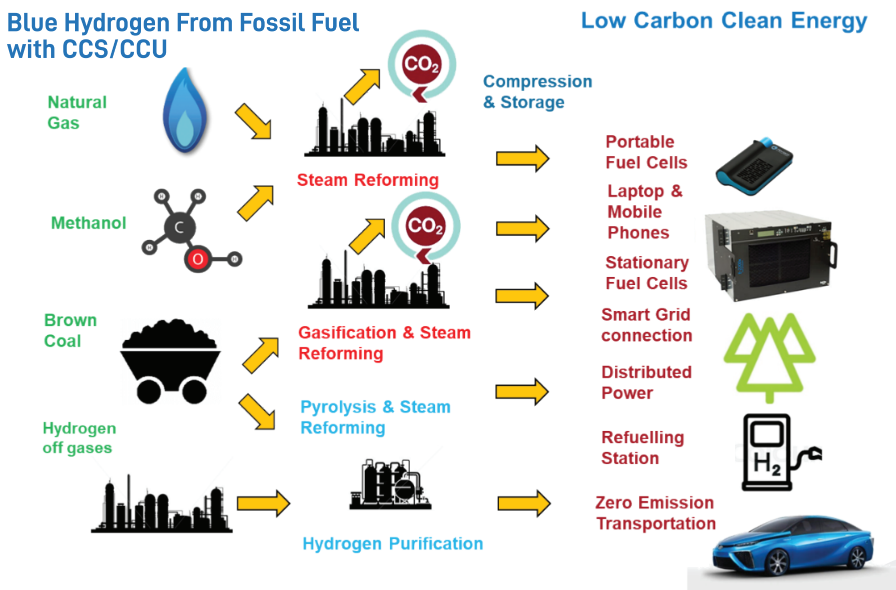

Figure 33:
Blue Hydrogen Supply Chain

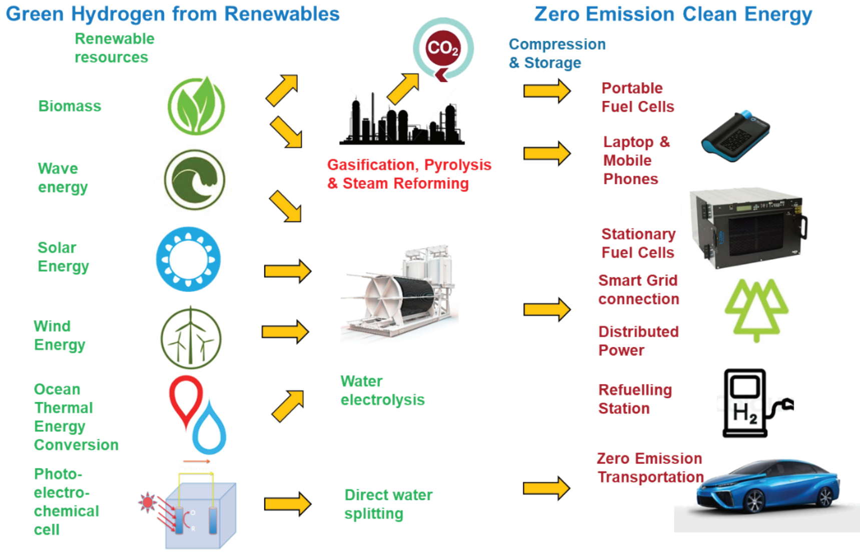

Figure 34:
Green Hydrogen Supply Chain

Table 2 shows the conversion of various feedstocks into 1 kg of hydrogen. A kilogram of hydrogen coincidentally is also equivalent to 1 US gallon of gasoline which is 5.976 kg or 3.78 litres of gasoline (Milbrandt & Mann 2009). Therefore, it called one US gallon of gasoline-equivalent (gge).

Table 2: Hydrogen yield from various feedstocks

Feedstock	Feedstock/H_2	Blue H_2	Grey H_2	Green H_2
Coal (gasification)	7.6 kg/kg H_2	With CCS/CCU	Without CCS/CCU	
Natural Gas (steam methane reforming)	3.1 kg/kg H_2	With CCS/CCU	Without CCS/CCU	
Water (renewable energy & electrolysis)	11.4 kg/kg H_2			Renewable Energy
POME (dark fermentation)	4,771.0 kg/kg H_2			Renewable Energy
POME (photofermentation)	4,080.2 kg/kg H_2			Renewable Energy
Biomass (EFB) (Gasification)	27.8 kg/kg H_2			Renewable Energy

Natural gas could be used as the feedstock for blue or grey hydrogen before the transition to renewable energy-based green hydrogen is completed. Coal is a cheaper alternative but Malaysia imports 90% of its coal because extracting domestic coal from remote coal mines is more costly, making coal gasification for hydrogen production less viable in Malaysia but could be feasible in the future. Coal gasification also produces more than twice as much carbon emissions from natural gas reforming.

3.1.2 Blue and Grey Hydrogen Production Technology

Steam methane reforming of natural gas with carbon capture and storage/use

At present, steam methane reforming (SMR) of natural gas (NG) is one the cheapest and most common methods of producing hydrogen. The SMR method currently produces almost 48% of hydrogen in the world. It is used mainly as feedstock for chemical synthesis or upgrading the quality of the products produced from crude oil in refineries.

SMR mainly consists of two steps steam methane reforming to extract the hydrogen from methane and water followed by a water-gas shift reaction (WGSR) to extract more hydrogen from water by oxidizing carbon monoxide (CO) produced in the first reaction into carbon dioxide CO_2 by using water. The SMR, which is an endothermic reaction, is run at high temperatures of 500-900°C and pressures of 30 atm to produce carbon monoxide (CO) and hydrogen (H_2) in the presence of a nickel (Ni) catalyst according to the reaction

$$CH_4 + H_2O \leftrightarrow CO + 3H_2 \qquad \Delta H_r^{o} = +206 \text{ kJ/mol.}$$

The WGSR, which is an exothermic reaction, is run at high temperatures of 310-450°C and moderate pressures in the presence of iron-chromium (Fe-Cr) catalyst and then followed by low-temperature WGSR at 200-250°C and moderate pressures in the presence of copper-zinc (Cu-Zn) catalysts to produce hydrogen and carbon dioxide (CO_2) from the reaction of CO with steam (H_2O) according to the reaction:

$$CO + H_2O \leftrightarrow CO_2 + H_2 \qquad \Delta H_r^{o} = -102 \text{ kJ/mol.}$$

Hydrogen is usually purified by a pressure swing adsorber (PSA) that could obtain nearly 99.99% pure hydrogen. In blue hydrogen production, CO_2 emission from this process could be reduced by using carbon capture and storage (CCS) or carbon capture and reuse (CCR) technology to produce commercial products such as methanol and formic acid.

The traditional process of SMR in tubes full of catalysts within huge furnaces has now evolved through modification in three major areas to address issues of diffusional and thermodynamic limitations, and catalyst deactivation due to coke formation.

This involves replacing the fixed bed reactor with a fluidised bed reactor, in-situ separation of hydrogen to drive the reaction beyond its thermodynamic equilibrium and changing the mode of heat supply from external firing to direct heating.

It could also be achieved by mass transfer enhancement through multifunctional particle design, improved heat transfer through coupled catalytic reactors and plasma technology, and combining SMR with in situ adsorption or membrane separation of hydrogen to overcome thermodynamic limitations, and novel catalyst design to achieve desirable kinetics.

Ni-based catalysts are so far the most commonly used catalysts for SMR because of their high activity and significantly lower cost compared to precious metal-based catalysts. However, nickel catalysts are susceptible to deactivation from carbon deposition, even when operating at steam-to-carbon ratios predicted to be thermodynamically outside of the carbon-forming regime.

The coking resistance of the Ni catalyst can be improved by the addition of small amounts of noble and rare earth metals and changing supporting materials like perovskites. Since the effect of the additives and support material for the Ni-based catalyst can drastically improve both catalytic performances as well as stability, research in these areas is very important.

Coal Gasification

Gasification of coal, a complex and highly variable substance is another cheap method for producing hydrogen. Hydrogen is produced by first reacting coal with oxygen and steam under high pressures and temperatures to form synthesis gas, a mixture consisting primarily of carbon monoxide and hydrogen.

The overall reaction for coal gasification reaction (unbalanced):

$$CH_{0.8} + O_2 + H_2O \rightarrow CO + CO_2 + H_2 + \text{Tar} + \text{ash (unbalanced)}$$

Tar and carbon are also produced but in lesser quantities. The actual chemical reactions of gasification consist of a few reactions: combustion, water-gas shift, Boudouard and methanation reactions.

Combustion reactions (CR):

$$C + \tfrac{1}{2} O_2 \rightarrow CO \qquad \Delta H_r^o = -111 \text{ MJ/kmol}$$

$$CO + \tfrac{1}{2} O_2 \rightarrow CO_2 \qquad \Delta H_r^o = -283 \text{ MJ/kmol}$$

$$H2 + \tfrac{1}{2} O_2 \rightarrow H_2O \qquad \Delta H_r^o = -242 \text{ MJ/kmol}$$

Water-gas reaction (WGR):

$$C + H_2O \leftrightarrow CO + H_2 \qquad \Delta H_r^o = +131 \text{ MJ/kmol}$$

Boudouard Reaction (BR)

$$C + CO_2 \leftrightarrow 2CO \qquad \Delta H_r^{o} = +172\ MJ/kmol$$

Methanation Reaction (MR)

$$C + 2H_2 \leftrightarrow CH_4 \qquad \Delta H_r^{o} = -75\ MJ/kmol$$

In a gasification process, combustion reactions take place partially using one-fifth to one-third of the required theoretical oxygen. The gasification products are hydrogen and carbon monoxide (CO), with a small amount of carbon dioxide (CO_2). The heat produced by partial oxidation provides most of the energy required to drive the endothermic gasification reactions. At the high conversion of carbon, the reactions could be reduced to two-gas phase reactions of WGSR and SMR.

In low oxygen, reducing environment, most of the sulfur coverts to hydrogen sulfide (H_2S), with a small amount of carbonyl sulfide (COS). Nitrogen converts to gaseous nitrogen (N_2), with some to ammonia (NH_3) and hydrogen cyanide (HCN). Chlorine is primarily converted to hydrogen chloride (HCl). Generally, the quantities of sulfur, nitrogen, and chloride are small enough to affect on the syngas.

After the impurities are removed from the synthesis gas, the carbon monoxide in the gas mixture is reacted with steam through WGSR to produce additional hydrogen and carbon dioxide. Hydrogen is removed by a separation system, and the carbon dioxide stream can be captured and stored or reused by conversion to chemical products for sale.

3.2.3 Green Hydrogen Production Technology

Biomass gasification

Biomass is widely available from agricultural activities in most countries. In Malaysia the main commercial biomass is EFB, whose chemical formula is $CH_{2.27}O_{0.83}N_{0.02}$ which could be approximated to glucose in gasification reaction. Biomass, like EFB as a renewable resource is widely used to replace fossil fuels for combustion in electricity generation.

Biomass gasification is a thermochemical process for the destruction of biomass such as lignocellulosic biomass like EFB, agriculture residues and organic solid wastes to produce hydrogen. Biomass is partially oxidized with steam and O_2 from the air in an endothermic high-temperature (>700°C) and high-pressure reaction to produce syngas that consists of mainly H_2, CO, steam and CO_2 according to the reaction (glucose is surrogate for biomass).

$$C_6H_{12}O_6 + O_2 + H_2O \rightarrow CO + CO_2 + H_2 + \text{char} + \text{tar (unbalanced)}$$

The actual chemical reaction of biomass gasification is like coal gasification.

The syngas is passed through a WGSR in order to increase the hydrogen yield further by water-gas shift reaction between CO and water. The hydrogen sulfide in the hydrogen gas product could be removed to recover elemental sulfur. CO_2 emission from this process could be reduced by using carbon capture and storage (CCS) or carbon capture and reuse (CCR) technology to produce commercial products such as methanol and formic acid.

The trend in biomass gasification is to gasify at a lower temperature of 800 to 900°C by searching for new better catalysts for tar cracking and to reduce mass transfer limitations by reducing biomass particle size and increasing mixing of the gas, biomass particles and bed material containing the catalyst by reactor design.

Biomass gasification reactors have evolved from updraft and downdraft fixed bed reactors to fluidised bed reactors. In fluidised bed gasifiers the fuel and bed material containing the catalyst behaves like a fluid when air, steam and oxygen is passed through them at fluidization velocity with a carbon conversion as high as 95%.

Tar cracking efficiency of previous catalysts such as dolomite, zeolite, olivine and alumina varies from 70 to over 90%. Although zeolite catalysts have less carbon and tar depositions compared to metal oxide catalysts, metal-metal oxide/alumina or zeolite catalysts have been shown to perform better at temperature conditions of 500–900°C.

Water Electrolysis

One of the key technologies in converting water to hydrogen from renewable energy is electrolysis. Water electrolysis into hydrogen and oxygen has now become an important hydrogen production process because it could become a green zero-emission process if electricity from renewable energy sources is used. Hydrogen obtained from electrolysis is of very high purity, up to 99.9%, while the electrolysis process itself is easy to use and does not require a long start-up time. It is also safe for in situ small productions of hydrogen for immediate use without storage. The electrolyzer is costlier than an SMR plant, and up to 75% of the cost of hydrogen production is from electricity cost. The cost of hydrogen from electrolysis could be reduced if cheaper off-peak electricity is used. Hydrogen from electrolysis could become green hydrogen also if electricity from renewable energy sources such as solar PV, wind and ocean thermal energy conversion (OTEC) is used.

In water electrolysis, the overall reaction of electrochemical splitting of water into hydrogen and oxygen by electrical (and thermal) energy is given by:

$$H_2O \rightarrow \tfrac{1}{2}O_2 + H_2$$

The heat of reaction ΔH_r^o gives the overall energy required for the reaction, which can be partly supplied by heat (Q) while another part, the change in Gibbs energy ΔG_r^o, has to be supplied electrically and is used to split the water into two gases, hydrogen and oxygen.

An electrolyzer consists of several stacks of electrolysis cells that are connected in series in each stack. The oxidation reaction occurs at the anode and the reduction reaction at the cathode in the cell, but the reactions differ according to the types of electrolysis. The efficiency of electrolysis decreases, or conversely, the overpotential increases with rising current density, decreasing temperature and increasing pressure.

The main types of water electrolyzers are alkaline (AEL), polymer electrolyte membrane (PEMEL) and solid oxide (SOEL) electrolyzer. Recently a new type of alkaline polymer electrolyte membrane electrolyzer, called the anionic exchancge membrane electrolyzer (AEMEL) is being developed. It combines the advantages of AEL and PEMEL.

a. Alkaline Electrolysis (AEL)

This is the most common and mature technology used in water electrolysis, which has been applied for large-scale hydrogen production in the MW-scale already at the beginning of the 20th century. Alkaline electrolysis is highly efficient, cheap, durable and long-lasting. The purity of hydrogen and oxygen is very high, 99.7% - 99.9% for hydrogen and 99%-99.8% for oxygen, which can be further increased to above 99.999% by catalytic gas purification (deoxidiser).

When a DC voltage is applied to the electrolysis cell, water is split to form hydrogen at the cathode releasing hydroxide anions that pass through the diaphragm and recombine at the anode to form oxygen. The partial reaction at the electrodes is given by:

V	Cathode
$2OH^- \longrightarrow ½O_2 + H_2O + 2e^-$	Anode

Figure 35: Layout of alkaline electrolysis for AEL

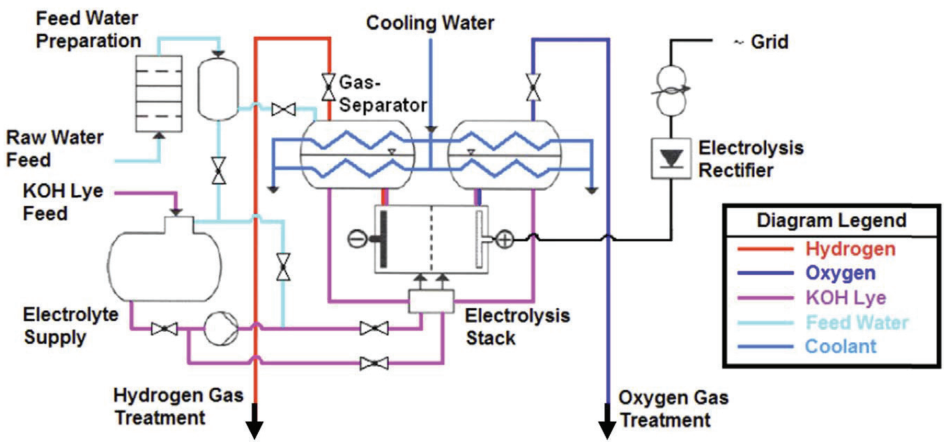

Figure 36: **Schematic Diagram of an Alkaline Electrolysis System**

In an alkaline electrolysis cell, a pair of electrodes are immersed in a liquid electrolyte consisting of a 25%-30% potassium hydroxide (KOH) solution, and are separated by an ion-permeable diaphragm. The electrolyte is recirculated to remove product gas bubbles and heat either by pumps or by natural circulation due to temperature gradients and buoyancy of the gas bubbles. The electrolyte is stored in two separate drums for each gas which also serve as a gas-liquid-separator.

When an alkaline electrolyzer is operated at low load, the rate of hydrogen and oxygen production reduces while the hydrogen permeability through the diaphragm remains constant, yielding a larger concentration of hydrogen on the anode (oxygen) side thus creating a hazardous situation at the anode that could cause explosion and fire.

b. Proton Exchange Membrane Electrolysis (PEMEL)

PEMEL splits deionised water into hydrogen and oxygen on the anode and cathode respectively on either side of a solid polymer electrolyte membrane, which replaces the liquid electrolyte solution in AEL.

When a DC voltage is applied to the electrolyzer, water fed to the anode (or oxygen electrode) is oxidised to oxygen and protons, while electrons are released. The protons (H+ ions) pass through the PEM to the cathode (or hydrogen electrode), where they meet electrons from the other side of the circuit and are reduced to hydrogen gas. The partial reactions at the electrode are as follows:

$2H^+ + 2e^- \rightarrow H_2$	Cathode
$H_2O \rightarrow ½O_2 + 2H_2O^+ + 2e^-$	Anode

Figure 37: **Layout of alkaline electrolysis for PEMEL**

Figure 38 shows the schematic diagram of a PEMEL system.

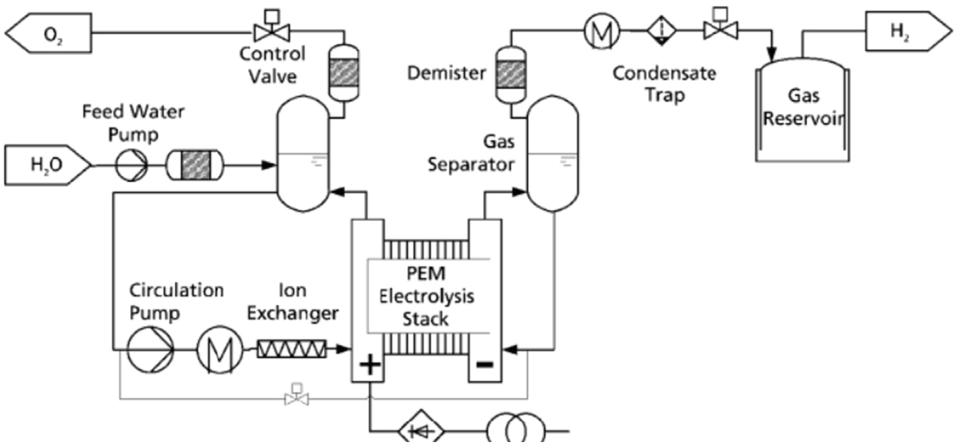

Figure 38:
Schematic Diagram of a PEM electrolysis system

PEMEL can operate at much higher current densities of up to 2 A cm^{-2}, which reduces the operational and overall cost of electrolysis. The thin solid PEM allows the cell to be thinner than the AEL cell. The low gas crossover rate of the PEM yields hydrogen with high purity. Proton transport across the membrane responds quickly to the power input, not delayed by the inertia of a liquid electrolyte. Unlike AEL, PEMEL covers practically the full nominal power density range (10-100%).

c. Anionic Exchange Membrane (AEM) Electrolysis (AEMEL)

The AEMEL cell has the same structure as PEMEL cell but the anionic exchange membrane transports anionslike the hydroxyl ions (OH−) instead of cations like protons (H+) as in the PEMEL. The AEMEL is classified as alkaline electrolysis because the reactions that occur in the electrodes are the same as in the traditional alkaline cells. The AEMEL has no carbonates deposits due to lack of metallic cations, lower ohmic losses because of thinner AEM, cheaper because AEM is less expensive than PEM and no concentrated KOH solution, making it easier to install and operate.

In addition, due to its basic/alkaline condition, AEMEL does not require platinum-group-metal (PGM) catalysts such as in PEMEL. Instead, transition-metal catalysts had been used successfully, which makes it cheaper. Moreover, it is possible to improve the purity of the gases by operating at high pressure, which is a clear advantage over the traditional alkaline electrolysis. However, one major drawback of the alkaline membrane is its low chemical stability.

d. SOE Electrolysis (SOEL)

SOEL performs electrolysis of water vapour at high temperatures, which has a higher efficiency compared with liquid water electrolysis. It could use waste heat also for supplying the heat required for part of the electrolysis. SOEL operates at high temperatures of 700–900 °C, which would give higher efficiencies than AEL or PEMEL, but its material stability is a challenge to solve. The high efficiency is the result of improved kinetics, favourable thermodynamics for internal heat utilisation at higher temperature and higher conversion of steam. Despite this, SOEL is not ready to be commercialised because of durability problems due to severe conditions. A simplified process layout of a SOEL system is shown in Figure 39. The reactions at the electrodes are:

$H_2O + 2e^- \rightarrow H_2 + O^{2-}$	Cathode
$O^{2-} \rightarrow ½O_2 + 2e^-$	Anode

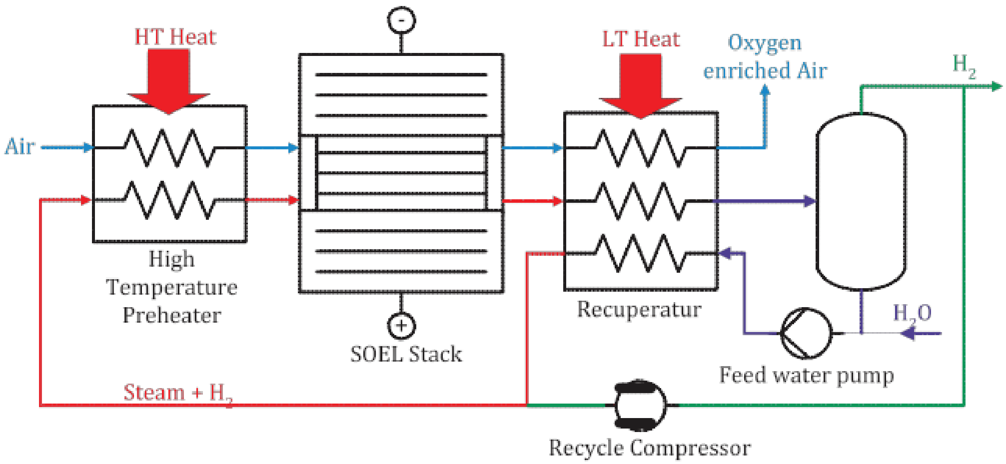

Figure 39: **Layout of a Solid Oxide Electrolysis System**

Photoelectrochemical water splitting

Photoelectrochemical (PEC) water splitting is a very promising green method to produce hydrogen. In contrast to the conventional photovoltaic panel and electrolyzer combo to produce hydrogen from water electrolysis, PEC technology merges the two separated equipment into a simple single device. It has a huge potential to be a cost-effective and efficient method to generate clean and sustainable hydrogen.

In the PEC, a semiconductor photocatalyst harnesses solar energy to photolyse water in-situ. During the photoelectrochemical reaction, solar energy is absorbed by a semiconductor material, resulting in the formation of electronic charge carriers called electrons and holes. The holes produced at the photoanode oxidise water to form oxygen gas and hydrogen ions, while both electrons and hydrogen ions move to the cathode via an external circuit and through a PEM membrane, respectively. The hydrogen ions are reduced by the electrons to form hydrogen gas at the cathode. Figure 40 shows the basic principles of PEC.

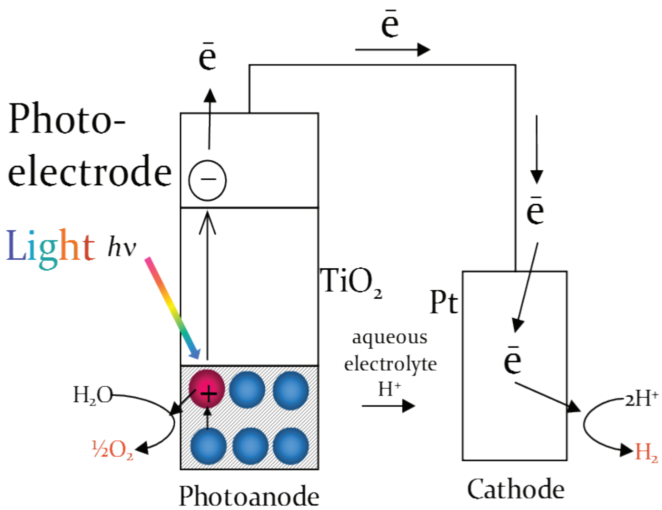

Figure 40:
Basic Principles of PEC

The goal towards worldwide sustainability for the PEC is to develop efficient, stable and cheap semiconductor photocatalysts on a large scale. In order to ensure high efficiency of the water splitting process, the semiconductor material must have a small band gap (1.8–2.2 eV), appropriate band positions for redox reactions (the conduction band edge position of semiconductor should be at a more negative potential than the reduction potential of water while the valence band edge position to be at a more positive potential than the oxidation reaction), high photocorrosion resistance and good stability in the electrolyte.

However, the challenge in PEC water splitting is well-established semiconductors have either relatively low efficiency or low stability in aqueous solutions. A lot of research has been done to study PEC reaction by using metal oxide semiconductors such as TiO_2, MoO_3, ZnO, Fe_2O_3, In_2O_3, WO_3, Cu_2O, $SrTiO_3$, SnO_2 and others with reasonable photocatalytic properties. Improvements of these semiconductors and new materials are actively researched globally with the goal to seek the efficient and stable semiconductors that can be economically viable for PEC water splitting to produce green hydrogen.

Biological processes

Hydrogen produced through natural biological processes is known as bio-hydrogen. It can be categorised into four primary groups: water-splitting photosynthesis, photo-fermentation, dark fermentation and microbial electrolysis cells. For each group, bio-hydrogen is either evolved from single microbial species or by a mixed consortium of species, with the latter involving some H2 producing species while the rest of the species consuming the H2 for their energy requirement. Initial research in this field focused on pure cultures with a defined substrate as the carbon source. The utilisation of wastewater for substrate that is more practical makes the mixed microbial population more favourable for scaled-up production. Furthermore, the mixed consortium of species is preferred because of operational ease, stability, diversity of biochemical functions and a wider range of substrates for a source of fuel.

a. Water-splitting photosynthesis

The water-splitting photosynthesis process, also known as bio-photolysis, utilises simple steps in producing H2 using light energy and water by the oxygenic photosynthetic microorganisms, such as green algae and cyanobacteria. There are two pathways: the direct and the indirect. The direct bio-photolysis derives the electrons from the light energy-mediated water splitting with the assistance of photosystem II (PS II) and photosystem I (PS I) (Figure 41).

For the indirect bio-photolysis, photosynthesis converts the light energy along with CO_2 fixation into carbohydrates before it is turned to H_2 through other pathways, such as fermentation. The Fe-hydrogenase enzyme responsible for the evolution of H_2 in green algae is O_2-sensitive, which becomes the drawback of the bio-photolysis. Unlike cyanobacteria, the production of H_2 occurs in the heterocyst, which protects its O_2-sensitive nitrogenase from O_2 exposure. Studies such as replacement of the photosynthetically evolved O2 with Argon gas, protein engineering for O_2-tolerant hydrogenases, replacing hydrogenases in green algae or replacing hydrogenase with nitrogenase in cyanobacteria, mutation of the PS II proteins, changes in operational conditions and heterologous expression of hydrogenase and Pd are done to overcome these disadvantages.

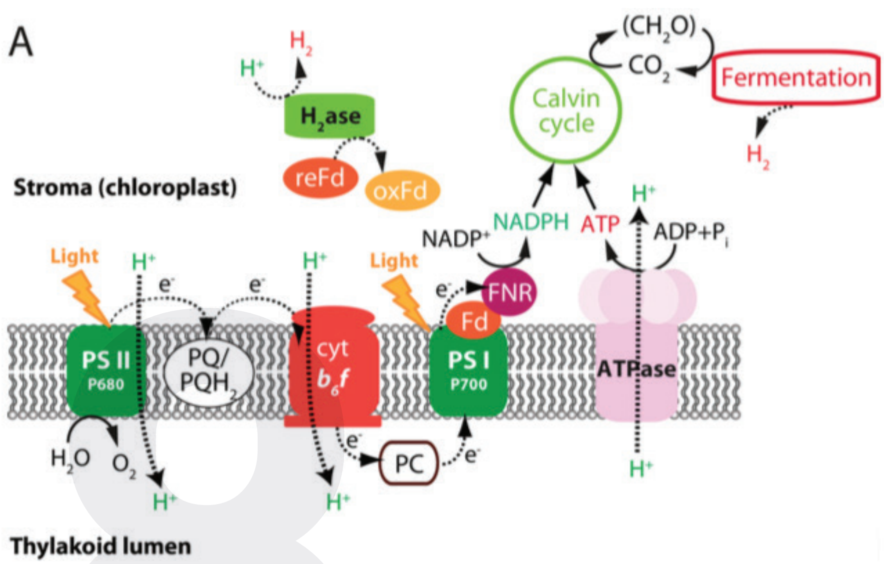

Figure 41:
Hydrogen Production from Direct and Indirect Bio-photolysis

b. Photo fermentation

Another photosynthetic pathway is photo fermentation that utilises light energy to convert organic acids such as acetate, lactate and butyrate to H_2 and CO_2 under anaerobic and anoxic conditions. The microorganism that utilises this pathway is the purple nonsulfur (PNS) photosynthetic bacteria, including Rhodobacter species. The PNS perform the fermentation using nitrogenases when in the absence of ammonium. Although there is no presence of O_2, the nitrogenases showed drawbacks in the production of H_2, including low catalytic activity, suppression of nitrogenases expression by NH_4 and lower photochemical ability. Genetic manipulation of the PNS bacteria could overcome the disadvantages.

c. Dark fermentation

Facultative and obligate anaerobic bacteria are mainly used for generating H_2 through the dark fermentation pathway. Unlike photofermentation and photolysis, dark fermentation is carried out in the dark at room temperature and often gives a higher H_2 production rate: 4 and 2 moles of molecular H_2 for acetate and butyrate pathways, respectively, from 1 mol of glucose degraded. The primary drawback is the low yield of H_2 on substrates due to the formation of various by-products. To overcome this issue, culture conditions, including the C/N and C/P ratios, carbon sources, pH, temperature, and effect of metal ions on enzymes, are being studied.

d. Microbial Electrolysis Cell

Microbial electrolysis cell (MEC) is a modified Microbial fuel cell (MFC). Certain types of bacteria on the anode (called exoelectrogens) oxidise organic material to CO_2 and proton, and release electrons to the anode. In MEC, electrons are used to reduce protons and produce H_2. Figure 42 shows Hydrogen production from microbial electrolysis cells.

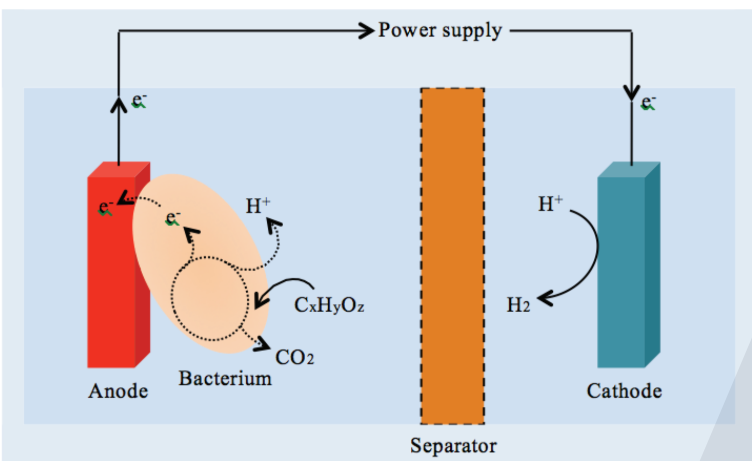

Figure 42: **Hydrogen Production from Microbial Electrolysis Cell**

However, this reaction does not occur spontaneously due to thermodynamic reasons. In practice, 400 to 1,000 mV is usually applied to the circuit to overcome energy losses due to electrode over-potentials and internal resistance. Platinum cathode and Nafion membranes are commonly used to catalyse H_2 evolution and allow only the transfer of protons to catholyte, respectively. However, platinum and Nafion are expensive: the former is non-renewable, ineffective for catalysing CO_2 reduction, and is susceptible to poisoning by sulphur and carbon monoxide. Alternatives to platinum include several inorganic materials (stainless steel, nickel and MoS_2) or microorganisms, while other polymeric membranes (SPEEK) and earthenware (ceramic) could be a cheaper substitute for Nafion.

3.2.4 Hydrogen storage and transportation

The key challenge to address in realising the hydrogen economy is to have an affordable, safe and effective hydrogen storage and distribution system from the source of hydrogen production to the end-user. Hydrogen can be stored and transported as a pressurised gas or cryogenic liquid or a combination of both methods. It can also be adsorbed on large specific surface area materials (e.g. MOF, Zeolite and carbon nanomaterials) at approximately 77K or absorbed on interstitial site (i.e. metal hydrides) in a host metal at disabled pressure and temperature (Mao et al., 2012). One of the promising methods for long-range handling and transport of hydrogen is in the form of NaBH4, solid-state hydrogen (Mao et al., 2012). Alternatively, hydrogen can also form a chemical compound via covalent and ionic bonds (i.e. chemical/complex hydride) at ambient pressure. The choice of the hydrogen storage and transportation mode depends on the distance of transportation, location of hydrogen production sites, the capacity of hydrogen, cost of infrastructure as well as portability and/or application of fuel cell.

For the past decade, the development of hydrogen storage technology has been focusing on its onboard applications for fuel cell vehicles (FCVs), where the emphasis is very much on developing light-weight, compact, high capacity, short refilling time and safe hydrogen storage systems. Currently, the major global car manufacturers have chosen a Type IV composite storage tank with a working pressure of 70 MPa as the solution to store hydrogen. The future outlook of an on-board hydrogen storage system will focus on the reduction of storage pressure while maintaining sufficient hydrogen capacity to drive for 550km on one fill-up.

On the other hand, the hydrogen storage system for stationary applications focuses on large scale storage, retail storage and self-sustained standalone power generation. In most cases, hydrogen is stored in pressurised and/or cryogenic systems; however, lately, advanced storage materials such as metal hydrides and liquid organic hydrogen carriers (LOHC) have gained substantial attention because of their attractive safety features. The mode of transportation and distribution of hydrogen varies according to the distance between the hydrogen production site, distributor and end user, and the model to transport LNG/LPG can be used as a reference. Liquefaction technology is used for very large volume and cross-continental sea transportation because of its high bulk density and low boil off rate.

Nevertheless, the challenge is to maintain a storage temperature of 20 K at all times. Meanwhile, the pipeline can be used for long-distance ground transportation from production sites to distribution points, and the hydrogen can be distributed to the retailers and end-users via truck using cryogenic, pressurised or metal hydrides technologies.

3.3 Utilisation of Hydrogen Energy in Fuel Cells for Electricity Generation

Fuel cell is an electrochemical device that converts the energy of a chemical reaction directly to electricity with zero or minimal emission. It is deemed to play an important role in future clean power generation as it offers few advantages, including higher conversion efficiencies as compared to conventional internal combustion engines. Fuel cell also offers many interesting possibilities in many applications such as transportation, commercial, industries, residential and telecommunication. Under this Chair, the research on several types of fuel cells will also be performed in conjunction with hydrogen production.

3.3.1 Proton Exchange Membrane Fuel Cell (PEMFC)

Proton exchange membrane fuel cell (PEMFC) is foreseen as one of the promising future energy sources particularly for portable applications such as transportation, portable and stationary backup power devices.

However, the large-scale commercialisation of PEMFC is still hindered by the high cost of platinum-based electrode catalysts and Nafion membranes. Most research on PEMFC focuses on the development of efficient, high performance and inexpensive materials, which is non-precious catalysts based on a combination of transition metal, carbon and nitrogen species, novel catalyst support materials to provide favourable catalyst interactions and on nano-hybrid composite membrane with high-temperature working range and increased ion transport capabilities.

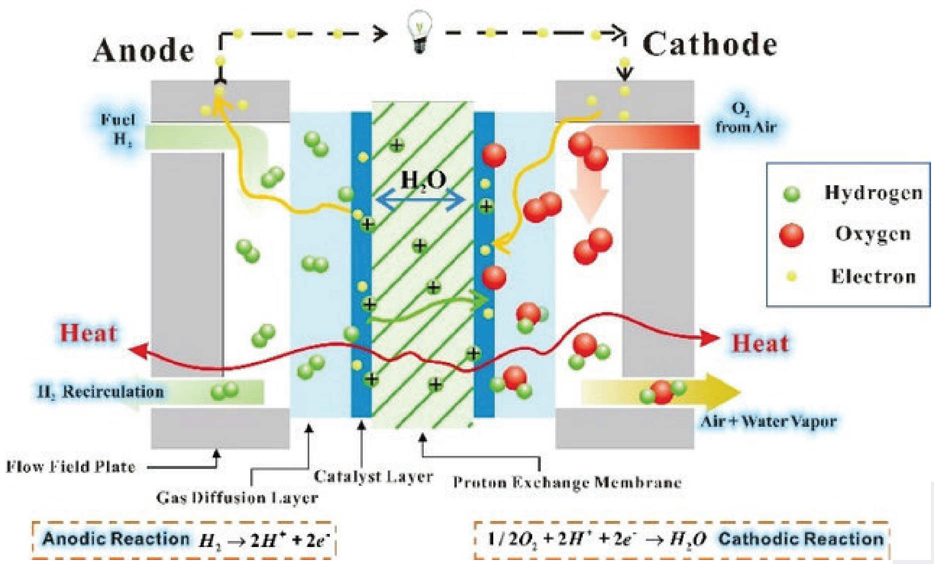

Figure 43:
Schematics of Proton Exchange Membrane Fuel Cell

3.3.1 Solid Oxide Fuel Cell (SOFC)

Solid oxide fuel cells (SOFCs) have emerged as energy conversion devices in achieving high efficiency of over 70 % with cogeneration. It has significant environmental benefits in terms of fuel flexibility (hydrocarbons and municipal waste). However, the practical implications (domestic and industrial) of SOFCs have not been realised as it has a high material cost (of electrodes, electrolyte, and interconnect) and mechanical failure at high operating temperatures (800-1000 °C). Such problems limited the development of SOFCs to a greater extent. Reducing the operating temperature generally decreases the ionic conductivity of current zirconia-based electrolytes (e.g. yttria stabilised zirconia, YSZ). Also, the performance of Ni-based anode composite materials (e.g. Ni-YSZ) is limited due to carbon deposition and sulphur poisoning when it is operated in hydrocarbon fuel. Figure 44 shows the schematics of a solid oxide fuel cell.

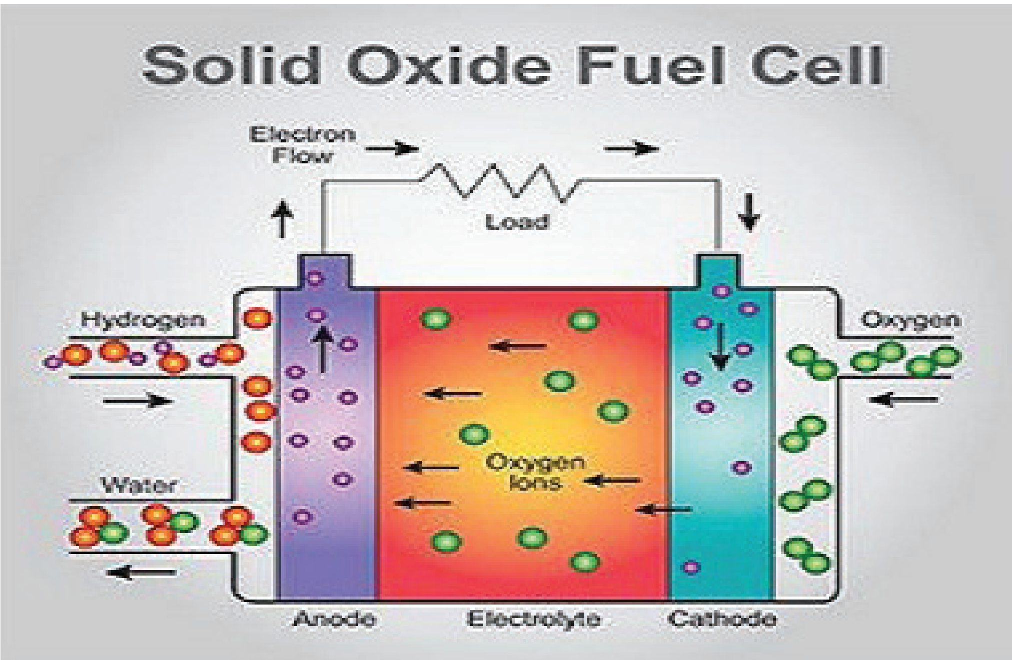

Figure 44: **Schematics of a Solid Oxide Fuel Cell**

Meanwhile, the current $LaMnO_3$-based cathode materials can interact with the Cr-based interconnect materials through the Cr diffusion into the cathode. This behaviour lowered the electrochemical performance of the cathode for oxygen reduction at high temperatures. Our research group has focused on reducing the operating temperature of SOFCs (< 800 °C) with the development of new and improved electrodes (Ni-Cu, Ni-Fe and Ni-Co based anodes, Co and Cr free cathodes), electrolyte (carbonated samarium doped ceria, SDCC, multi-doped ceria electrolyte) and interconnect pr26000 coating ($(Cu,Mn,Co)_3O_4$ spinel) materials. However, further investigation is necessary to ensure these materials have long term reliability and compatibility at a reduced temperature in both oxidizing (fuel) and reducing (oxidant) environments. Also, the development of new materials, improvement in the materials properties and fabrication conditions are critical to realising the operation of SOFCs at a reduced temperature with minimal cost.

3.3.2 Direct Liquid Fuel Cell (DLFC)

Direct liquid fuel cells (DLFCs) are among the most promising types of fuel cells due to their high energy density, simple structure, small fuel cartridge, instant recharging, and ease of storage and transport. Alcohols such as methanol and ethanol were the most common types of fuel used, although glycols and acids are also used. The main problem that arose in DLFCs was the high cost of the catalyst and the high catalyst loading. Other issues, such as fuel crossover, cathode flooding, the generation of various side products, fuel safety and unproven long-term durability, must also be solved to improve the performance of DLFCs. More research studies are required to increase its performance and foster its commercialisation. Currently, there are some commercial products using direct methanol fuel cells (DMFCs) and direct ethanol fuel cells (DEFCs). Non-alcohol fuels, such as formic acid, dimethyl ether, hydrazine, ammonia-borane and sodium borohydride, also can be used in DLFCs. Although DLFCs have advantages over rechargeable batteries, the current power supply systems in portable electrical devices are still mainly dominated by rechargeable lithium and nickel-based batteries.

The commercialisation of DLFC, especially DMFC, has been continuously postponed since the early 2000s due to their high cost, low lifetime, and technical barriers. Thus, our research group focuses on the development of high performance DLFC including DLFC system, the material of catalyst, membrane and electrode, storage system as well as DLFC application in education, portable power supply and medical purposes.

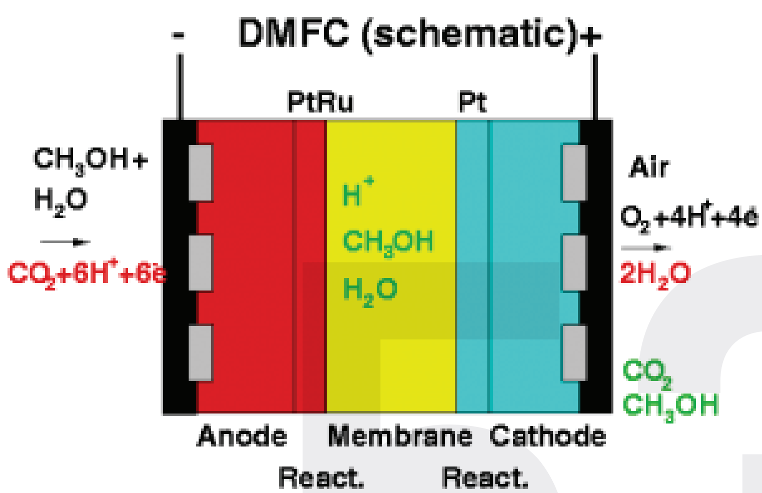

Figure 45:
Schematics of a Direct Methanol

3.3.3 Microbial Fuel Cell (MFC)

A microbial fuel cell (MFC) system is a bioenergy converter that utilises bacteria to generate electricity through a bacterial metabolic pathway. In an MFC, bacteria are put in an oxygen- free anolyte compartment together with a suitable carbon source, while the catholyte acts as an electron sink. The high electronegativity at the cathode relative to the anode attracts the bacteria in the anode compartment to transfer electrons outside their cell and pass it to the anode electrode, which acts as an electron acceptor. These bacteria are known as exoelectrogens and could transfer electrons to an anode electrode via direct electron transfer and mediated electron transfer. When oxygen and other anaerobic electron acceptors exist in the anolyte, electricity generation in the MFCs will be impacted.

Further studies on the optimisation of the MFC configuration is required to lower the overpotential of large scale MFCs. Preferred materials ranging from carbon to metal, are used to modify and fabricate electrodes to improve power generation. Another challenge is the comparatively lower power production compared to the precious metal abiotic cathodes such as Pt. Useful by-products conjugated with concurrent waste removal and bioelectricity production of biocathodes are promising and worth being further explored as well.

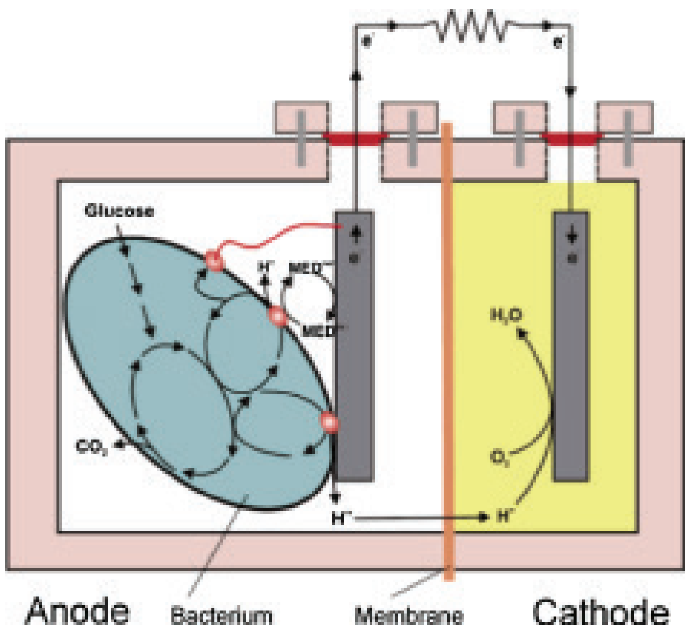

Figure 46: **Schematics of a Microbial Fuel Cells**

3.4 Hydrogen Supply Chain

3.4.1 Cost of Hydrogen Production

The main barrier to hydrogen energy is the cost of production of hydrogen, its storage and transport to users. The cost of hydrogen produced from current hydrogen technology by steam reforming hydrocarbon fuels ranges from USD 0.65-1.09 per kg that does not include transport and storage. If storage and transportation are included, the price of hydrogen from hydrocarbon fuel increases three to four-fold at USD 2.50-4.00 per kg.

When green hydrogen is in demand by 2050, the current cost of green hydrogen from commercial biomass and electrolyzer plants without storage and transport of between USD 1.45-1.57 per kg and USD 1.57-1.95 per kg respectively, must be reduced by half to USD 0.73-0.97 per kg by 2050 through a research and development program in order to become competitive with conventional steam reforming.

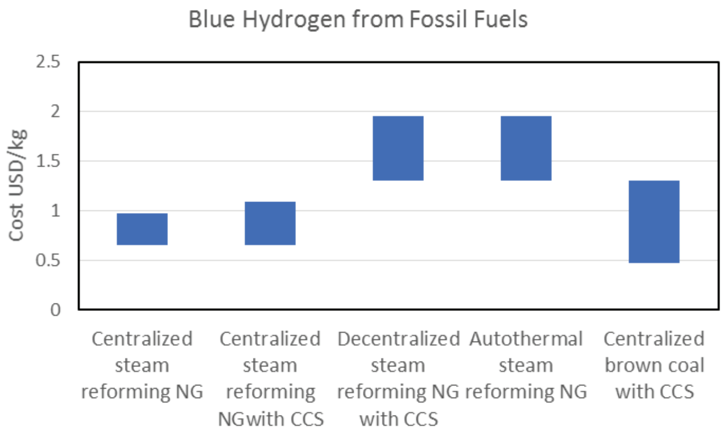

Figure 47: Cost of Blue and Grey Hydrogen from Fossil Fuels

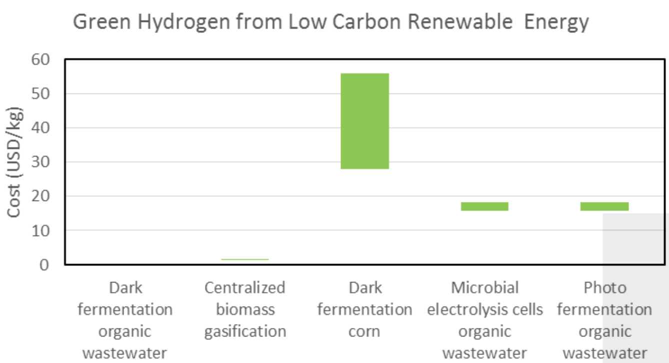

Figure 48: Cost of Green Hydrogen from Low Carbon Renewable Energy

While the cost of green hydrogen from renewable energy, such as dark fermentation of wastewater and biomass gasification varies from USD 0.15 – USD 1.57 per kg respectively, the cost of hydrogen from newer green hydrogen production technology from renewable energy such as microbial electrolysis of wastewater, photoelectrochemical and photosynthetic splitting of water are much higher, ranging from USD 15.70 – 24.20, which must be reduced by tenfold to USD 1.57-2.42 by 2050 through a research and development programme in order to be competitive with conventional steam reforming.

3.4.2 Centralised Off-site Hydrogen Production

Hydrogen could be produced in a centralised off-site or distributed on-site mode. Suppose hydrogen is produced off-site centrally on a large industrial scale from natural gas, the main problems are the transportation of hydrogen to the point of use at the petrol station and the decarbonisation of the hydrogen production process. The CCS method of decarbonisation had not been successfully proven to be commercially viable because it requires high demand for hydrogen and heavy investments in carbon dioxide pipelines to storage sites.

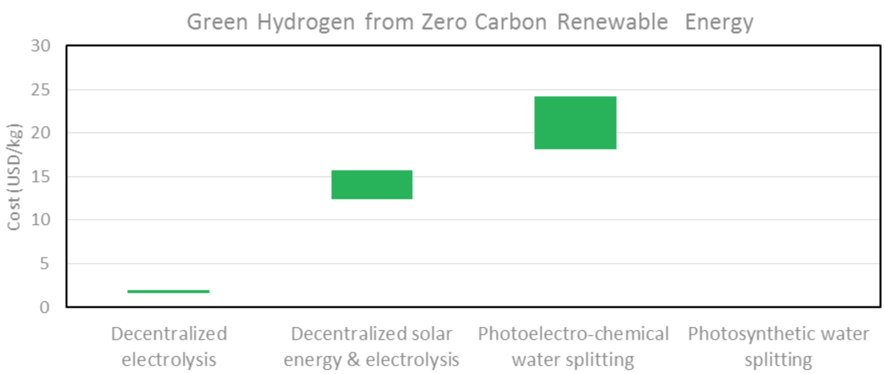

Figure 49:
Cost of Green Hydrogen from Zero Carbon Renewable Energy

a. Hydrogen Pipelines

For early adoption, the existing hydrogen pipeline network, now mainly for captive use in oil refineries and chemicals production, can be utilised for initial demonstrations to study the feasibility of hydrogen transportation via pipelines in Malaysia. Construction of new hydrogen pipelines requires a high capital investment and hydrogen's energy-intensive nature limits its economic feasibility over only short distances. A 2006 study by the United Nations Environment Programme on the United States and Europe shows that even though there are hydrogen pipeline systems in operation, they are small in scale and none is more than 200 km long. Hydrogen transportation by land (road or rail) and water (barge) in cryogenic tanks to be vapourised on-site is generally considered as a less costly alternative.

Another option to consider is blending hydrogen by injecting hydrogen in the existing natural gas pipeline network and later separated on-site to be used in a fuel cell. However, the separation costs, such as the pressure swing adsorption PSA method, are expensive, and a large quantity of hydrogen is also required to maintain the significant hydrogen blends. A 2013 report specific to the U.S. natural gas pipeline system can be used as a guide for a similar study to be conducted in Malaysia (Melaina et al. 2013). It shows that hydrogen transportation via pipelines is location-dependent and the blending concentration may vary. However, a relatively low range of 5-15% by volume is considered a feasible hydrogen concentration without requiring too many modifications to the existing pipeline systems or end-use appliances. An extraction at a pressure regulation station with a pressure drop from 2000-200 kPa is estimated to cost from USD0.3-1.3 per kg hydrogen for a 10% hydrogen blend.

b. Tanker Truck Delivery

A study on the future hydrogen supply chain in Peninsular Malaysia mapped the hydrogen supply chain on to the existing fossil fuels supply chain, i.e. petrol and diesel on the assumption that hydrogen would most likely be supplied by the same plants (Kamarudin et al., 2009).

Table 3 shows hydrogen cost for various production processes, storage units and transportation modes. Water electrolysis is much more costly than SMR because of the cost of electricity to run it. Compressed hydrogen gas is less costly to produce than liquid hydrogen due to the costly liquefaction process. However, liquid hydrogen is less costly to be transported due to the much larger capacity of a tanker-truck, which requires fewer trips for delivery. A total of 18 hydrogen production plants are needed to sustain the delivery of hydrogen to service stations to fulfil the demand.

Table 3: Hydrogen Production Cost

	Production cost (USD/kg):	
	Liquid hydrogen	**Compressed hydrogen**
SMR (NG)	1.52	0.8
Water electrolysis	6.63	5.9
Transportation cost (USD/kg):		
Tanker-truck	0.04	
Tube Trailer		0.39
Storage cost (USD/kg):		
Cryogenic tanker	0.06	
High pressure vessel		0.18

Source: Kamarudin et al., 2019

A vital building block in the hydrogen infrastructure for transportation is the hydrogen refuelling station. Figure 50 shows the map of hydrogen refuelling stations in Asia as compiled by a global online information service. It shows that the nearest stations to Malaysia are the two 'One North Zone' hydrogen filling stations built by BP Singapore in Singapore; however, they are currently reported to be out of operation (Netinform.net 2015). It is obvious that the development of hydrogen refuelling stations in the Southeast Asia region is still very sluggish and almost non-existent. A serious collaborative effort between all the countries in the region is required to initiate and nurture the highly potential market for fuel cell and hydrogen technologies.

Figure 50:
Map of Hydrogen Refueling Stations in Asia
Source: Netinform.net 2015

Following the California Fuel Cell Partnership projects models, the recommended hydrogen station installation will not be a standalone model but added to an existing fuelling station of compressed natural gas (CNG). The common features in any station design are:

- Equipment: hydrogen production (on-site), purification, safety, as well as mechanical and electrical operations
- Storage tubes/tanks/vessels, dispenser, and compressor

For on-site storage, gaseous hydrogen is a compressed gas stored above ground. For off-site storage, hydrogen will be delivered to the station as compressed gas or liquid, which will be transformed into gas and compressed upon arrival for on-site storage. On-site hydrogen generation from natural gas will significantly increase the capital investment due to the production equipment.

The cost to build and maintain a hydrogen station is much higher than for a typical CNG refuelling station. 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.

Feasibility studies must be carried out with substantial collaborations from all stakeholders in terms of time, effort, and investment. Commitment to cost-share must also be put in place in order to relieve the early adopters of this burden. A government-appointed body that deals specifically with all issues pertaining to fuel cell and hydrogen domestically and internationally must be set up to manage this collaborative effort efficiently.

Equipment suppliers, such as Air Products and Chemicals, Inc., Air Liquide, Linde, and Hydrogencis, are vital stakeholders to Malaysia's fuel cell and hydrogen industries. For example, Air Liquide has a proven track record of delivering more than 60 hydrogen stations worldwide, especially in Europe. In 2014, Air Liquide announced its plans to provide 'a fully-integrated hydrogen fuelling infrastructure' in order to support Toyota's fuel cell electric vehicle (FCEV) entry into the northeast United States. It was claimed that the stations would have a fuelling time of less than 5 minutes with the Toyota FCEVs predicted to reach up to 500 km in range (Air Liquide 2014).

Identification and involvement of experienced engineering companies in the collaboration effort are also essential as they can determine the location suitability, work together on any operation and maintenance issues, and assist in obtaining conditional use permits as well as building codes. Therefore, this can be managed better by collecting and purifying it to be produced as hydrogen fuel. Hydrogen suppliers are also necessary for a hydrogen station that does not have on-site production facilities. Large industrial gases companies have participated in many demo projects, e.g., Linde was involved in demo projects held in Europe, the US, and Japan, as they have the technologies to purify hydrogen emitted in oil and gas, and petrochemical operations.

3.4.3 Distributed On-Site Hydrogen Production

Hydrogen production processes, SMR of natural gas and water electrolysis, could also be deployed on-site at the point of use, such as at petrol service stations in distributed mode using their existing infrastructures, i.e. natural gas pipelines and reticulation and electrical power grid from hydropower. Using existing gas and electrical infrastructure could reduce the initial investment required for the transportation and distribution of hydrogen to users. An optimum underground space of (10m x 3m x 3m) could be used to produce hydrogen of up to 500-700 Nm^3/hr. (OECD & IEA 2006).

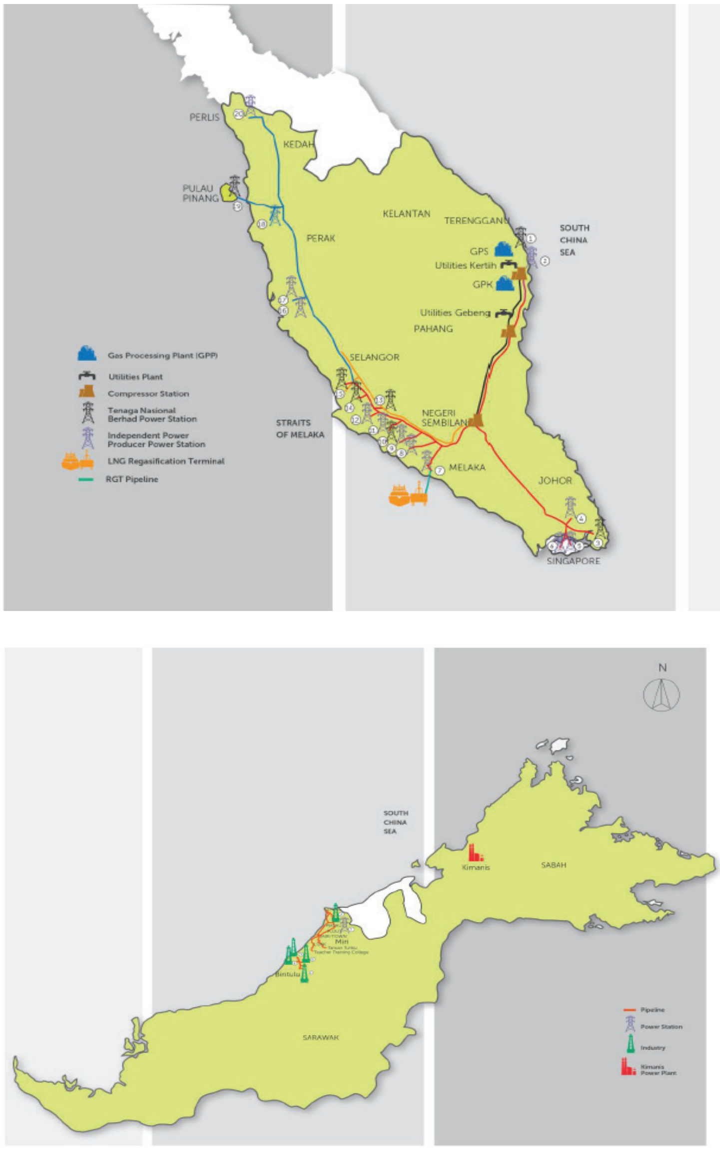

Figure 51:
Map of Gas Utilisation Network in the Peninsular (Top) and Distribution Network in Sarawak (Bottom)

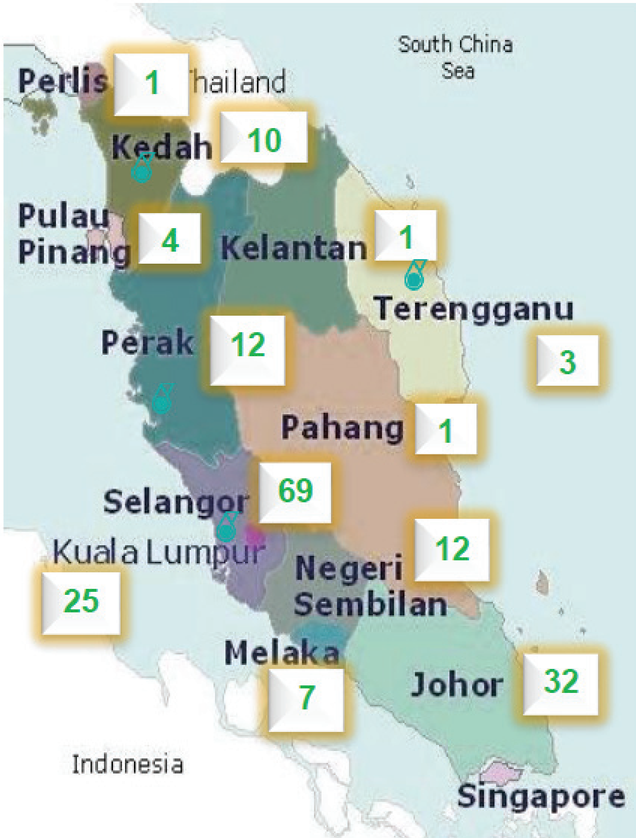

Figure 52:
Number of NGV Stations by States
Source: Malaysiangas.com

Off-site hydrogen production using SMR of natural gas is a possible option in Malaysia because natural gas already has wide gas utilisation networks in the Peninsular and smaller distribution network in Sarawak as shown in Figure 51. The most likely location of off-site SMR plants would be at petrol service stations that are already equipped for natural gas refuelling of natural gas vehicles (NGV). However, the number of existing petrol stations with NGV refuelling stations is too few at less than 200 (177), Most of them are located in the Klang Valley, and only 5 stations are available on the east coast of Peninsular Malaysia (Figure 53).

3.4.4 Carbon Capture and Storage (CCS)

Since SMR of natural gas also produces carbon dioxide as a by-product, the latter must be removed by CCS that reduces carbon emission by storing it in suitable underground geologic formations. Although CCS technology could reduce atmospheric carbon emissions up to 85%, it adds additional costs to hydrogen production (Board on Energy and Environmental Systems 2014).

Deploying CCS also incurs large incremental investments especially for grass roots CCS projects depending on the type of capture technology and fossil fuel used, location of the geologic storage, and percentage of captured carbon dioxide. The high capital and operating costs are due to the additional carbon capture equipment, while the additional amount of electricity required by the capture equipment can decrease the net power output of the plant considerably.

Data from the National Energy Technology Laboratory (NETL) in 2010 shows that the cost of CCS for levelized cost of electricity (LCOE) of a newly built natural gas combined cycle (NGCC) power plant with CCS is about 46% more than without CCS. The US estimate on the cost of industrial carbon capture and transportation for hydrogen plants is in the range of USD36.67-46.12 per metric tonnes, while the Environmental Protection Agency gives an estimate of USD15 per metric tonne for the long-term average cost of carbon transportation and storage.

There are currently 14 large-scale CCS projects in operation around the world, with 8 still under construction, which represents a total carbon capture capacity of around 40 million tonnes per year. Various CCS projects are under development in several countries with a total carbon capture capacity of around 64 million tonnes per year.

Although CCS is still a relatively expensive technology, captured carbon dioxide can potentially bring in revenue from its use in enhanced oil recovery (CO_2-EOR) projects. The CO_2-EOR offsets the high costs and lessen the financial risks for early adopters of CCS projects (Global CCS Institute 2015). Malaysia already has one of the largest CO_2-EOR projects in Southeast Asia in the Tapis field led by ExxonMobil in partnership with Petronas.

3.4.5 Recovery of hydrogen from hydrogen off-gases in oil refineries and petrochemical plants

Large quantities of hydrogen off gases are flared off from oil refineries and olefin plants in Port Dickson, Melaka, Kerteh, Tanjung Pelepas, and Pengerang. Hydrogen could be extracted from these off-gases quite easily instead of being burnt off. Hydrogen in oil refineries is produced from natural gas by large SMR plants and is used to improve the quality of the fuel. Unreacted hydrogen off-gases are flared off as refinery off-gases (ROG). Straight chain naphtha is cracked by a fluidised catalytic cracker (FCC) into branched, cyclic and aromatic components to improve the RON of petrol. Typical FCC contribution for the hydrogen component in ROG is 10-50 mol% (Malik & Slack, 2009).

Hydrogen could be extracted from refinery and petrochemical off-gases using a pressure swing adsorber (PSA) to get hydrogen purity of 99.9% or higher. Impurities in the off-gases, such as sulfur and arsenic, could be removed by the adsorption method using high capacity sorbents as they can poison the catalysts used in the conversion. Low steam to carbon ratio design (typically 2.5 mol H_2O/C-atom or lower) for a hydrogen plant can result in a smaller equipment size, which reduces the capital cost, and in a more energy-efficient plant, lowers the operating costs (Rostrup-Nielsen & Rostrup-Nielsen, 2001).

3.4.6 Hydrogen Production from Renewable Energy

Alternatively, hydrogen could also be produced from renewable energy sources such as ocean thermal energy conversion (OTEC), wave/tidal/current energy and solar energy without the need for CCS because they do not produce carbon dioxide.

a. Solar energy

Solar conversion techniques to produce hydrogen:

- Electrolysis: water electrolysis using electricity and is capable of producing pure hydrogen of 108.7 kg of hydrogen from 1 m^3 of water.
- Thermolysis: thermochemical reactions to produce hydrogen driven by the heat produced from concentrated solar power (CSP)
- Photoelectrochemical water splitting (photolysis): biological or electrochemical reactions that produce hydrogen using solar photons

Figure 53 and 54 gives the solar energy potential in Malaysia that shows the solar irradiance map and the average yearly solar irradiance. Solar energy is dependent on solar distribution based on specific land area grids that can be covered with photovoltaic cells, including electrolyzers.

One way to jump-start the hydrogen economy in Malaysia is to convert the excess energy from existing and future solar energy farms into hydrogen as energy storage that could be used to continue to supply electricity at night via fuel cells or to refuel the public and private transport or homes.

In terms of transportation, one of Honda's solar-powered hydrogen production and filling station facilities at their Swindon factory uses pressurised alkaline electrolysis of water at their solar farm and has a hydrogen-producing capacity of 20 tonnes/yr. Honda also claimed that their FCX Clarity could run about 16000 km/yr with their 6kW solar panel system (Crosse, 2014).

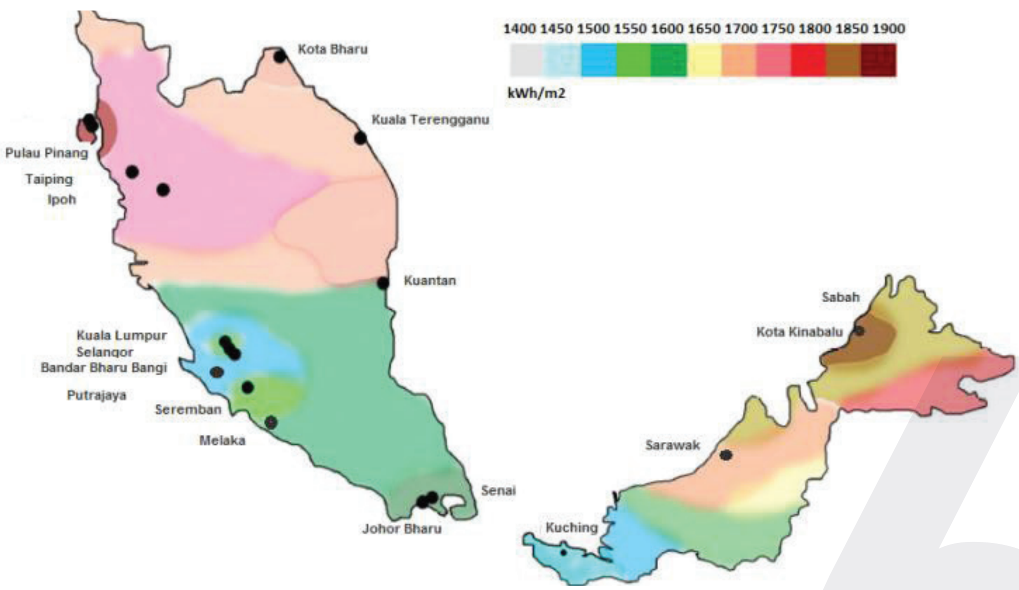

Figure 53:
Solar Irradiance Map of Malaysia
Source: Hussin et al. 2012

Town/Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Averange
Alor Setar	5.26	5.86	5.81	5.65	5.05	4.82	4.84	4.69	4.65	4.37	4.23	4.42	4.96
Georgetown	5.62	6.09	5.93	5.69	5.07	4.97	4.92	4.71	4.67	4.53	4.76	5.00	5.15
Kota Baru	5.14	5.95	6.23	6.28	5.54	5.33	5.35	5.30	5.42	4.76	3.98	4.24	5.28
Kuala Lumpur	4.79	5.37	5.42	5.27	5.11	4.98	4.92	4.87	4.88	4.76	4.36	4.17	4.90
Johor Baru	4.48	5.22	5.05	4.87	4.57	4.41	4.30	4.33	4.53	4.57	4.34	4.07	**4.55**
Kota Kinabalu	5.11	5.78	6.43	6.45	5.77	5.33	5.19	5.17	5.31	5.03	4.75	4.65	**5.41**
Kuching	3.96	4.36	4.69	4.99	4.87	4.93	4.84	4.87	4.68	4.59	4.48	4.16	4.62

Figure 54: Average Solar Irradiance, kWh/m2/day
Source: Akorede et al., 2012

b. Ocean thermal energy conversion (OTEC) energy

One of the potentially competitive sources of RE in Malaysia is the ocean thermal energy conversion (OTEC) to electrical energy, which could then be used to produce hydrogen by water splitting using electrolyzers (Jaafar, 2019).

The difference in buoyancy between warm surface water and cold deep-sea ocean water with about 20°C temperature difference could be utilised in the OTEC process. Huge pipes, i.e., about 1 km long with a diameter of a few metres, are required for the cold deep-sea water being pumped to the platforms placed at the surface. The heat energy difference is converted to electricity using various equipment such as heat exchangers and turbines. Seawater is turned into hydrogen gas by utilising the electrolysis process that splits water into hydrogen (H_2) and oxygen (O_2) using electricity: $2H_2O \longrightarrow 2H_2 + O_2$ (Dessne & Golmen, 2015).

This method can be configured to yield as much as 1,300 kg/h of liquid hydrogen for a 100 MW-net OTEC plant ship. Hydrogen is then delivered to the facilities at the port in liquid form to be used primarily as a transportation fuel (Vega, 2010; 2013). The surface seawater may potentially be evaporated and turned into fresh or potable water of high quality.

c. Wave/tidal/current energy

A barrage, such as a dam, is built to block the incoming and/or outgoing wave/tidal/current of water, which is then channelled through a turbine and converted into electricity using a generator. The electricity produced is then used in an electrolysis process to generate hydrogen. Wave/tidal/current energy is location-specific; for example, facilities in Russia and France can generate electricity with capacities of 400 kW to 240 MW, respectively, while the one in Canada can generate up to 30,000 MW. It is also nature-dependent; for example, a tidal-based energy facility is not expected to generate electricity more than about half a day of a 24-hr day.

3.5 Initiatives in Malaysia

3.5.1 Transition Steps to a Hydrogen Economy

Hydrogen Economy is a term coined to describe a system of delivering energy using hydrogen to replace the fossil fuels-based system currently used worldwide. The Hydrogen Economy envisioned for Malaysia is not the "total replacement of fossil-based fuels with hydrogen for energy generation", but one that promotes an energy portfolio comprising Malaysia's important primary fuels, which must include hydrogen as the Sixth Fuel in the energy/fuel mix. In order to contribute to the required GHG emissions reduction, the country has committed itself to the INDC presented at COP21 in 2015.

Table 4 shows the necessary transition steps to a Hydrogen Economy. A "whole system" approach is needed concerning hydrogen system integration where a number of crosscutting, system-level issues are necessary to ensure the smooth workings of the complex dependencies between various components of the system. This requires further deliberation as it will influence diverse hydrogen matters such as hydrogen production, storage, conversion, delivery, and applications as well as in terms of policy, standards, education, and program outreach in hydrogen energy.

Table 4: Transition steps towards Hydrogen Economy

Issues	Transition steps
Regulations	• National and international codes and standards for hydrogen use • Safety issues regarding hydrogen usage
Technical know-how	• Demonstrations of hydrogen systems for technology validation by government/ industry partnerships • Domestic and worldwide database that is readily accessible by the parties involved as well as the inquiring public

Stakeholders	• Industry-led support and programs • Consumer acceptance, especially on the performance-based cost of hydrogen • Research, development, and deployment (RD&D) efforts and collaborations
Infrastructure development	• Hydrogen production, conversion, and storage • Hydrogen delivery to refueling sites • Maintenance and governance of cross-cutting systems

The biggest challenge in establishing Hydrogen Economy in Malaysia is to develop a large-scale supportive infrastructure in production, conversion, and storage technologies needed for energy applications as the existing commercially available hydrogen infrastructure is in the chemical and refining industries. A sizable delivery infrastructure must also be considered as the present storage and delivery methods in road transportation, which normally use liquefaction for cryogenic hydrogen and high-pressure compressors for gaseous hydrogen have high capital and operating costs as well as energy inefficiencies.

3.5.2 Hydrogen Energy and Fuel Cells Roadmap 2006

In the effort to take up this challenge, *Pusat Tenaga Malaysia* (now Malaysian Centre of Green Technology & Climate Change) released the document "Roadmap for Solar, Hydrogen and Fuel Cell Research and Development Directions and Markets in Malaysia" in 2006 on behalf of the Ministry of Energy, Water, and Communications, Malaysia for the Government of Malaysia. Figure 55 show the first half of the 2006 roadmap, which focuses on hydrogen, and fuel cells development.

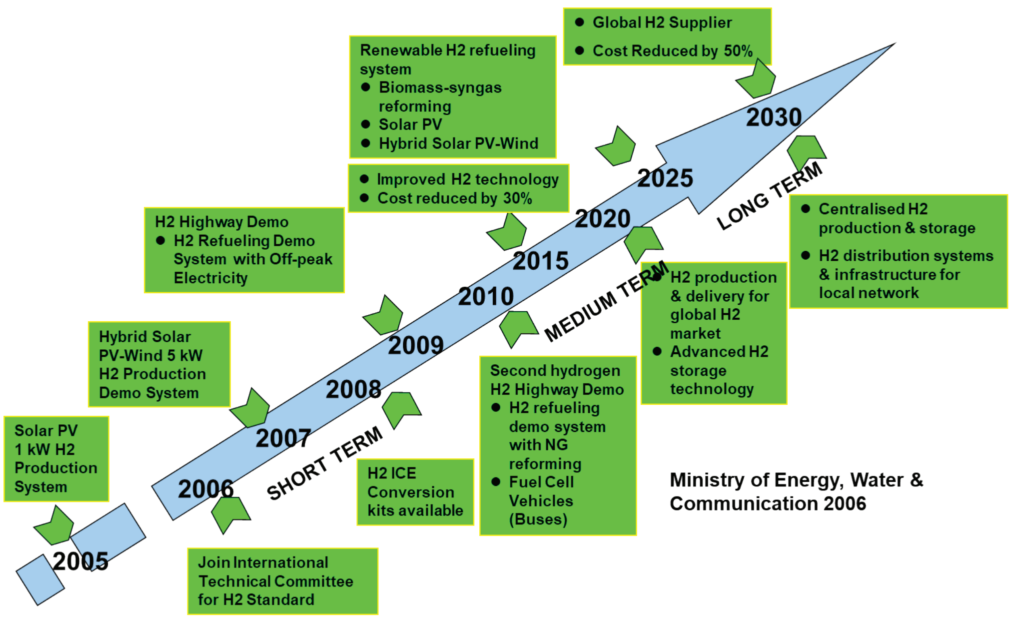

Figure 55:
Malaysia's Hydrogen Roadmap 2006

The Roadmap addressed the role of hydrogen, solar and fuel cells in future renewable energy systems and recommendations for actions in the early stage of the roadmap (have been successfully included in the 9th Malaysia Plan (2006-2010). The policy specifies that activities such as technology development and knowledge sharing regarding solar, hydrogen and fuel cells will be put into effect while financing mechanisms are explored. However, except for R&D funding, the action plans for the deployment of hydrogen energy and fuel cell applications further down the time scale was subsequently not implemented in the 10th (2011-2015) and 11th Malaysia Plans (2016-2020) because of change in leadership in the ministry and shift in national priorities.

3.5.3 Hydrogen Energy and Fuel Cells R&D in Malaysia

From 1995 until now, the Malaysian government had given a total fund of RM 40 million to fund the national fuel cell programme through *Skim Program Penyelidikan Mengikut Bidang Keutamaa*n (IRPA) grants from MOSTI (1996-2000, 2002-2007) and later through Long Term Research Grant Scheme (LRGS) grants from MOHE (2013-2018). Funding for the programme was initially utilised for learning the fundamentals of hydrogen production and fuel cells technologies (1996-2000) and developing them indigenously further into cheaper hydrogen and fuel cells by reducing catalyst loading and replacing the Nafion membranes with cheaper home-grown composite membranes to achieve a reduction in fuel cell costs (2002-2007, 2013-2018).

During the 7th Malaysia Plan (1996-2000), as recipients of a large IRPA research grant from MOSTI shared between UTM and UKM. Pioneering work was carried out by Malaysian researchers at UKM on process system engineering of an integrated hydrogen production plant from methanol/natural gas reforming, hydrogen purification by pressure swing adsorption, and membrane gas separation and PEMFC power system. Researchers at both UKM and UTM started work on catalysts for methanol/methane steam reforming. Researchers at UTM started early work on radiation grafted composite proton exchange membranes to replace the Nafion membrane.

During the 8th Malaysia Plan (2002-2007), MOSTI funded the national fuel cell program shared between UKM and UTM (RM30 million) under the IRPA-PR scheme. The researchers at UKM developed metal oxide catalysts for hydrogen production by steam reforming of methanol, nano-porous ceramic and Pd membrane reactors for simultaneous hydrogen production and purification from steam reforming of methanol/methane, hydrogen purification using pressure swing adsorption and humidification of feed air and hydrogen. In addition, prototypes of the PEMFC stacks, a small fuel cell motorcycle and a solar hydrogen eco-house with solar photovoltaic cells and PEM electrolyzers for hydrogen production was also demonstrated at UKM. Researchers at UTM had developed radiation grafted composite proton exchange membrane, catalysts for hydrogen production by steam reforming of methane, a fuel cell motorcycle prototype and a fuel cell air-condition system for buses.

During the 9th Malaysia Plan, MOHE funded the third national fuel cell programme (2013-2018) under the LRGS scheme also led by UKM and shared with UTM, UM, UITM and UNITEN (RM 7million).

The hydrogen infrastructure considerations certainly require major investments; however, such investments are necessary and energy policies should deliberate more on issues concerning external environmental and security costs of energy to promote expanded usage of hydrogen. For hydrogen to be developed as an attainable energy option in Malaysia, it is imperative to have a coordinated and sustained commitment by a myriad of stakeholders, comprising industry practitioners and technical experts from private and public organisations, who share a common vision for the hydrogen economy.

Hydrogen energy (and fuel cells) were later introduced in the 9th Malaysia Plan (2006-2010) as a potential energy source. The R&D on its performance was supposed to be carried out within the petroleum industry. With the substantial investment that has been made, it is hoped that support will continue to be given for the development of fuel cell and hydrogen energy by the effective implementation of research, development and deployment of the flagship programme for fuel cells and hydrogen energy in Malaysia from now until 2050.

During the 10th Malaysia Plan, a zero-emission vehicle powered by fuel cells using hydrogen energy was developed at UKM. The project mainly involved prototyping a new water-cooled 5kW PEMFC stack of up to 50 kW total power to be used to power a PROTON electric car and a new concept car, new power control systems for the FCVs, and new high-temperature proton exchange membranes for more efficient PEMFCs. The project also involved the assessment of the socio-economic impact of the introduction of fuel cell vehicles in the world and Malaysia.

Domestic PEMFC technology in Malaysia developed by the Fuel Cell Institute (FCI) UKM ranging in maximum power of 200 W, 1 kW, 1,5 kW and 5 kW including the balance of plant, has currently reached technology readiness level (TRL) 4. The PEMFC stack could be used in uninterruptible power supplies (UPS) or backup power systems, small portable power generation sets and power plants for small fuel cell motor cycles and small cars. FCI UKM also offers the full range of R&D support for the manufacture of the PEMFC stacks including material formulations for membrane electrode assemblies and bipolar plates and the assembly of the stack or "stacking" to form complete PEMFC stacks. PEMFC integration into existing electric or hybrid power trains was also developed for fuel cell-powered motorcycles a golf buggy as vehicle demonstrator prototypes, along with its own testing facilities. Domestic DMFC technology was developed up to 1 W for micro and small DMFC multi-cell stack systems. SOFC capability is still in development electrode and electrolyte materials for low and intermediate temperatures.

The fuel cell market in Malaysia is still relatively small, and substantial growth to the domestic market must be developed to ensure its significant contribution to Malaysia's energy mix in 2050. However, the indigenous technological innovations that have been developed can be depended on to produce all parts of the fuel cell locally by using local manufacturing technologies, including the following: the bipolar plates can be made using injection moulding of polymer composites and the MEA can be manufactured using battery electrode making technology. Only the raw materials like polymer composites, Pt catalyst ink and the proton exchange membrane have to be imported. These imports can hopefully be replaced with locally made polymer composites, Pt catalyst ink, and proton exchange membrane in the next 5 years.

Horizon FC Malaysia Sdn Bhd is currently the sole fuel cell distributor based in Malaysia, with orders for small fuel cells of size < 1500 W dominating the market. Horizon's product range encompasses the education sector (GT1500 technical training panel with introduction teaching curriculum for polytechnics and universities), aerospace sector (AEROPAK unmanned aerial vehicle fuel cell system), telecommunication sector (Telco BTS for primary power), military (AEROPAK military power pack), hydrogen generation (electrolyzer and methanol reformer), and portable applications (Minipak and Aquigen 180 backup power). They also collaborated with research teams from local universities in high profile projects such as with UTM in the 2011 International Fuel Cell Car Racing Award in Taiwan, where the team won second place in the fuel efficiency category and third place in the speed category, as well as powering the first successful fuel cell-powered unmanned aerial vehicle in Southeast Asia.

In the transportation industry, the deployment of FCVs in the global scene, such as Toyota Mirai, Honda Clarity, Mercedes B-Class, and Hyundai Tucson, must fully support Malaysia's green technology corporations. FCV specifications have reached maximum power of 114kW for Toyota Mirai, while others are still at 100kW. The range is highest for the Hyundai Tucson at 650km, while the shortest is 385km for the Mercedes B-Class. Car manufacturers, such as Proton Holdings Berhad, and oil companies, such as PETRONAS, must be involved in the development efforts for fuel cell transportation so as to ready the market and infrastructure for the future influx of imported fuel cell cars.

Developments of advanced materials and systems focus on different types of fuel cells such as PEMFC, DMFC, SOFC, and MFC. The progress of the national fuel cell projects up to 2005 have been elaborated in the 2005 "Roadmap for Solar, Hydrogen and Fuel Cell Research and Development Directions and Markets in Malaysia", while recent progress in terms of advances in fuel cell components are numerous. These achievements include low-loading in catalyst-impregnation for cathode fabrication, new radiation-grafted proton exchange membranes, and new mixed-transition metal oxides Cu-Al hydroxide-based catalyst for steam reforming of methanol and natural gas to produce hydrogen cheaply. A new adsorbent made of Sn-impregnated activated carbon that can remove the Pt-poisoning carbon monoxide from hydrogen streams in the steam reforming process was also found.

A PEMFC prototype was completed and well integrated into the working prototype of a buggy vehicle. A micro DMFC using silicon wafers as bipolar plates and a multi-celled DMFC stack, as well as low and intermediate temperature electrolyte, cathode and anode materials for SOFC, have been successfully developed. Other fields of interest are photo-electrochemical devices for splitting of water to produce hydrogen and a scaled-up version of a system that produces biohydrogen using palm oil mill effluent. Developments of novel materials for improving fuel cell performance include:

- Prototype equipment for manufacturing electrodes by spray painting the Pt-containing ink onto the activated carbon and carbon black on a gas diffusion layer of the electrode
- A new tungsten-based organic dye sensitiser on TiO_2 photo anodes was found for water-splitting technology
- New polymer composites based on thermoplastics and thermoset polymers
- A new type of composite inorganic-polymer proton exchange membrane
- Mixed transition metal oxide catalysts for steam reforming of methanol and methane
- Nano-structured metal hydrides as adsorbents for hydrogen storage

- Nanomaterials and nano-structured materials for more efficient PEMFC electrodes and electrolytes, such as graphene-based cathode due to graphene's high electron conductivity and graphene oxide (GO)-based proton exchange membranes due to GO's high proton conductivity

Cost can be reduced by improving performance using new nanostructures, nanomaterials, and nanosystems that increase efficiencies, such as cheaper alternatives to polymer electrolytic membrane nanocomposites as well as new nanostructured electrocatalysts for oxygen reduction (cathode layer) and hydrogen oxidation (anode layer). Durability can be increased by using stable new nanostructures, nanomaterials, and nanosystems that reduce degradation such as good proton conductivity and water diffusion in PEM to prevent drying and degradation in the cathode layer due to catalyst dissolution and agglomeration. Future advances in terms of materials, multiple components, and systems must focus on the following areas to benefit a range of applications

- Stack components: catalysts, electrodes, electrolytes, MEAs and single cells, gas diffusion media, seals, and bipolar plates

- Performance and durability: mass transport, durability, and impurities

- Systems and balance of plant (BOP): BOP components, fuel processors, stationary power, auxiliary power units (APUs), and early markets

4.
HYDROGEN ECONOMY ACTION PLAN FOR THE 12TH MALAYSIA PLAN AND BEYOND

4 Hydrogen Economy Action Plan for the 12th Malaysia Plan and Beyond

4.1 Hydrogen Economy Roadmap

Hydrogen would be one of the dominant energy carriers in the 21st Century (Ibrahim Dincer, 2008) as the world struggles to address the unprecedented threats of global warming and climate change due to carbon emission. Decarbonisation involves a multidimensional approach that has sparked renewed interest in hydrogen energy. Green hydrogen is a zero-emission clean energy carrier and feedstock that enables extensive decarbonisation across the energy, transportation, and industrial sectors.

The interest levels in the development of global hydrogen industries have fluctuated over recent decades. However, only in recent years there have been increasing activities focusing on hydrogen. This includes policy commitments from countries across Europe and Asia as well as increasing investment from multinational technology manufacturers and energy companies. Governments around the world recognise hydrogen's ability to decarbonise sectors that are otherwise impossible or difficult to abate such as private and public transport; logistics and freight; electricity generation; industrial heating and industry feedstock; and hydrogen's role in energy security.

According to Japan's Strategic Roadmap for Hydrogen and Fuel Cells 2019, Japan intends to establish a robust hydrogen energy supply chain for private and public transport by increasing their hydrogen supply to 5-10 million tons per year. For hydrogen to be competitive and able to replace conventional energy sources, World Energy Outlook 2019 estimated that hydrogen price needs to be reduced to 1.46 USD/kg. After incorporating environmental cost, Japan targeted to reduce the cost of hydrogen to about 3.14 USD/kg in 2030 and further down to 2.13 USD/kg in the future (Hydrogen and Fuel Cell Strategy Council, 2019). Currently, Japan is embarking on several Regional Cooperation and Low-Carbon Hydrogen Technology Demonstration Project, to develop green hydrogen technology (Li and Taghizadeh-Hesary, 2020). However, domestic hydrogen production is insufficient to fulfil the domestic hydrogen market. Therefore, Japan is developing a hydrogen supply chain from overseas to fill the gap. In SPERA Hydrogen, methyl cyclohexane from hydrogenation of toluene by hydrogen produced from natural gas, is used as a hydrogen organic liquid carrier for export from Brunei to Japan. In HySTRA, hydrogen produced from the gasification of brown coal and SRM of synthesis gas is liquefied to -235° C and is transported in a liquid hydrogen tanker ship from Australia to Japan.

Similarly, South Korea's government allocates USD 22 billion for to establish a public and private Hydrogen vehicle industry ecosystem by 2022. Large government subsidies are allocated for the fuel cell stations to keep the price low to attract more users on board. South Korea released the Hydrogen Economy Roadmap of Korea and the National Roadmap of Hydrogen Technology Development in 2019, setting a national target to become a leader in hydrogen technology (Hydrogen Roadmap Korea, 2018).

Cost reduction will be the key enabler for hydrogen energy to be competitive as a replacement for conventional energy resources. The current strategy to reduce the cost of hydrogen energy in private and public transport undertaken by most countries is by scaling up its deployment. This is in accordance with the strategy promoted by the Hydrogen Council that says "...scale-up will be the biggest driver of cost reduction" (Hydrogen Council, 2020).

Australia's National Hydrogen Strategy 2019 aims to produce low-cost hydrogen that increases its cost-competitiveness in the global market. Australia is already developing HySTRA project to supply blue hydrogen to Japan. Similar hydrogen supply chain projects are being developed for South Korea, China and California. Hydrogen hubs are developed in Port of Hastings, Victoria, Australia, with centralised infrastructure for cost-effective hydrogen production from brown coal and export to Japan.

ASEAN has good potential a green hydrogen producer because it has huge renewable energy resources, which includes 220 GW of wind energy, 158 GW of hydropower, 61 GW of biomass and 200 GW of geothermal (Li, 2019). However, the hydrogen supply chain and technologies are still expensive depending on different usage and pathway of hydrogen supply.

Indonesia has started their fuel cell development for 15 years. In 2019, a roadmap released by Badan Pengkajian dan Penerapan Teknologi (BPPT) showed that Indonesia aims to develop various fuel cell applications, including FC vehicles, drones and forklifts (Dewi, 2019). BPPT also collaborated with Toshiba to deploy autonomous hydrogen energy supply systems, with the aim to establish a hydrogen system for transportation in Indonesia by 2024 (Toshiba, 2018). Indonesia has chosen to produce hydrogen through biomass gasification (Dewi, 2019).

While our neighbouring countries are actively venturing into the hydrogen economy, it is timely for Malaysia to develop its own hydrogen economy roadmap.

4.1.1 Malaysian Hydrogen Economy Roadmap

Since many of the action plans for the deployment of hydrogen energy and fuel cell technology recommended by the 2006 Solar Energy, Hydrogen Energy and Fuel Cells roadmap for Malaysia were included only in the 9^{th} Malaysia Plan but not in the subsequent 10^{th} and 11^{h} Malaysia Plans except for the R&D activities, a second Hydrogen Roadmap, "The Blueprint for the Fuel Cells Industry in Malaysia" was developed by the ASM in 2017. The Hydrogen Roadmap crafted the strategies and action plans to be implemented in the 12^{th} and successive Malaysia Plans.

The aim of the updated Hydrogen Roadmap in the Blueprint is not to replace completely the existing total energy mix and the five fuel mix for electricity generation consisting of three fossil fuels (gas, coal and oil), hydro and renewable energy but to complement the energy mix by including hydrogen officially as the Sixth Fuel, so that it is better equipped to face the challenges of global warming and climate change with less carbon emissions from hydrogen.

The development of the Hydrogen Roadmap in the Blueprint focussed on three major areas, namely, Hydrogen Infrastructure, Fuel Cell Applications, and Emerging Fuel Cell Technologies. The barriers of the transition to hydrogen economy were identified and assessed. The strategies and action plans were then developed to overcome the barriers by gathering insights on the challenges and barriers faced by Malaysia, formulating recommendations on how to overcome them and developing the action plan needed to achieve them.

The Hydrogen Roadmap in the Blueprint sought firstly to create and develop local hydrogen safety technical codes, standards, guidelines, regulations, policy structure, and monitoring bodies by considering existing international standards. Secondly the Roadmap sought to raise awareness and a better understanding of the hydrogen economy by the public and industry through education and training.

Thirdly, it sought to continuously work towards obtaining better financial support for investments in the hydrogen economy and making investments more attractive by reducing hydrogen and fuel cell costs and developing the business and market for the products. Fourthly, it sought to develop intensive education and training programmes for capacity building to create and increase skilled personnel and industry champions of the hydrogen economy.

It also sought to develop indigenous hydrogen and fuel cell technology through fundamental and commercial R&D to create, develop, and maintain a sustainable supply chain and infrastructure for the hydrogen economy.

4.1.2 Potential in Malaysia to become a pioneering country in Hydrogen Economy

At present, industry players started to pay attention to developing the hydrogen economy in Malaysia. Sime Darby Foundation partnered with Universiti Kebangsaan Malaysia to establish the UKM-Yayasan Sime Darby Chair Professor to carry out research in biomass gasifier technology and biohydrogen production. A total of RM 15 million endowment fund has been invested for the study. In addition, PETRONAS invested RM 8.25 million to establish UKM-Petronas Chair Professor of Sustainable Hydrogen Energy, focusing on developing electrolysers-based hydrogen technology. With these initiatives taken by the two largest companies in Malaysia, it is optimistic that other industry players will start to shift their focus to hydrogen energy.

PETRONAS can become a global hydrogen supplier by producing hydrogen from natural gas. Sarawak Energy is planning to become a hydrogen supplier by producing hydrogen from water splitting and hydro energy (Sarawak Energy, 2018).

Currently, the incentives available under MIDA for fuel cell manufacturing are as follows:

1. Investment Tax Allowance of 60% a period of 5 years for the purchase of green technology assets; or

2. Pioneer Status of 70% for a period of 5 years

These incentives are to be submitted to MIDA by 31 December 2020. However, MIDA is currently trying to negotiate an extension with the relevant authorities. To make Malaysia a pioneer in the hydrogen economy, the incentives should be extended.

4.1.3 Barriers of Transition to Hydrogen Economy

Barriers to Hydrogen Infrastructure Development

Hydrogen infrastructure is one of the main challenges in the transition to a Hydrogen Economy. It involves the safe production, delivery, and storage of hydrogen to power fuel cells in various applications. The hydrogen infrastructure also includes hydrogen refuelling, hydrogen distribution systems and low-cost renewable hydrogen generation.

The first main barrier in hydrogen infrastructure development is the **high cost of fuel cell deployment and hydrogen infrastructure development**. Components of hydrogen infrastructure such as pipelines, compressor stations, storage tanks and liquefaction plants are costly to develop, construct and operate. In addition, the local hydrogen supply chain is limited and inadequate to justify the costly infrastructure.

The second main barrier is **inadequate support for hydrogen energy in the National Energy Policy**. There is no clear strong policy on hydrogen energy. There are no Malaysian standards and policies regarding fuel cells and hydrogen energy. There are also no proper guidelines, technical codes and standards to support the hydrogen infrastructure.

The third barrier is the **limited financial and human resources** available for investments in the hydrogen economy. There is also a lack of funds from the industry for R&D in fuel cells and hydrogen energy. As a result, very few local hydrogen energy and fuel cells products could be commercialised successfully in the global marketplace.

Finally, there is **public uncertainty** in hydrogen energy. There is low consumer confidence in fuel cell technology due to issues in hydrogen safety. This is because there is a lack of public awareness and advocacy on hydrogen energy as safe zero-emission energy. Hydrogen energy suffers from false public perception of hydrogen safety. There are also a few proven track records of successful hydrogen energy deployment in the few demonstration projects, mainly in Europe, US, Japan, China and Korea.

Barriers to Fuel Cell Applications

The main fuel cell applications are in industrial, public and private transport, stationary applications for distributed electricity generation for homes and buildings and portable power applications. Other interesting applications are micro combined heat and power (mCHP), backup power for remote and shipboard facilities.

The main barrier of fuel cell applications is the **high costs of fuel cell components and parts.** The Pt on the electrodes and the proton exchange membranes are costly. Fuel cells R&D is focussed on reducing the cost of both the electrochemical catalysts by more dilute dispersion of the Pt or by replacement with cheaper transition metal alternatives and the proton exchange membrane by developing alternative cheaper membranes.

The second barrier is the **lack of understanding, education and awareness** of the fuel cell technologies among the public, the relevant ministries, and to some extent, the R&D communities.

The third barrier to be overcome is the **lack of clear and strong national policies** that support new fuel cells applications and insufficient capacity, especially in innovation and technical know-how of hydrogen infrastructures such as hydrogen distribution, storage, and refuelling facilities, the high cost of deployment and inconvenient and impractical fuel cell applications.

4.1.4 Strategy Recommendations - Hydrogen Economy Roadmap 2020

To create an optimal path to achieve hydrogen economy, building a complete ecosystem for hydrogen economy should be one of the focuses on 12th Malaysia Plan. Three key areas were identified in The Blueprint for the Fuel Cells Industry in Malaysia, namely Hydrogen Infrastructure, Fuel Cell Applications and Emerging Fuel Cell Technologies.

Establishing hydrogen infrastructure is the most challenging step due to its high cost and uncertain market demand. It requires a high degree of government intervention to develop a local supply chain and specific market. Investment by the industry players plays a huge part in building hydrogen infrastructure.

Fuel cell applications need to be diversified and widely accepted by the market to establish a robust supply chain. At the same time, the nation should continue to keep up the pace of emerging fuel cell technologies. One of the demonstration projects to consider is to develop a model city powered by fuel cell technology.

A complete ecosystem needs to be in place, which includes:

Governance

- Comprehensive guidelines, regulations, and policies to support hydrogen infrastructure according to international standards
- Policies, standards, and guidelines for novel fuel cell products and components
- Comprehensive technical codes and standards for hydrogen and fuel cell safety
- Hydrogen infrastructure for the electricity generation and transportation sectors to be set as National Priority
- Monitoring bodies to align collaborations between research institutes, government and industry

Public and market acceptance

- High public awareness and acceptance of the government's policy on the hydrogen economy
- High track records of involvement in hydrogen energy industries
- Strong and stable support from all stakeholders to maintain progress and growth

Technology and Human Capital readiness

- Manufacturing line for high-quality components in the fuel cell and hydrogen industries
- New indigenous resources to replace raw materials from expensive imports
- R&D institutions on hydrogen and fuel cell technology, especially exploring advanced hydrogen usage in fuel cell applications.
- Adequate capacity building in human resources for the hydrogen and fuel cell industry, including relevant education programs in higher education institutions

Finance readiness

- Development effort to reduce the cost of the technology
- Large-scale campaigns to ensure continuous funding

The implementation of each strategy is further sub-divided in the timeline into the Short Term (12th Malaysia Plan 2021-2025), Middle Term (13th & 14th Malaysia Plans 2026-2035) and Long Term (15th, 16th & 17th Malaysia Plans 2036-2050). Targets are crafted for each stage of implementation (Figure 56).

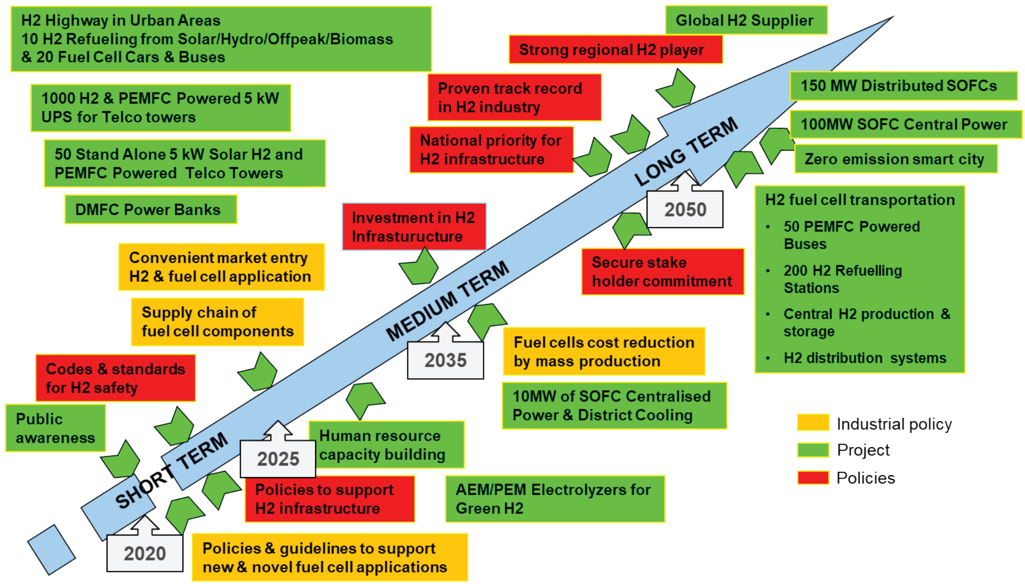

Figure 56:
Hydrogen Roadmap in 2020

4.2 12th Malaysia Plan 2021-2025 (Short Term)

4.2.1 Hydrogen Infrastructure

Objective	Strategies	Action Plans	Stakeholders
To utilise advances in R&D on hydrogen infrastructure	Improve components in the fuel cell and hydrogen industries	1. Fully utilise hydrogen sources from existing local hydrogen producers and resources. Utilising the available sources of renewable energy in Malaysia that could be exploited to generate power should be converted into hydrogen fuel. 2. Identify priority application areas for R&D and establish demonstration projects: a. Green hydrogen production from renewable resources and energy using • AEM/PEM Electrolyzers • Biomass gasifiers • Biohydrogen b. Hydrogen transportation and storage in liquid hydrogen (LH), compressed hydrogen, liquid ammonia or solid-state metal hydride and hydrogen refuelling stations 3. Incentivise investment from local industry in deployment and commercialisation of key technologies in hydrogen production from RE such as electrolyzers, biomass gasifiers and wastewater biohydrogen fermenters. Feed-in Tariff scheme should be revived for electricity generation from hydrogen and solar energy with hydrogen as energy storage 4. Identify and appoint champion(s) for hydrogen and fuel cell technology	UKM, UTM, MGTC, KASA, MOT, KeTSA, MITI, MIDA, SEDA, EC Potential stakeholders to be engaged: PETRONAS, Airproducts, HYUNDAI MOTORS (under SIME DARBY), Linde Malaysia, UMW

Objective	Strategies	Action Plans	Stakeholders
To publish guidelines, regulations, and policies	Develop comprehensive guidelines, regulations, and policies according to global standards	1. Enhance management skills in commercialisation relevant to the Hydrogen economy 2. Train managers, engineers and operators to handle hydrogen production and refuelling 3. Complete the development of capabilities for independent product accreditation and testing for the Malaysian fuel cell industry 4. Fully standardise key components and design of fuel cell systems and hydrogen fuel dispensing stations 5. Extend Feed-in-Tariff (FiT) programme at SEDA to include renewable hydrogen energy 6. Establish Hydrogen Council of Malaysia chaired by Prime Minister, led by industry players	MTDC, TPM, MyIPO, UKM, UTM, TVET, Jabatan Standard Malaysia, SEDA, KeTSA, KASA, MOT, EPU, MITI, MIDA and industry players
To raise public awareness	Hold public awareness & advocacy campaigns	1. Raise more market awareness relating to hydrogen and fuel cells through relevant channels and media 2. Raise the nation-wide awareness campaigns on domestic and international career opportunities in hydrogen and fuel cells 3. Organise high profile awareness raising campaigns, which focuses on carbon dioxide emission problems and benefits of energy security. Aim the campaigns at politicians, policy makers and local planners as well as insurance, financial, and underwriting communities 4. Lower the perceived risk of indigenous fuel cell and hydrogen technology through improved public understanding 5. Raise awareness by encouraging hydrogen fuel cell-based project learning in public education curriculum and work towards developing hydrogen and fuel cell courses at selected schools and universities	KASA, KeTSA, UKM, NGOs, Persatuan Tenaga Hydrogen Malaysia (MAHE)

Objective	Strategies	Action Plans	Stakeholders
To ensure safety measures are in place	Develop local codes and standards for hydrogen safety	1. Complete the development of nationally acknowledged credentials, benchmarks, and standards with a shared database for the fuel cell industry and suppliers 2. Register Malaysia as a member country for the ISO/TC 197 Hydrogen Technologies technical committee to develop local standards for hydrogen safety 3. Ensure compliance with Codes and Standards requirements with clear codes and standards framework that incorporates the input from Malaysian industry 4. Integrate relevant existing global codes and standards for hydrogen applications in Malaysia 5. Designate hydrogen safety as a high priority by reference to Hydrogen Codes and Standards as well as the accompanying codes and standards 6. Demonstrate and conduct R&D in the safe handling of hydrogen used for fuel cells to the public	Jabatan Standard Malaysia, SIRIM, DOSH, NIOSH
	Establish robust policies to support the hydrogen infrastructure	1. Formulate policy decisions based on life-cycle analysis costs and evolving methodologies to account for external features and social benefits of fuel cells 2. Associate the relevant codes and standards for fuel cells and hydrogen with demonstration projects to initiate and grow a hydrogen fuel infrastructure 3. Collaborate globally in developing a 'codes and standards' information clearing house 4. Complete the development of local codes and standards for hydrogen as a fuel for light-duty and heavy-duty vehicles through the International Standards Organization (ISO) and Technical Committee (TC197)	KASA, KeTSA, Jabatan Standard Malaysia, SIRIM

4.2.2 Fuel Cell Applications

Objective	Strategies	Action Plans	Stakeholders
Satisfactory local standards and policy structure	Establish a policy structure that supports the new application of fuel cell technology	1. Relevant ministries and agencies establish a national entity to prepare and promulgate uniform codes and standards for fuel cell applications in Malaysia 2. Incorporate practical elements from past domestic and international exercises into the evolving fuel cell and hydrogen policy framework for Malaysia 3. Incorporate training components in fuel cell demonstration projects or early adoption to meet immediate needs	KASA, KeTSA, Jabatan Standard Malaysia, SIRIM, UKM, UTM, Industry players
To utilise advances in R&D on fuel cell applications	Improve components in the fuel cell applications	1. Fuel cell applications for public and private transport, telecommunication towers, data centres, offices, homes and H2 highway in an urban area • 20 Fuel Cell Vehicles – 10 Cars & 10 Buses • 10 H2 Refueling from Solar/ Hydro/ Offpeak/ Biomass • 1000 H2 & PEMFC Powered 5 kW UPS for Telco towers • 50 Stand Alone 5 kW Solar H2 and PEMFC Powered Telco Towers • DMFC Power Banks	UKM, UTM, MGTC, KASA, MOT, KeTSA, MITI, MIDA, SEDA, EC Potential stakeholders to be engaged: PETRONAS, Airproducts, HYUNDAI MOTORS (under SIME DARBY), Linde Malaysia, UMW

4.2.3 Emerging Fuel Cell Technologies

Objective	Strategies	Action Plans	Stakeholders
To enact policies, standards, and guidelines	Develop policies, standards, and guidelines for novel fuel cell products and components	1. Provide a comprehensive set of financial incentives for high profile fuel cell stakeholders to set up in Malaysia and stimulate early adoption 2. Lower the perceived risk for early adopters by developing leasing programmes that can help offset high upfront purchase costs 3. Import management personnel already skilled in technology commercialisation	MITI, MIDA, Industry players

4.3 13th & 14th Malaysia Plans 2026-2035 (Medium Term)

4.3.1 Hydrogen Infrastructure

Objective	Strategies	Action Plans	Stakeholders
To secure financial support from relevant stakeholders	Pursue responsible institutions on fuel cell technology	1. Fully update the stakeholder list for fuel cell and hydrogen industries with representatives from lawmakers, ministry and military personnel, coalition teams (government, industry, and academia), economic development agencies, energy and environmental agencies, business owners, university researchers, and enthusiastic end-users/customers 2. Recognise the specific roles of stakeholders from different backgrounds in addressing and overcoming the barriers faced by the fuel cell and hydrogen industries in Malaysia 3. Collaborate with early adopters that agree on premium payment from strategic partners in different agencies, institutions, and market segments	MITI, KASA, KeTSA, UKM, UTM

Objective	Strategies	Action Plans	Stakeholders
To set up a local supply chain and related facilities	Develop local supply chain and specific market penetration	1. Develop Malaysia-based supply chains by adopting market mechanisms to reflect fuel cell advantages 2. Provide appropriate support to ensure that viable technologies can overcome the gap between academic-based innovations and their commercial applications in the marketplace 3. Secure appropriate support framework to stimulate a sizable local deployment of fuel cells in diversified applications and situations 4. Develop a detailed understanding of early markets and mid-markets where specific fuel cell applications are most effective and respond in terms of production volumes as markets develop 5. Accommodate the growing fuel cell commercialisation scenario and adjust various stages of the planning processes accordingly	MOSTI, KeTSA, KASA, MTDC, TPM
To enhance capacity building in human resources	Build adequate capacity building in human resources for the hydrogen industry	1. Develop training and certification programmes for producing skilled engineers and technical personnel 2. Coordinate demonstrators from government institutions, academia, and industry to align everybody in moving towards a common vision 3. Develop the short and long term needs of the industry by expediting effective communication between stakeholders from various backgrounds and expertise	MOE, MOHE, MOHR, TVET, UKM, UTM, industry players

4.3.2 Fuel Cell Applications

Objective	Strategies	Action Plans	Stakeholders
To reduce cost by mass production	Carry out development effort with cost considerations	1. Collaborate with stakeholders to cost-share the costs that the market will have to bear in each fuel cell application and implement cost-reducing measures 2. Eliminate technical and institutional barriers faced in the implementation of hydrogen infrastructure and fuel cell applications 3. Secure early adoption in competitive market applications focusing on material handling vehicles, back-up power (UPS) systems, distributed generation, and portable power systems	Industry players, MTDC, TPM
To have suitable alternatives for convenient fuel cell applications	Advance hydrogen usage in convenient fuel cell applications	1. Secure financial support from various stakeholders in the government and industrial sectors for R&D projects 2. Develop industry-focus R&D appropriate to the Malaysian market environment • 10MW of SOFC Centralised Power & District Cooling 3. Develop indigenous technologies in smaller and lighter hydrogen storage 4. Develop innovative capacity to obtain appropriate alternatives for convenient local technologies in fuel cell applications	Industry players, UKM, UTM

Objective	Strategies	Action Plans	Stakeholders
To raise the profile of fuel cells	Organise large-scale campaigns to ensure continuous funding	1. Permit selected imported solutions, which can upgrade local experience, to be included in subsidised demonstrations and deployment exercises 2. Coordinate workshops on public safety and handling of hydrogen fuel with appropriate international bodies/agencies such as the National Hydrogen Association, International Code Council (ICC), and United Nations 3. Ensure awareness in financial and underwriting communities as well as amongst suppliers currently active in established relevant sectors in terms of the long term prospects and potential opportunities of fuel cells 4. Secure partners from government agencies and original equipment manufacturers (OEM)/end-users to cost-share in market demonstrations and early applications	KeTSA, KASA, MTDC, TPM, NGOs, Persatuan Tenaga Hydrogen

4.3.3 Emerging Fuel Cell Technologies

Objective	Strategies	Action Plans	Stakeholders
To have sufficient funding for the local fuel cell industry	Ensure financial support from various stakeholders	1. Secure incentives for tax benefits with involvement and endorsement from relevant ministries 2. Secure financing from willing stakeholders to cost share in developing production volumes and related business activities 3. Fully immerse in early markets for fuel cell applications that are not significantly affected by the cost	MIDA, SEDA
To have a pool of champions for the fuel cell industry	Appoint champions for the fuel cell industry	1. Secure market champions from willing development partners that cost-share technology and application demonstration activities 2. Collaborate with fuel cell champions on a regional Government-Industry Roadmap in developing commercial-scale infrastructures 3. Channel the strengths of domestic champions to potential international stakeholders in order to stimulate inbound investment 4. Foster synergistic relationships with international partners from major manufacturers of light-duty vehicles and their suppliers	Industry players
To set up monitoring bodies	Set up monitoring bodies to align collaborations between research institutes, government and industry	1. Set up a national body to plan, approve, and declare uniform codes and standards for hydrogen use as a fuel for vehicles 2. Coordinate and synchronise regional activities fuel cells and hydrogen initiatives 3. Harmonise the development of the adopted codes and standards by Malaysia with other countries in the global setting	KeTSA, KASA, MTDC, TPM Jabatan Standard Malaysia, SIRIM

Objective	Strategies	Action Plans	Stakeholders
To nurture fuel cell technology and infrastructure in target market segments	Target specific market segments for the local industry	1. Maximise the development of early adoption to increase opportunities for local fuel cell companies 2. Develop mechanisms that provide a supportive environment for potential stakeholders and investors to convey a consolidated stance in the local and global markets 3. Develop a strong network linking related technical facilities to a central fuel cell cluster	MTDC, TPM, EC
To educate the public on the potentials and benefits of fuel cells	Plan for education programmes in higher education institutions	1. Execute a multi-disciplinary approach with a fuel cell focus on various scientific and engineering disciplines 2. Support the development of appropriate skilled and advanced workers for appropriate sectors of fuel cells in Malaysian Universities 3. Run co-op/internship university programmes at regional and international fuel cell companies 4. Develop Malaysia into becoming the regional centre of fuel cell education 5. Expand the existing Malaysian research capabilities to achieve significant outcomes over recognised challenges	MTDC, TPM, TVET, universities, industry players

4.4 15th, 16th, 17th & 18th Malaysia Plans 2036-2050 (Long Term)

4.4.1 Hydrogen Infrastructure

Objective	Strategies	Action Plans	Stakeholders
To establish National Priority for hydrogen fuel infrastructure	Establish National Priority in hydrogen infrastructure for the electricity generation and transportation sectors	1. Complete the cultivation of political initiatives to focus the government on hydrogen and fuel cell-related obligations 2. Attain full government cooperation as an early adopter of fuel cell technology for a range of high-profile applications 3. Install effective mechanisms for information dissemination to relevant regulatory bodies regarding the adopted codes and standards for Malaysia 4. Ensure substantial government commitment to develop and deploy hydrogen infrastructure in Malaysia by securing high-level political buy-in • Central H2 production & storage • H2 distribution systems	KeTSA, KASA, MOT, MTDC, TPM
To gain proven high track records in the industry	Obtain proven high track records of involvement in hydrogen energy industries	1. Collaborate with stakeholders by concentrating technical expertise and learning at chosen sites that canvas numerous domestic and industrial applications 2. Establish efficient hydrogen infrastructure for high capacity storage system facilities, purification, production, distribution, and refuelling 3. Involve fuel cells in the Malaysian market by utilising high profile infrastructure development plan	MTDC, TPM, EC

Objective	Strategies	Action Plans	Stakeholders
High-quality green hydrogen producer	Develop hydrogen production hub	Develop hydrogen supply chain as a global Hydrogen supplier	MITI, MIDA, Industry players

4.4.2 Fuel Cell Applications

Objective	Strategies	Action Plans	Stakeholders
To secure active involvement by stakeholders	Secure strong and stable support from all stakeholders to maintain progress and growth	1. Organise awareness campaigns with stakeholders to raise a positive local and global profile for the fuel cell industry and technology in Malaysia 2. Develop high-profile collaborative ventures focusing on demonstration projects 3. Give clean fuel tax subsidies and incentives to hydrogen users and utility companies to encourage their involvement in the fuel cell and hydrogen supply chain 4. Install mechanisms to effectively publicize milestone achievements to stakeholders and markets as soon as they are accomplished 5. Formulate a business model that is capable of selling fuel cells at a discount but with sufficient volume secured to reduce payback time and increase the return of investment after 3 years	KeTSA, KASA, MTDC, TPM, NGOs, Persatuan Tenaga Hydrogen, MIDA, industry players

Objective	Strategies	Action Plans	Stakeholders
To become a strong regional market leader	Advance R&D to be a strong regional market leader	1. Lead in areas that the domestic market is strongest at and collaborate with global partners in other areas 2. Install system design & integration of fuel cell technologies to suit the domestic setting and climate 3. Install full hydrogen production capacity from renewable sources for domestic usage and export 4. Fully develop the skills and technologies to build publically accessible hydrogen refuelling stations for the fuel cell transport sector	Universities and industry players
To have industrial projects for fuel cell applications	Develop the fuel cell transportation industry	1. Successfully develop capabilities to test and certify suitable all aspects of hydrogen facilities and systems for light-duty vehicles 2. Obtain full hydrogen refuelling station capabilities 3. Instal mechanisms to support the deployment of fuel cell vehicles and refuelling of hydrogen fuel in Malaysia • 50 PEMFC Powered Buses • 200 H2 Refuelling Stations	Industry players

Objective	Strategies	Action Plans	Stakeholders
To have a sustainable fuel cell powered-city model	Develop a model city powered by fuel cell technology	1. Execute Distributed Generation (DG) projects by communicating the benefits of DG and adapting the regulatory framework to comprehend and remove the institutional, infrastructural, and policy barriers facing DG 2. Complete the development of islanding systems around fuel cell-powered DG installations 3. Integrate a renewable energy-based system to assist in producing hydrogen for a centralised or distributed energy facility to supply power • 100MW SOFC Central Power • 150 MW Distributed SOFCs 4. Provide heat and power using stationary fuel cells to the household and commercial installations 5. Power all security lighting (crime-prevention lamps) and streetlamps with fuel cells 6. Plan urban development, including the next generation transportation system, lifestyle and business opportunities • Zero-emission smart city 7 Instal subsidy mechanisms to replace the residential power system with fuel cells in order to reduce GHG emissions in the residential sector	SEDA, EC, MTDC, TPM, TNB, State governments

4.4.3 Emerging Fuel Cell Technologies

Objective	Strategies	Action Plans	Stakeholders
To have new indigenous resources to replace expensive components	Replace raw materials from expensive imports to new indigenous resources	1. Locally mass-produce the materials and components required for producing fuel cells in order to reduce cost and nurture cost-reduction certainty 2. Implement investment and development plans for local component production that will be monitored and reviewed continuously	MITI, industry players

4.5 Positioning Hydrogen Economy through 10-10 *My*STIE

The 10-10 Malaysian Science, Technology, Innovation and Economic (*My*STIE) Framework (Figure 57) is an integration of 10 key Malaysian socio-economic drivers with 10 global leading science and technology drivers aligned to our strengths and needs (Academy of Sciences Malaysia, 2020). This Framework provides a systematic approach to translate research and development to the benefits of social and economy through high impact projects. It aims to generate shared economic prosperity across the diverse ecosystems in the country and shift Malaysia up the global innovation value chain. This Framework will enable key sectors of the economy to become more knowledge-intensive and innovation-driven. This will enhance the competitiveness and sustainability of Malaysian industries. It is designed to enhance the quality of life of the rakyat.

The 10-10 *My*STIE is designed to implement through six main steps which are Focus, Prioritise, Systematic, Collaborate, Inclusive and Future-proof, as illustrated in Figure 57.

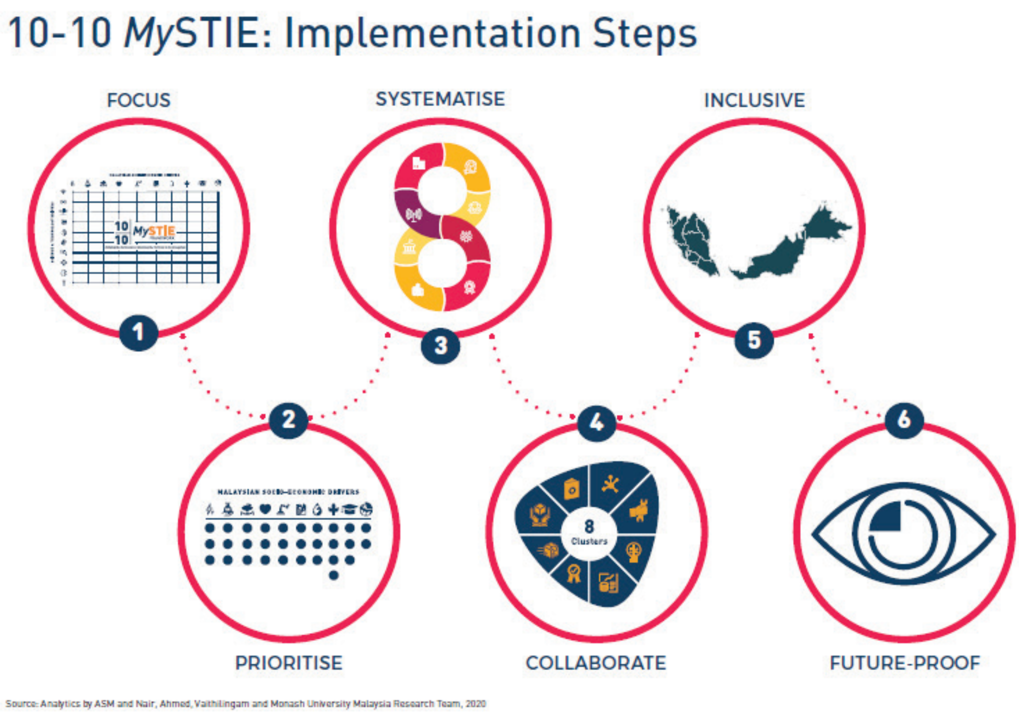

Figure 57: 10-10 *My*STIE Implementation Steps (source: ASM (2020)

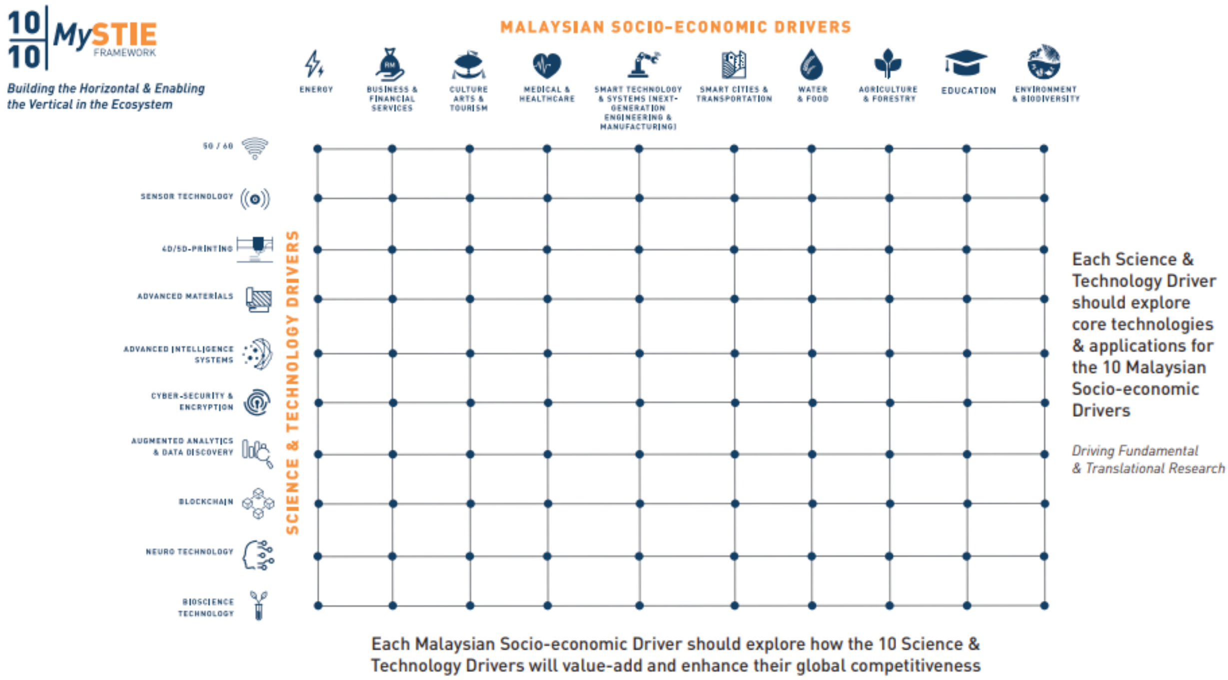

Figure 58: **10-10 *My*STIE Framework (source: ASM (2020)**

Step 1: Focus

The Hydrogen Economy is mapped against the 10-10 *My*STIE framework. Although Hydrogen Economy is an underlying force that directly and indirectly improves all socio-economic drivers, it appears most impactful on Energy, Smart Technology & System (Next Generation Engineering & Manufacturing), Smart Cities & Transportation, Water & Food, Agriculture & Forestry and Environment and Biodiversity.

Step 2: Prioritise

Under the 10 Socio-economic Drivers, 30 National STIE Niche Areas were identified through a series of stakeholder engagements to ensure that they are aligned with national aspirations. These niche areas were endorsed by the National Science Council on 14 July 2020 and will be reviewed every 2-3 years to ensure relevance to changing times (Figure 59).

Take Energy as an example, Hydrogen is critical for developing the niche areas of diversified renewable energy and energy storage as explained in Section 3. It is also a transformative pathway towards a green transportation system under Integrated Urban Infrastructure and Infostructure Management. Hydrogen Energy can also boost the niche area of Manufacturing of Smart Devices & Technology where Malaysia can leverage its advantage in manufacturing to produce high-quality fuel cells and electrolyzers.

Figure 59: **National Niche Areas across 10 socio-economic drivers (ASM, 2020)**

An exercise was done by mapping the latest hydrogen technologies with the 10 Science and Technology Drivers (Figure 60). Through this exercise, technologies needed to support the development of the hydrogen industry is outlined and need further attention from the respective Center of Excellence.

Through developing hydrogen technologies, the energy sector can be transformed. The related technologies can impose a multiplier effect on other socio-economic drivers, such as Agriculture & Forestry, Smart Technology & System, Environment & Biodiversity, Smart Cities & Transportation and Business & Financial Services. For example, an hydrogen-regulated solar energy system can be applied to electricity independent hydroponic systems on a farm.

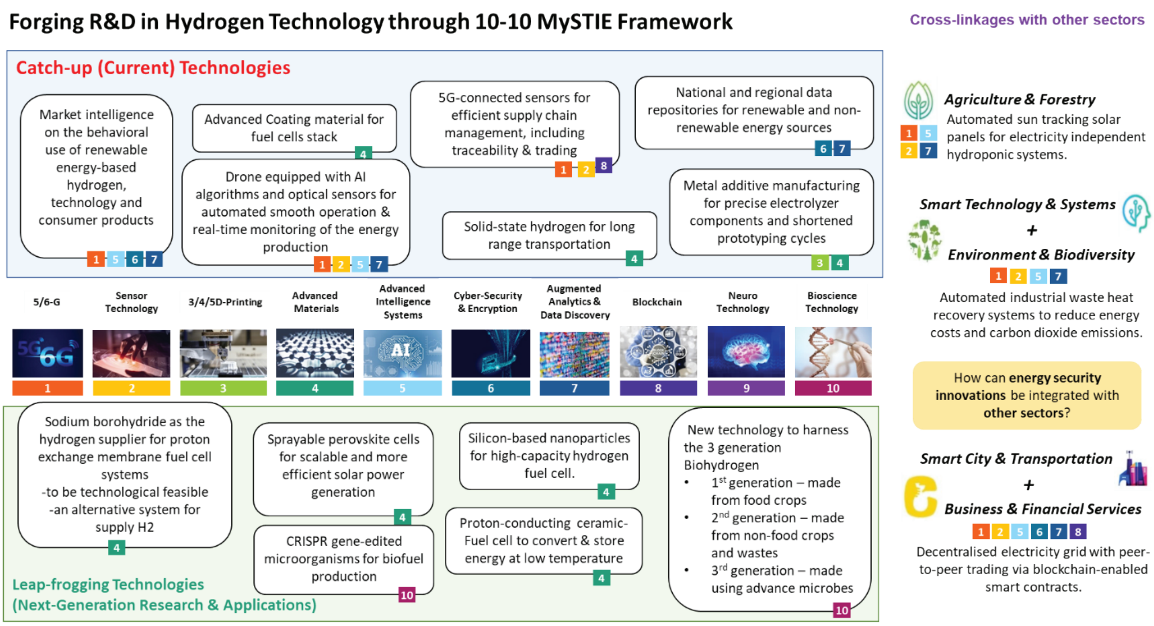

Figure 60: Application Map of the 10-10 *My*STIE Framework to Hydrogen Technology (ASM, 2020)

Step 3: Systematise

In order to deploy Hydrogen Economy, a full ecosystem approach needs to be taken to ensure sustainable growth of the industry. Guided by the 8i ecosystem analysis (Figure 61) in the 10-10 *My*STIE framework, the current issues and challenges of the ecosystem ecosystem, as well as the way forward, have been analysed, as shown in Table 4.

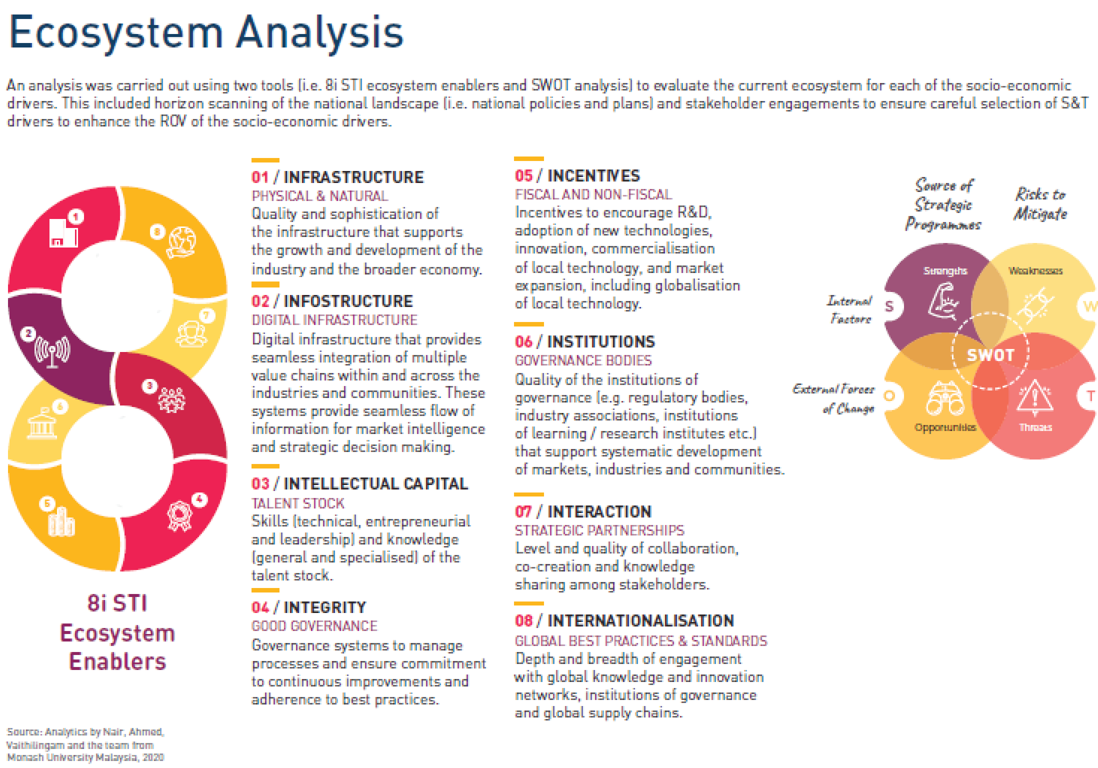

Figure 61: 8i Ecosystem Analysis (ASM, 2020)

Table 5: Issues and Challenges versus Way Forward for Hydrogen Economy

Issues and Challenges	Way Forward
1. Infrastructure	
High infrastructure cost i. Expensive raw materials for fuel cell technologies & limited resources for clean hydrogen	**Establish stable and cost-effective local hydrogen logistics and supply chains.** i. Explore new indigenous resources as an alternative to costly components. ii. Introduce Onboard Hydrogen system for easy storage handling
Logistic and supply chains are under-developed and fragmented. i. Lack of logistics network to transfer renewable energy especially from rural areas.	**Capitalising on existing natural gas infrastructure for hydrogen transmitting** i. Taking the United Kingdom as an example, UK research shows natural gas pipeline is capable of mixing with ~20% of hydrogen without increasing the risk of the integrity of the infrastructure
2. Infostructure	
Lack of a database (one-stop portal) on current & up-coming projects, investment opportunities and its related regulations & procedures	**Establish a one-stop portal for players in the hydrogen value chain that provides information on expertise, R&D programs, industry, institutions, incentives and support systems** **Ensure best technologies used throughout Supply Chain (10-10 *My*STIE)**
3. Intellectual Capital	
Lack of local specialised skills & low knowledge transfer from foreign to local players i. R&D fundamental breakthroughs and translational impact ii. Business talents to develop viable markets for HE are necessary	**Invest in talent with specialised skills to lead the national hydrogen economy**

4. Integrity	
Lack of proper guidelines, standards and policies specifically for HE i. Slow implementation although plans are in place e.g. Fuel Cell & Hydrogen Blueprint 2017, SEDA Act 2012 Feed-in Tariff for Renewable energy, Renewable Energy Act 2011 ii. Need a consistent review of Net Energy Metering quota to allow supply from renewable energy meeting customers' demand.	**Establish Hydrogen Energy Governance System/ authority** i. Ensure systematic implementation of the plans and milestones **Adoption of global best practices & technical standards** i. ISO on safety, hydrogen generators and stationary applications **Clear business-friendly policies, guidelines and regulations** i. Encourage technology transfer and investment
5. Incentives	
Lack of consistent, stable and competitive incentives and funding i. No hydrogen-specific incentives & government funding ii. Low funding for experimental R&D and commercialisation support. iii. Constant policy changes	**Provide fiscal and non-fiscal incentives & funding** i. Help deployment of demonstration projects ii. Intensify R&D and commercialisation of HE iii. Encourage the utilisation of renewable energy

6. Institution	
No champions key institutions in the country (government agencies, industry associations and institution of learning/R&D) **Lack of institutional framework to support the import/export of hydrogen technologies including electrolyser & other related technologies**	**Select champions for the fuel cell industry (Government agencies and industry players)** i. E.g. PETRONAS, Airproducts, Hyundai Motor **Establish a national centre of excellence** i. Good understanding of market needs, trends & latest technologies ii. Nurture multi-stakeholder partnership between research institutions, universities, local industries and community to lead the development and promote the use of HE
7. Interaction	
Lack of public awareness and understanding among consumers on renewable energy, hydrogen technologies and safety challenges **Lack of Collaborative Platform that combines efforts and building knowledge network among the players in the industry**	**Establish a collaborative platform for all stakeholders to facilitate discussion on new opportunities, issues & challenges** **Communication, Education and Public Awareness** i. Demonstration projects to showcase safe handling of HE ii. Transpire global climate challenges iii. Discuss risk and benefits of HE

8. Internationalisation	
Lack of understanding and awareness on global trends, future directions in the hydrogen economy space	**Build strong knowledge networks and partnerships with leading global centres of excellence, industry players and researchers**
i. Lack of investment in building strong international knowledge networks	i. Contribute to global knowledge network in the region (integration in ASEAN market)
ii. Lack of interaction with potential global market	ii. Establish international collaboration (e.g. USA collaborated with Hyundai for technology transfer)
iii. Lack of understanding of regional competitors (e.g. Australia)	

Step 4: Collaborate

Once Hydrogen Economy is recognised as a strategic priority, effective implementation on the ground requires the establishment of a collaborative platform that brings together key players. This collaborative platform will enable integrated strategies, holistic solutions, and active implementation involving all important stakeholders in the supply chain. A conducive ecosystem for the hydrogen industry shall include the eight clusters, as illustrated in Figure 62.

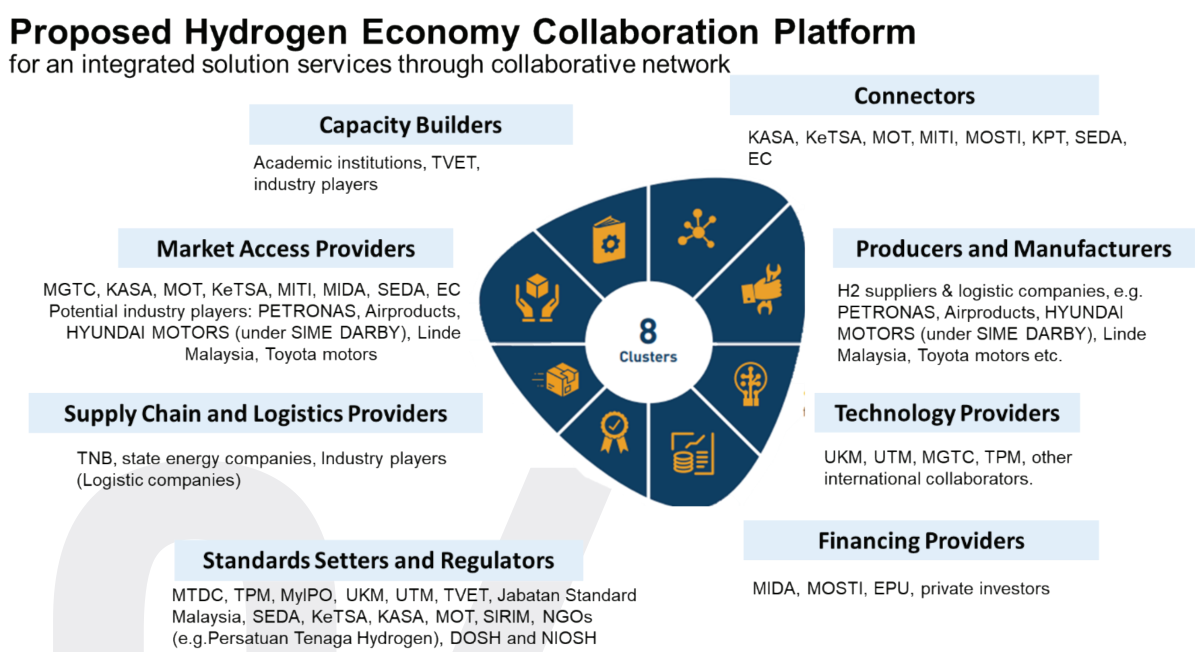

Figure 62: **Proposed Hydrogen Economy Collaboration Platform (ASM, 2020)**

Step 5: Inclusive

As mentioned in Section 4.2, the Feasibility of Hydrogen Economy needs to be proven through a demonstration project. It is important to identify demonstration projects that can be deployed at selected localities. The two most feasible areas for demonstration projects are as follows:

1. Fuel Cell Public Transport and Logistics

Strategic Programmes/ Interventions	Actions	Timeline	Proposed Players
Carry out Feasibility Study (technical & economic)	• Study the technical and economic viability of hydrogen technologies • Understand the supply and demand in the domestic market	Short-term (5 years)	• MOSTI • MOT • KASA • NGO • SEDA • Suruhanjaya Tenaga • Jabatan Standards Malaysia • Industry players • Federal & State governments
Establish policies, regulations, codes and standards	• Define and set the technical code and standards for hydrogen technology in Malaysia, adhering to international standards, e.g. Hydrogen/Fuel Cells Standards listed by FCHEA • Becoming a member country for the ISO/TC 197 Hydrogen Technologies technical committee • Establish policies that support hydrogen applications	Short to Mid-term (5 to 10 years)	

<table>
<tr><th>Strategic Programmes/ Interventions</th><th>Actions</th><th>Timeline</th><th>Proposed Players</th></tr>
<tr><td>Identify renewable sources, roll out fuel cell vehicles & build hydrogen infrastructures</td><td>• Identify sources of energy through leveraging current renewable sources at localities. E.g. hydrogen fuel cell pilot project in Kuching Sarawak is powered by micro-hydropower plant
• Roll out fuel cell vehicles, e.g. Fuel cell buses
• Build refuelling stations from renewable energy,</td><td>Short-term (5 years)</td><td rowspan="3">• MOSTI
• MOT
• KASA
• NGO
• SEDA
• Suruhanjaya Tenaga
• Jabatan Standards Malaysia
• Industry players
• Federal & State governments</td></tr>
<tr><td>Integrated Framework of Public Transport & Logistics</td><td>• Build hydrogen highways in urban areas involving fuel cell buses, trucks and trains. E.g. London Hydrogen Network Expansion, a hydrogen transport system across London</td><td>Mid-term (10 years)</td></tr>
<tr><td>Hydrogen Fuel Cell Transportation Collaborative Network</td><td>• Establish collaborative platforms involving government bodies, academia, industry players and civil society
• Actively measure & communicate the outcome of the demonstration project for improvement</td><td>Mid-term (10 years)</td></tr>
</table>

2. Industrial and residential power generation

Strategic Programmes/ Interventions	Actions	Timeline	Proposed Players
Carry out Feasibility Study (technical & economy)	• Study the technical and economic viability of hydrogen technologies • Understand the supply and demand in the domestic market • Plan demonstration project	Short-term (5 years)	• MOSTI • KeTSA • MITI • KASA • SEDA • Suruhanjaya Tenaga • Industry Players • All city and municipal councils
Identify potential sectors & industry players for hydrogen adoption	• Work with existing industry players in the energy and other sectors to roll out hydrogen infrastructure » Example 1: Based on feasibility study, TNB to build H2 & PEMFC Powered 5 kW UPS for Telco towers » Example 2: PETRONAS to mix hydrogen (5-15%) and natural gas for electricity generation through the existing gas pipeline	Short-term (5 years)	
Carry out spatial planning	• Identify strategic industrial areas for the building of hydrogen energy storage & distribution system, e.g. 10MW of SOFC Centralised Power & District Cooling, Central H2 production storage • Leverage on existing infrastructure (e.g. gas pipeline) to generate hydrogen-powered electricity at selected residential areas. » Example: France GRHYD demonstration projects blend hydrogen and natural gas using a variable hydrogen content below 20%	Short-term (5 years)	

Strategic Programmes/ Interventions	Actions	Timeline	Proposed Players
Establish ecosystem of hydrogen application	• Establish ecosystem of hydrogen applications in potential sectors, e.g. steel production, food processing • Provide incentives to encourage supply chain development of hydrogen applications in the selected industries, e.g. manufacturing AEM/PEM Electrolyzers for Green H2, fuel cell components, DMFC Power Banks etc	Short-term (5 years)	• MOSTI • KeTSA • MITI • KASA • SEDA • Suruhanjaya Tenaga • Industry Players • All city and municipal councils

Suitable localities need to be identified by the industry players and relevant parties who undertake the demonstration projects. Hence, it is vital to carry out spatial planning to understand the supply and demand of hydrogen energy and eventually select the most feasible localities where hydrogen infrastructures are suitable to be built. For example, an STIE ecosystem was taken by the 10-10 *My*STIE handbook. Industry areas in Johor, for instance, might have a conducive ecosystem that consists of several manufacturing industries that may require hydrogen fuel cell electricity generation.

Step 6: Future Proof

In order to ensure the hydrogen technologies adopted by Malaysia is up-to-date and competitive globally, regular foresight should be undertaken. This is to ensure that future technologies in the field are used to increase the supply of hydrogen energy, making it cost-competitive vis-à-vis other energy sources. Intensify market intelligence, branding and positioning of hydrogen energy as the preferred energy source. Increasing the supply and demand for hydrogen energy will ensure that it can pursue greater economies of scale and scope and be an important renewable energy source that contributes to the country's wealth. Understanding current global trends and risk management is crucial to ensure the hydrogen ecosystem is agile in adapting to future challenges associated with uncertainties and volatilities.

5.0 CONCLUSIONS

It is prudent and timely for Malaysia to continue incorporating fuel cells as an alternative energy source and hydrogen as the Sixth Fuel in the total energy mix and the fuel mix for electricity generation under the Fuel Diversification Strategy. This is to ensure that energy for the country is secure and the country will honour its contributions to reducing carbon emissions according to the INDC commitment at COP21 Paris in 2015 that will help to reducing global warming and climate change. More focused R&D efforts in hydrogen technologies, including electrolyzers and fuel cells by the combined enterprise of both government agencies and the industries, are required to ease the transition from the research stage to the infrastructure development and on to the implementation stage in the industry. The substantial investment and support by the government must continue for the development of the fuel cell and hydrogen energy by the effective implementation of research, development and deployment of the flagship programme for fuel cells and hydrogen energy in Malaysia until 2050 and beyond.

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