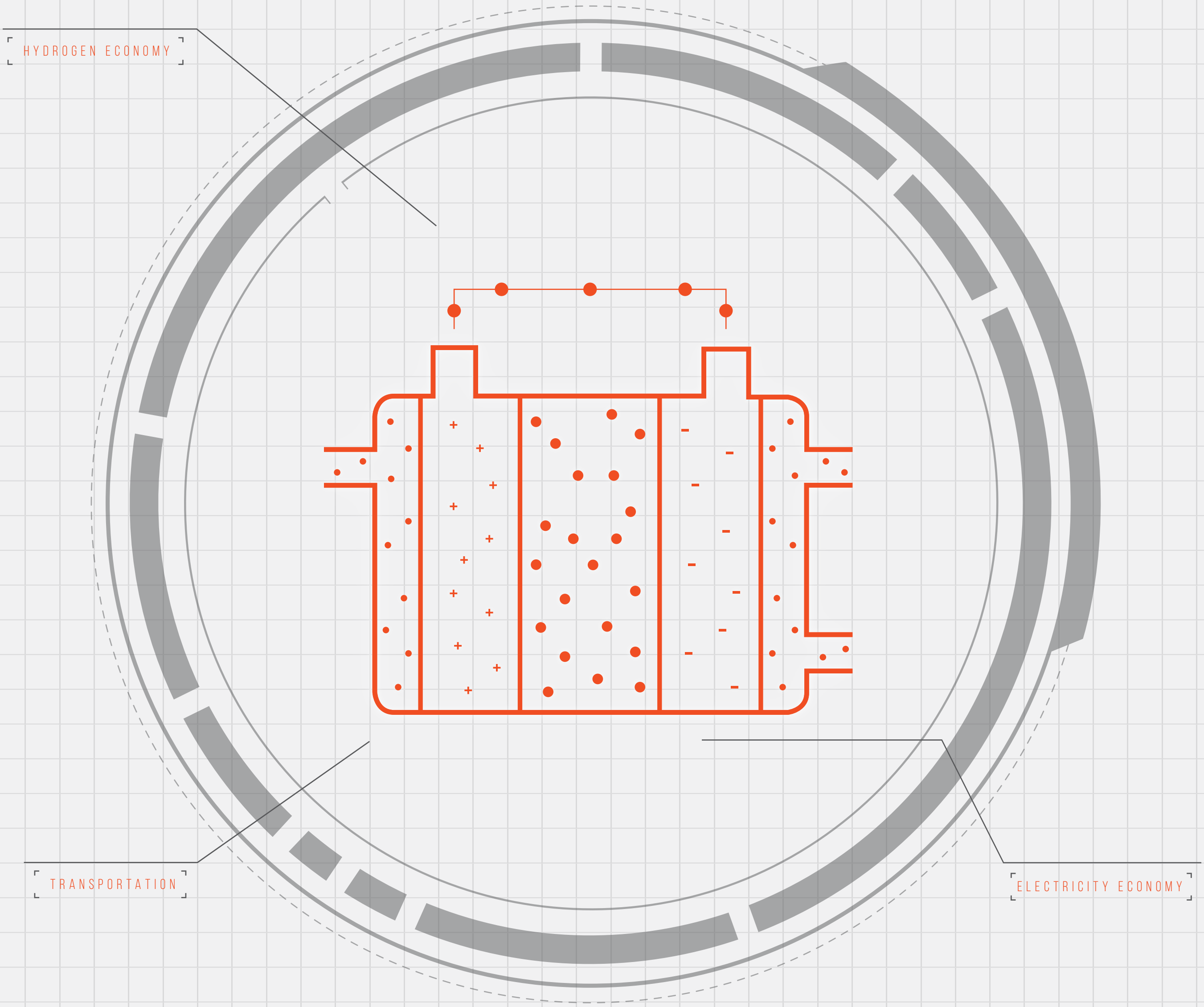
THE BLUEPRINT FOR FUEL CELL INDUSTRIES IN MALAYSIA



THE BLUEPRINT FOR FUEL CELL INDUSTRIES IN MALAYSIA

AKADEMI SAINS MALAYSIA

2017

Published by:
Academy of Sciences Malaysia
Level 20, West Wing, MATRADE Tower,
Jalan Sultan Haji Ahmad Shah,
off Jalan Tuanku Abdul Halim,
50480 Kuala Lumpur, Malaysia
Phone: +6 (03) 6203 0633
Fax: +6 (03) 6203 0634
admin@akademisains.gov.my

ASM Advisory Report 04/15
Endorsed: Dec 2015

Perpustakaan Negara Malaysia Cataloguing-in-Publication Data
ISBN

THE BLUEPRINT FOR FUEL CELL INDUSTRIES IN MALAYSIA.
ISBN 978-983-2915-30-0
1. Fuel Cell Industry.
2. Blueprints.
621.312429

CONTENT

CONTENT

FOREWORD

In carrying out its mandate as the 'Thought Leader' in science, technology and innovation (STI), the Academy of Sciences Malaysia (ASM) has always endeavoured to address the nation's highest concerns. On the energy front, the focus of ASM's strategic studies has been on greening energy through technology. This year, ASM has completed three energy related advisory reports namely, the Blueprint for Fuel Cell Industries in Malaysia, Carbon Free Energy Roadmap, and Energy Efficiency and Energy Usage in Transportation.

The International Energy Agency (IEA) argued that energy supply can be regarded as secure only if it is produced and delivered in a manner compatible with modern environmental expectations. Many countries including Malaysia have responded to the anticipated energy security crisis and climate change by diversifying their fuel-resources to include renewable and alternative energy as well as developing green-energy technologies for the future.

Although at one time fuel cell technology may have been dismissed as an environmentalist's dream, today, there is a significant amount of investment being directed to research and development in this area. Worldwide, fuel cell technology that directly converts chemical energy to electrical energy with low or zero carbon emission has been rapidly advancing. This has also paved the way for the vision of a hydrogen economy to be realised.

According to "Global Fuel Cell Market Forecast & Opportunities 2020" report, the global market for fuel cells is forecast to exceed USD3 billion by 2020. This has been accorded to the increasing applications of fuel cell technology in sectors such as automotive, communication and power generation. This provides an opportunity for Malaysia to tap into a new source of energy as well as develop a new economic sector. However, bringing about the adoption of this technology will require the partnership and commitment of policymakers, industry players and academia to enable supportive policies, strategic interventions and investment in requisite infrastructure.

In playing our part to contribute to this effort, ASM through its Task Force on Fuel Cell Energy embarked on this study and developed the Blueprint of Fuel Cell Industries in Malaysia. I would like to congratulate the ASM Task Force on Fuel Cell Energy chaired by Professor Dato' Ir Dr Wan Ramli Wan Daud FASc. for producing this report. I believe this report is timely as we usher a new era of sustainable energy possibilities through cutting edge scientific interventions and technologies.

Tan Sri Dr Ahmad Tajuddin Ali FASc
President
Academy of Sciences Malaysia

PREFACE

Fuel cell technology promises a clean, zero emission energy technology for a sustainable world to produce electricity. However, fuel cell is constrained by costs and durability as well as by the safety of hydrogen transport and storage. Many wide ranging research and development programmes all over the world are commissioned to address these issues and to make a business case for fuel cells. Despite these constraints, fuel cells technology is gaining ground all over the world as one of the most sustainable solutions for reduction of greenhouse gas emissions and by extension the carbon emission intensity.

This Blueprint is developed to focus on the discussion regarding these issues and is based on these three key groups: Hydrogen Infrastructure, Fuel Cell Applications, and Emerging Fuel Cell Technologies. These key groups are the results of discussions with stakeholders from across the board that includes government agencies, industrial players, researchers and academia. Insightful views of the challenges and barriers faced by the Malaysian fuel cell and hydrogen industries, and recommendations on how to overcome the challenges and plan of actions are also presented.

The objective of this report is to identify the advantages and opportunities of Malaysia to embark Fuel Cell Industries in the country. This report discusses the technology, research and development (R&D), human capital development, market opportunities, proper energy project funding, incentives, new standards, policy development, cost competitiveness as well as market enhancement for the fuel cell and hydrogen industries.

Fuel cells and hydrogen energy research has a long history in Malaysia since 1995 and the human resource at both MSc and PhD levels in both technologies are being produced at a steadily increasing rate. Thus, it is appropriate for Malaysia to chart its own strategies and develop a blueprint for the research, development and deployment of fuel cell and hydrogen technologies in Malaysia.

On behalf of the Academy of Sciences Malaysia (ASM), I wish to thank all of the Task Force members and all stakeholders who participated in the consultative workshop for their valuable input and insights. The contribution of each one who has been involved in producing this report in one way or another is highly appreciated. It is hoped that this Blueprint will be a guide for the effective implementation of research, development and deployment of the flagship programme for fuel cells and hydrogen energy in Malaysia.

Thank you.

Prof Dato' Ir Dr Wan Ramli Wan Daud FASc
Chairman
ASM Task Force on Fuel Cell

ACKNOWLEDGEMENT

The team that has worked towards the successful completion of this report:

1. **Prof Dato' Ir Dr Wan Ramli Wan Daud FASc**
   Chairman of the ASM Task Force on Fuel Cell;
   Former Director-Founder of the Fuel Cell Institute, Universiti Kebangsaan Malaysia

2. **Prof Dr Arshad Ahmad**
   Member of the ASM Task Force on Fuel Cell;
   Senior Director of the Institute of Future Energy, Universiti Teknologi Malaysia

3. **Prof Dr Abu Bakar Mohamed**
   Member of the ASM Task Force on Fuel Cell
   (Key Group Leader : Emerging Fuel Cell Technologies);
   Director of the Fuel Cell Institute, Universiti Kebangsaan Malaysia

4. **Prof Dr Siti Kartom Kamarudin**
   Member of the ASM Task Force on Fuel Cell
   (Key Group Leader: Hydrogen Infrastructure);
   Deputy Director of the Fuel Cell Institute, Universiti Kebangsaan Malaysia

5. **Mr Joseph Koh I Shen**
   Member of the ASM Task Force on Fuel Cell
   (Key Group Leader: Fuel Cell Applications);
   Director of Horizon FC Malaysia Sdn. Bhd.

6. **Mr Nurfarizal Rasid**
   Member of the ASM Task Force on Fuel Cell;
   Proton Holdings Berhad

7. **Mr Zulfadli B Daud**
   Member of the ASM Task Force on Fuel Cell;
   Proton Holdings Berhad

8. **Dr Umi Azmah Hasran**
   Writer of The Blueprint For Fuel Cell And Hydrogen Industries In Malaysia;
   Research Fellow of the Fuel Cell Institute, Universiti Kebangsaan Malaysia

9. **Ms Nitia Samuel**
   Principal Analyst

10. **Mr Mohd Ikhwan Abdullah**
    ASM Analyst

ACKNOWLEDGEMENT

Sincere appreciation is also expressed regarding the assistance and valuable contribution of the participants in the "Workshop on Fuel Cell Energy in Malaysia" on March 3rd 2015, as listed below:

- **Prof Mohamed Mahmoud Nasef**
  Deputy Director of the Center for Hydrogen Energy,
  Institute of Future Energy,
  Universiti Teknologi Malaysia (UTM)
- **Dr Ebrahim Abouzari-Lotf**
  Center for Hydrogen Energy, Institute of Future Energy,
  Universiti Teknologi Malaysia (UTM)
- **Dr Mohd Nor Azman Hassan**
  Kementerian Sains, Teknologi dan Inovasi (MOSTI)
- **Mr Paul Wong**
  Kementerian Tenaga, Teknologi Hijau dan Air (KeTTHA)
- **Ir Lalchand Gulabrai**
  Fellow of the Academy of Sciences, Malaysia (ASM)
  and Director, G&P Professionals Sdn Bhd
- **Prof Dr Farid Nasir Ani**
  Universiti Teknologi Malaysia (UTM)
- **Prof Dr NorAishah Saidin Amin**
  Universiti Teknologi Malaysia (UTM)
- **Dr Ernee Noryana Muhamad**
  Universiti Putra Malaysia (UPM)
- **Assoc Prof Dr Salina Muhama**
  Universiti Selangor (UNISEL)
- **Mr Mohd Razwan Rusli**
  NB Research Sdn. Bhd.
- **Mr Mohd Aswadi Alias**
  UniKL British Malaysian Institute
- **Dr Jong Bor Chyan**
  Agensi Nuklear Malaysia
- **Dr Pauline Liew Woan Ying**
  Agensi Nuklear Malaysia
- **Ms Michelle Kwa**
  Institute of Strategic and International Studies (ISIS)
- **Ms Masrisazlin Bakri**
  Maritime Institute of Malaysia (MIMA)
- **The ASM rapporteurs:**
  Dr Tan Shu Ying (ASM Analyst)
  Ms Habibatul Saadiah Isa (ASM Analyst)
  Ms Shaneeta Visuvanathan (ASM Analyst)
  Mr Loh Chia Hur (ASM Analyst)
  Ms Padmini Karananidi (ASM Analyst)

LIST OF FIGURES

LIST OF TABLES

EXECUTIVE SUMMARY

Introduction

Malaysia is facing challenges, along with the rest of the world, regarding climate change and greenhouse gas (GHG) emission. As an oil-producing country, where fossil fuels are the biggest sources of GHG emissions, this is a huge concern as they continue to be used for some time to come. In the meantime, renewable and alternative fuel resources to replace fossil fuels still have some uncertainties that need to be addressed. Its strategic geographical position along important routes for seaborne energy trade enhances Malaysia's global competitiveness. This makes the energy industry, which delivers up to 20% of the total Malaysia's GDP, as a significant industry in the region. The fuel mix that contributes to Malaysia's current energy supply are oil, natural gas, coal, hydropower, and renewable energy. Malaysia is the second largest oil producer in Southeast Asia and has the fourth highest reserves in Asia-Pacific.

However, oil is an expensive fuel source for power generation and there is a gradual decline in production at major producing oil fields for the last decade. Natural gas is currently the biggest contributor for Malaysia's energy industry and accounted for about half of the country's total installed capacity and electricity generation. Renewable energy was included as a crucial source for electricity generation in Malaysia's energy mix and has been included in the Malaysia Plans from 2001. It is developed as the Fifth Fuel due to the increasing concern in the global community regarding the challenges of climate change. Nuclear energy has recently been included as well.

It is vital for Malaysia to have greener technologies, cleaner fuels, and low carbon emission due to its high carbon dioxide emissions, fossil fuels depletion, and energy security issues. In view of this, a system of delivering energy using hydrogen is envisioned for Malaysia and is called Hydrogen Economy. It 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, with hydrogen as the Sixth Fuel. Fuel cells, which are highly efficient static electrochemical devices that convert the chemical energy from a fuel directly into electrical energy with low or zero carbon emission, are used to harness the power of hydrogen.

The Blueprint is developed to focus the discussion on these issues and are based on these three key groups: Hydrogen Infrastructure, Fuel Cell Applications, and Emerging Fuel Cell Technologies. Insightful views of the challenges and barriers faced by the Malaysian fuel cell and hydrogen industries and recommendations on how to overcome the challenges and plan of actions are also presented.

EXECUTIVE SUMMARY

Roadmap Development Process

To produce the Blueprint, a workshop was organised in March 2015 by the Academy of Sciences Malaysia (ASM) to gather together all stakeholders in order to discuss and work out the solutions to these challenges with the aim of establishing Malaysia's own fuel cell and hydrogen industries. The Blueprint also reviews and revises the 2005 "Roadmap for Solar, Hydrogen and Fuel Cell Research and Development Directions and Markets in Malaysia" released by Pusat Tenaga Malaysia as it takes into account the current local and global scenarios. The comprehensive discussion held in the workshop on the Blueprint is facilitated towards achieving the following objectives:

1. To identify the technology, research and development (R&D), and the major stakeholders involved;
2. To identify the Human Capital Development aspects that support the fuel cell and hydrogen industries growth;
3. To identify market opportunities and proper energy funding and incentives for the fuel cell and hydrogen industries and its relevant sub-industries;
4. To deliberate on the new standards and policy development for the fuel cell and hydrogen industries; and
5. To analyse the cost competitiveness and market enhancement of the fuel cell and hydrogen industries.

Logical Framework Analysis

The Logical Framework Analysis (LFA) is used as the tool for planning, designing and managing the Blueprint project. The data is laid out systematically in a tabulated form to give a succinct and unambiguous presentation. The LFA is developed by covering the following topics:

- Focus Areas - each of these three areas received particular attention from their respective stakeholders]group; namely Hydrogen Infrastructure, Fuel Cell Applications, and Emerging Fuel Cell Technologies;
- Drivers - principal trends, people, knowledge, and conditions that the participants believed contribute to the market development and growth;
- Main Problems - internal and external obstacles or setbacks associated with the fuel cell and hydrogen industries;
- Proposed Recommendations/Action Plan - proposals are given regarding the steps to be taken by the stakeholders towards achieving the project objectives; and
- Strategies – plans are laid out to accomplish the short term (2020), middle term (2035) and long term (2050) goals.

Diagram

I. Hydrogen Infrastructure

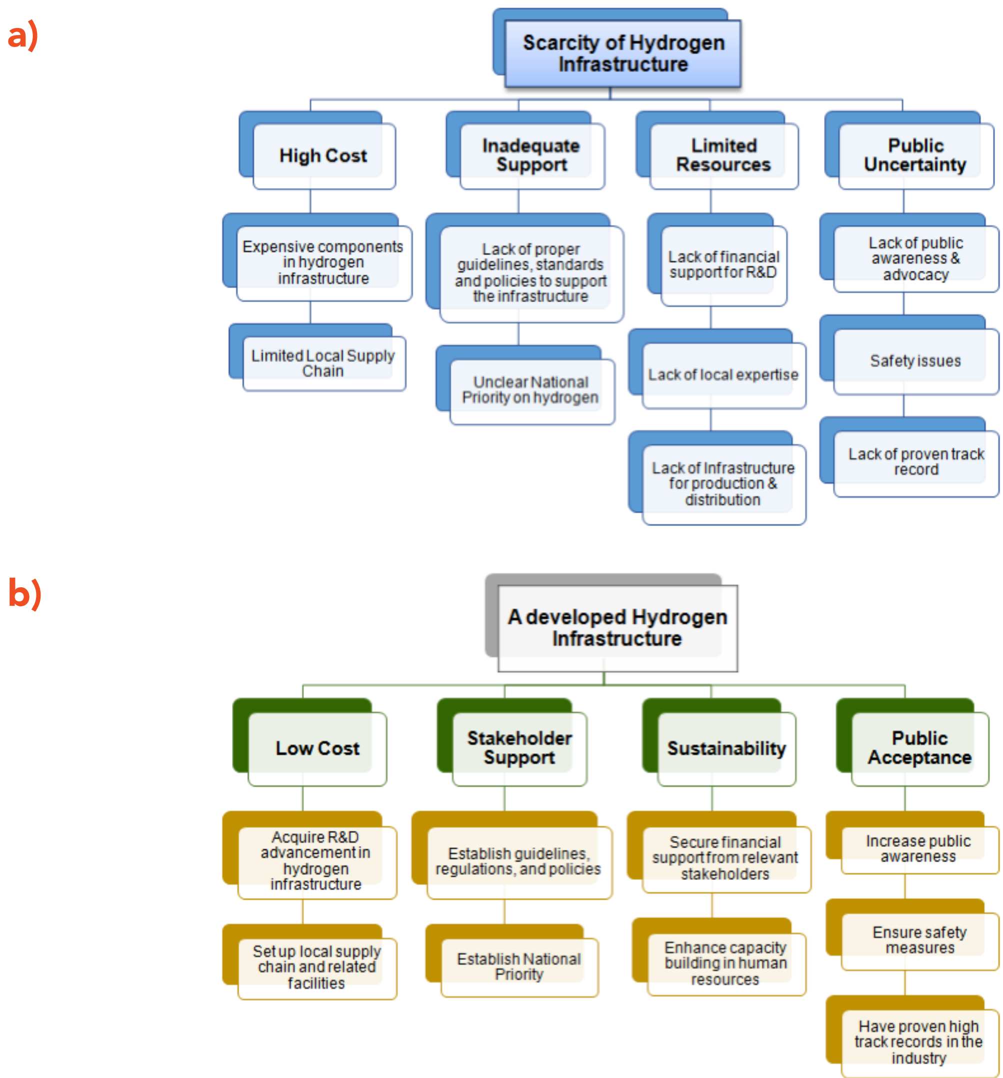
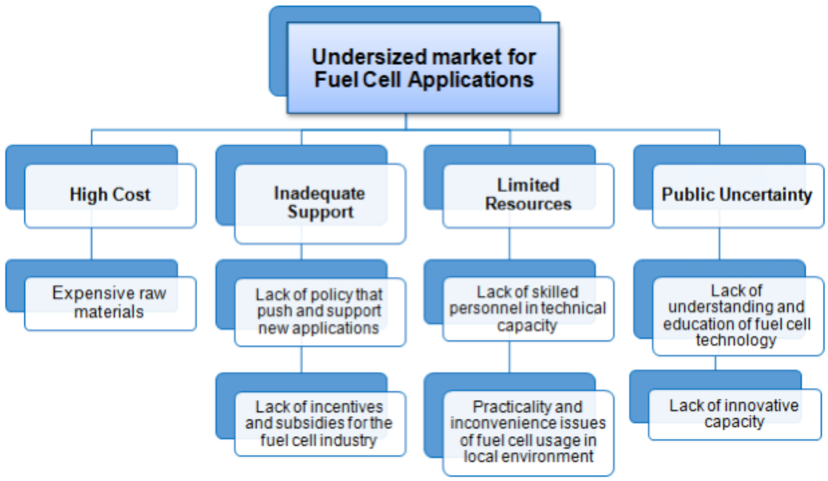


Figure 1. Hydrogen Infrastructure: (a) Problem Tree and (b) Objective Tree

Diagram

II. Fuel Cell Applications

a)



b)

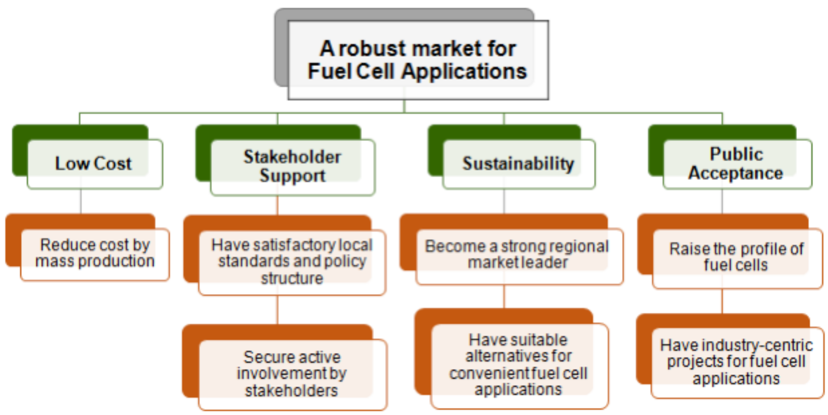
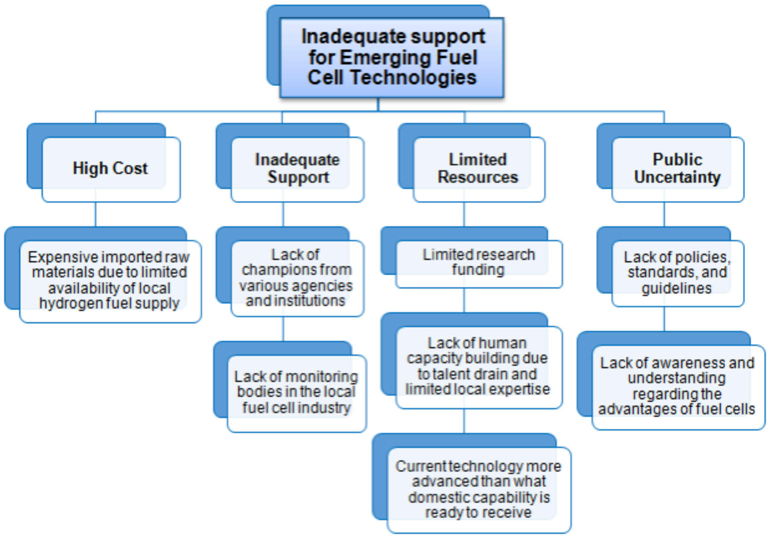


Figure 2. Fuel Cell Applications: (a) Problem Tree and (b) Objective Tree

Diagram

III. Emerging Fuel Cell Technologies

a)



b)

Figure 3. Emerging Fuel Cell Technologies: (a) Problem Tree and (b) Objective Tree

Recommended Strategies

Strategies have been formulated to initiate, improve, and nurture the fuel cell and hydrogen industries on the three key groups involved.

Hydrogen Infrastructure	1. Improve components in the fuel cell and hydrogen industries 2. Develop comprehensive guidelines, regulations, and policies according to global standards 3. Hold public awareness & advocacy campaigns 4. Develop local codes and standards for hydrogen safety 5. Establish robust policies to support the hydrogen infrastructure 6. Pursue responsible institutions on fuel cell technology 7. Develop local supply chain and specific market penetration 8. Build adequate capacity building in human resources for the hydrogen industry 9. Establish National Priority in hydrogen infrastructure for the electricity generation and transportation sectors
Fuel Cell Applications	1. Obtain proven high track records of involvement in hydrogen energy industries 2. Establish a policy structure that supports new application of fuel cell technology 3. Carry out development effort with cost considerations 4. Advance hydrogen usage in convenient fuel cell applications 5. Organise large scale campaigns to ensure continuous funding 6. Secure strong and stable support from all stakeholders to maintain progress and growth 7. Advance R&D to be a strong regional market leader 8. Develop the fuel cell transportation industry 9. Develop a model city powered by fuel cell technology
Emerging Fuel Cel Technologies	1. Develop policies, standards, and guidelines for novel fuel cell products and components 2. Ensure financial support from various stakeholders 3. Appoint champions for the fuel cell industry 4. Set up monitoring bodies to align collaborations between research institutes, government and industry 5. Target specific market segments for the local industry 6. Plan for education programs in higher education institutions 7. Replace raw materials from expensive imports to new indigenous resources

Conclusion

It is prudent and timely for Malaysia to continue incorporating fuel cells as an alternative energy source and hydrogen as fuel in the Fuel Diversification Strategy in an effort to obtain energy security, reliability and maintenance of the ecological state of the nation. A more focused R&D efforts in fuel cell and hydrogen technologies 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.

1.0 INTRODUCTION

INTRODUCTION

The world is facing major challenges ahead due to climate change and greenhouse gas (GHG) emission is identified as the primary contributor to this predicament. Fossil fuels, one of the biggest sources of GHG emissions, will continue to be used for some time to come before being phased out in favour of renewable and alternative fuel resources. However, there are also some uncertainties that still need to be addressed regarding these renewable and alternative fuel resources. With nuclear energy, unfavourable public opinion comes from the fear of its negative effects such as in the Chernobyl and Fukushima disasters, as well as international tensions due to global nuclear energy expansion. There is also uncertainty over large scale deployment of biofuels, which faces a lot of resistance over the conflict between the potential usages of land to produce crops for fuel against the very real need for land to produce crops for food. Renewables such as solar, wind, and wave energy are still constrained by costs. They are dependent on natural elements and inherently face uncertainties in terms of energy extraction efficiency, seasonal variability, and weather unpredictability. Hydrogen energy has a great promise of zero emission but it is still constrained by the high costs of manufacturing and deployment, low durability of some of its current applications, and the safety concerns over hydrogen transport and storage.

To produce a blueprint that addresses these challenges, as well as working towards solutions that focus on establishing Malaysia's fuel cell and hydrogen industries, a workshop was organised in March 2015 by the Academy of Sciences Malaysia (ASM). The Blueprint aims to review and revise the 2005 "Roadmap for Solar, Hydrogen and Fuel Cell Research and Development Directions and Markets in Malaysia" released by Pusat Tenaga Malaysia, where the discussions specific to fuel cell technology and hydrogen energy take into account the local and global scenarios that have changed over time.

The comprehensive discussion held in the workshop on the Blueprint is facilitated towards achieving the following objectives:

- To identify the technology, research and development (R&D), and the major stakeholders involved;
- To identify the Human Capital Development aspects that support the fuel cell and hydrogen industries growth;
- To identify market opportunities and proper energy funding and incentives for the fuel cell and hydrogen industries and its relevant sub-industries;
- To deliberate on the new standards and policy development for the fuel cell and hydrogen industries; and
- To analyse cost competitiveness and market enhancement of the fuel cell and hydrogen industries.

The direction of the Blueprint is mainly based on these three key groups: Hydrogen Infrastructure, Fuel Cell Applications, and Emerging Fuel Cell Technologies, in order to focus the discussion on the critical issues at hand. Insightful views of the challenges and barriers faced by the Malaysian fuel cell and hydrogen industries and recommendations on how to overcome the challenges and plan of actions to address those barriers are also presented in the Blueprint.

Energy Scenario in Malaysia: Current & Future

Malaysia is positioned strategically along important routes for seaborne energy trade, one of which links the Indian Ocean and the Pacific Ocean. However, it is still in territorial disputes with Indonesia over an area of the Celebes Basin and with China, Vietnam, and the Philippines due to deep-sea oil and gas exploration issues. Malaysia's global competitiveness is further enhanced when it was ranked 18th ahead of Indonesia and Thailand from 189 countries in the World Bank's Ease of Doing Business report benchmarked to June 2014, which was an improvement from its 20th place in 2013 (Worldbank.org 2015). The energy industry contributes up to 20% of the total Malaysia's GDP.

The comparison between these fuels in terms of energy contribution for Malaysia are as shown in Figure 4 and Figure 5 with natural gas as the current biggest contributor. The fuel mix of Malaysia's energy supply from 1980 up to 2013 are oil, natural gas, coal and coke, hydropower, and renewable energy (Abdul Rahman Mohamed & Lee Keat Teong 2004; US EIA 2014).

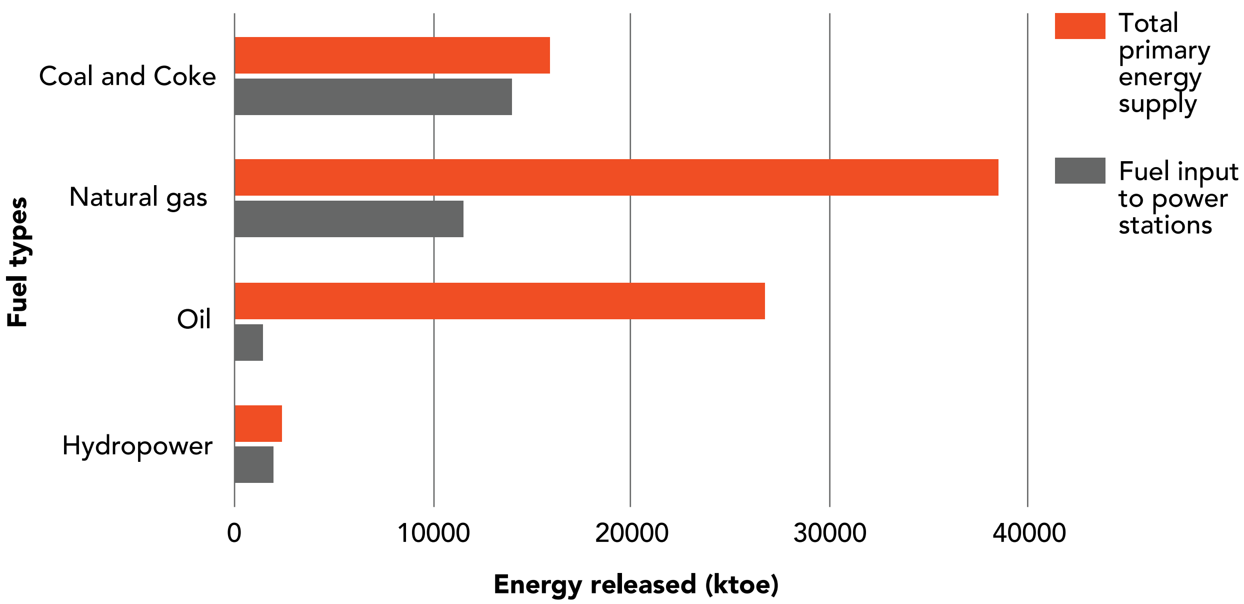


Figure 4. Comparison of fuel types for Malaysia's energy contribution in 2012

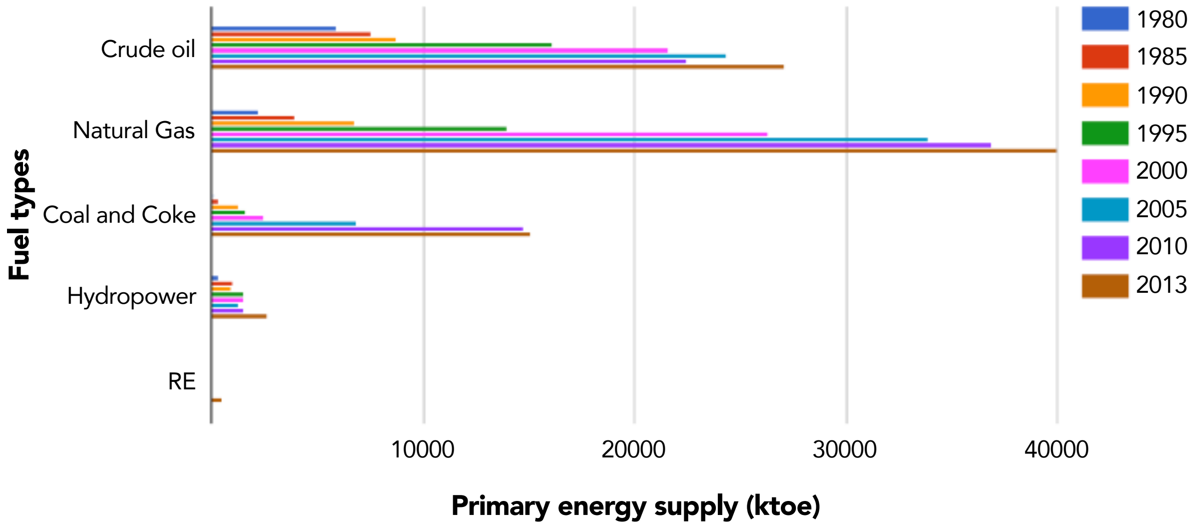


Figure 5. Malaysia's primary energy supply by fuel types

i. Oil

Malaysia is the second largest oil producer in Southeast Asia and listed in the world's top 25 highest oil-proved reserves. Figure 6 shows a comparison with several other countries in the region in terms of oil production and total consumption with oil as the source of energy (Lee 2015). Petroliam Nasional Berhad (PETRONAS), which is Malaysia's only firm listed in the Fortune Global 500, has the exclusive ownership rights to all oil and natural gas exploration and production projects in Malaysia. The national oil and gas company is the single largest contributor to the country's revenue in the form of taxes and dividends of nearly 45% with over 1000 petrol stations in operation. Malaysia's main trade is within Asia, especially with Singapore, and it exports crude oil mostly to Asia Pacific, namely Australia, India, Thailand, and Japan (Abdul Rahman Mohamed & Lee Keat Teong 2004; US EIA 2014).

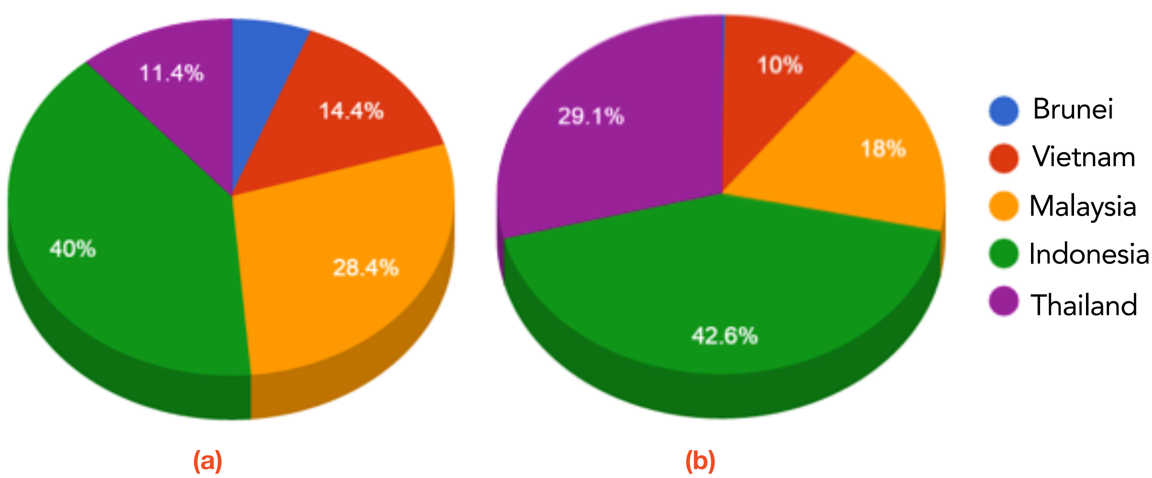


Figure 6. Malaysia in comparison to other Southeast Asian countries in
(a) oil production (2013-2014) and (b) total energy consumption sourced from oil (2013)

Oil is an important, albeit expensive, fuel source for power generation. The continuous increase in demands for crude oil and oil products in both regional and domestic markets and the gradual decline in production at major producing oil fields for the last decade due to maturing fields, as shown in Figure 7, have forced Malaysia to take the following important steps for the country's energy infrastructure development:

- Encouraging hydrocarbon investment in enhanced oil recovery and deep water marginal discoveries
- Increasing the capacity of oil refining and storage as preparation to become the region's oil trading and storage hub
- Enhancing oil exploration in existing deep water areas by new major upstream and downstream oil projects
- Diversifying fuels by optimising the fuel mix used in electricity generation with renewable energy (biomass, biofuel, solar energy, and wind energy) and alternative energy (nuclear and hydrogen energy) to reduce the country's over dependence on fossil fuel resources

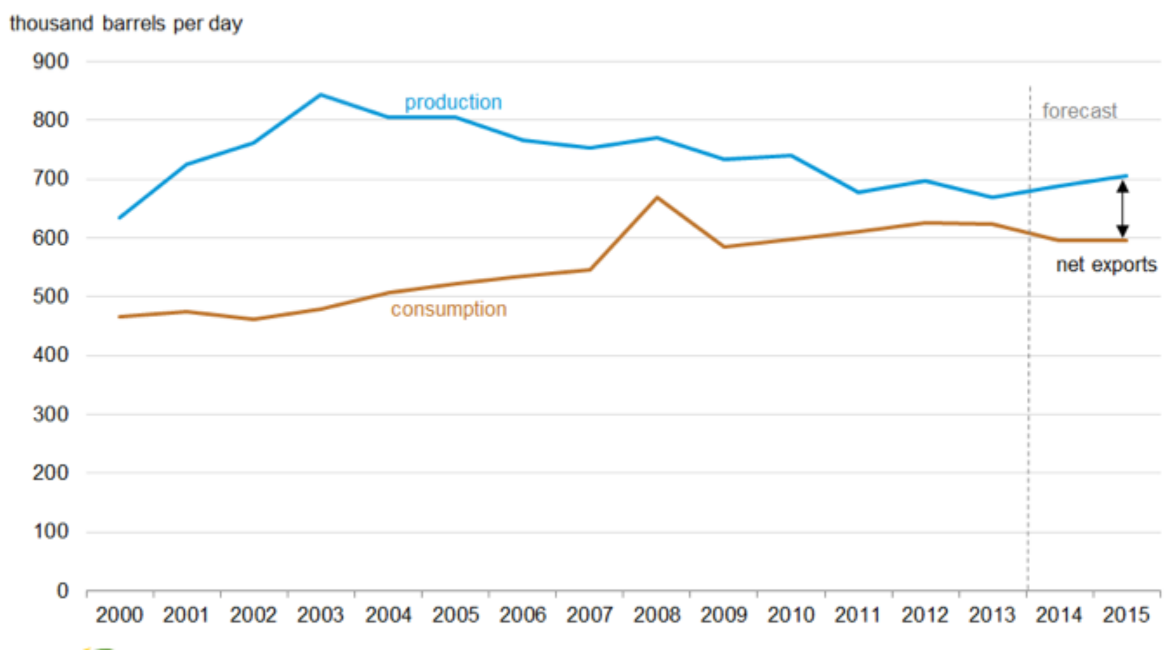


Figure 7. Malaysia's petroleum and other liquids production and consumption (2000-2015)

Source: US EIA 2014

Following the 1979 National Energy Policy, the National Depletion Policy was introduced in 1980 to protect the country's oil reserves from being exploited as the crude oil production rapidly increased. After the 1973 and 1979 international crisis, and due to Malaysia's reliance on oil as the main energy source at the time, fuel diversification has been pursued and reviewed regularly. This is to ensure that Malaysia will not be overly dependent on it for the purpose of energy security and reliability of cost-effective energy supply.

The 'Four-fuel Diversification Policy' came into effect in 1981. It focused on three more primary energy resources with relatively low and steady prices that were largely unexplored and abundant, which are natural gas, hydropower and coal.

ii. Gas

Natural gas accounted for about 53% of the country's total installed capacity and about 46% of the electricity generation in 2012 (Malaysia Energy Information Hub 2014). The PETRONAS LNG Complex in Sarawak, which is the largest producing state in Malaysia since 2005, is the world's largest production facility of liquefied natural gas (LNG) and produces 23 million metric tonnes every year (Malaysia Productivity Corporation 2014). However, domestic consumption usually refers to Peninsular Malaysia due to its high natural gas consumption with the main demand from the power sector of about 58%. With the current average daily production rate of around 6 bscf, Malaysia's natural gas resources should last for more than a couple of decades. Figure 8 shows a comparison between the natural gas resources and consumption by region (Enerdata.net 2015; Malaysiangas.com 2014).

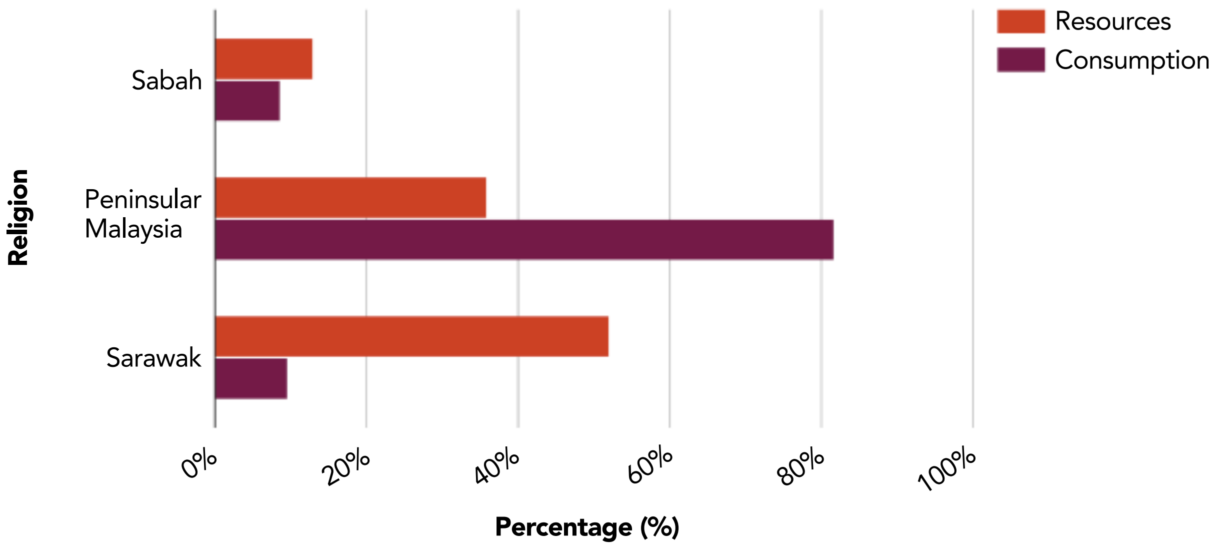


Figure 8. Natural gas resources and consumption by region, 2013

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's 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 9 shows the country's energy balance for natural gas in terms of its production, import, export, and consumption by Suruhanjaya Tenaga.

More than 1.2 Tcf/y of LNG was shipped, which is around 95% of the country's gas exports and 11% of LNG exports worldwide. The rest is in the form of piped gas to Singapore. Key importers for LNG are Japan (60%), South Korea (17%), Taiwan (12%), and China (11%). Export value of LNG is about RM59.2 billion worth, which is 8.2% of Malaysia's total export value, as illustrated in Figure 10. A link between ASEAN's major gas production and consumption centers by 2024 may see Malaysia as a hub for the Trans-ASEAN Gas Pipeline (TAGP) system. Natural gas consumption is predicted to grow faster than coal, nuclear, and hydro with the China market as the biggest player.

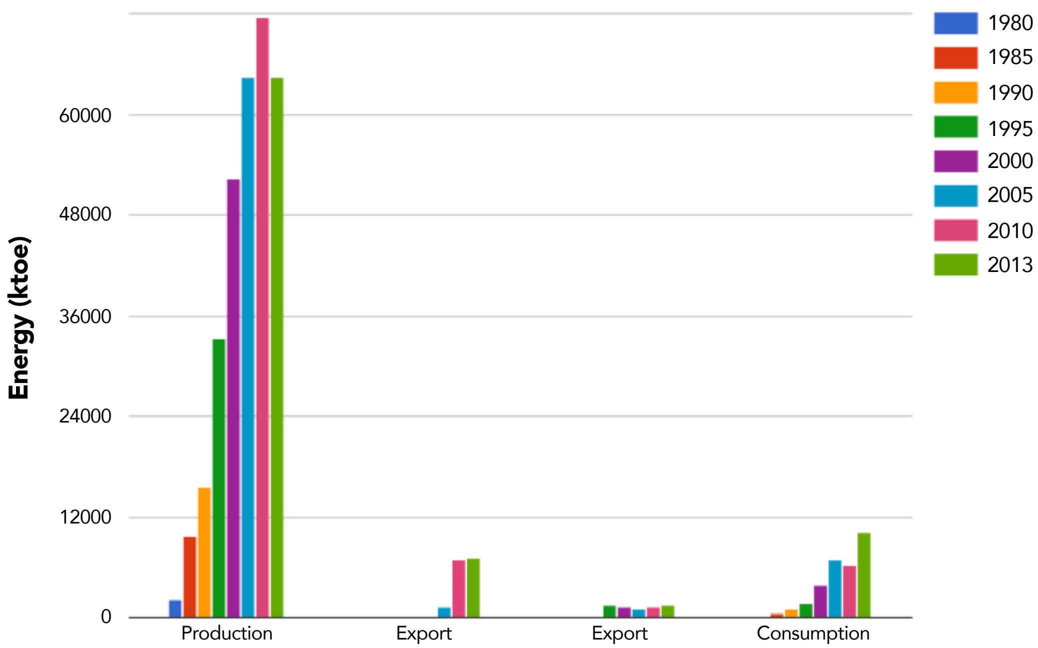


Figure 9. Malaysia's natural gas scenario

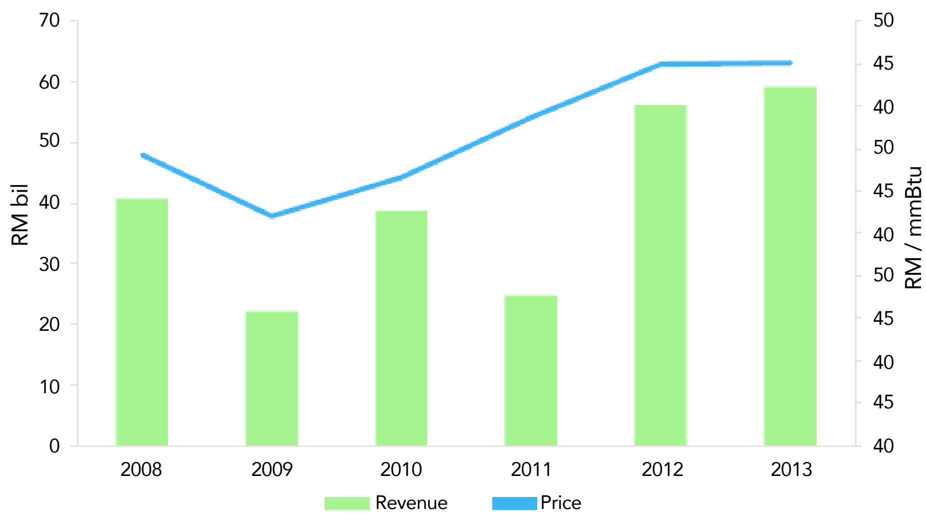


Figure 10. LNG Revenue and Price

Source: Malaysiangas.com 2014

iii. Renewable Energy

Renewable energy (RE) was included in Malaysia's energy mix as a crucial source of energy for electricity generation in the 'Five-Fuel Diversification Policy' in 2001 under the Eighth Malaysia Plan (2001-2005) and this policy is still continued in the Ninth and Tenth Malaysia Plans (2006-2010). The utilisation of RE is due to the increasing concern in the global community regarding climate change while nuclear energy was later introduced in the Tenth Malaysia Plan (Yahaya 2014). Legal, regulatory, and financial frameworks were then developed in the strategy development of RE as the Fifth Fuel.

The resources considered for RE include biomass, biogas, municipal waste, solar, and hydro. There are conflicts between crops for fuel and food due to insufficient arable lands to be used for planting, which creates uncertainties for large scale deployment of biofuels. Fiscal incentives under the 2001 Budget were mainly focused on biomass resources such as palm oil, wood residues, sugarcane bagasse, manure, and rice husks to generate heat and electricity.

RE contribution to electricity generation was only 12 MW in 2005 while the target of 300 MW in Peninsular Malaysia and 50 MW in Sabah for the Ninth Malaysia Plan was not achieved as only 41.5 MW was able to be contributed by the end of the year. In the Tenth 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).

Skepticisms regarding nuclear energy are mainly due to the fears of global nuclear energy expansion and international tensions, while negative effects of the recent Fukushima disaster changed people's perception of nuclear energy. Countries like Japan and Germany are putting considerable effort towards reducing nuclear energy production and increasing alternative energy sources. In Southeast Asia, Vietnam is the most active country that pursues nuclear energy, while the focus for Malaysia at this initial stage is still on feasibility studies, human capital development and public awareness campaigns. Only around 1 MW of electricity is currently generated from a small reactor in Bangi, Selangor for R&D purposes (Ahmad & Abdul-Ghani 2011).

Figure 11 shows a 20-year projected generation mix (excluding oil) for Malaysia's primary fuels (Yahaya 2014). Coal and natural gas will likely remain the major fuels for power generation despite some fluctuations throughout the years whereas RE, while still important, is currently perceived as the least impactful contributor to the mix as it is believed to unlikely be able to fulfill the required base-load. However, this perception needs to change as the RE projection is considered too low for Malaysia to reduce its carbon dioxide emissions in the future.

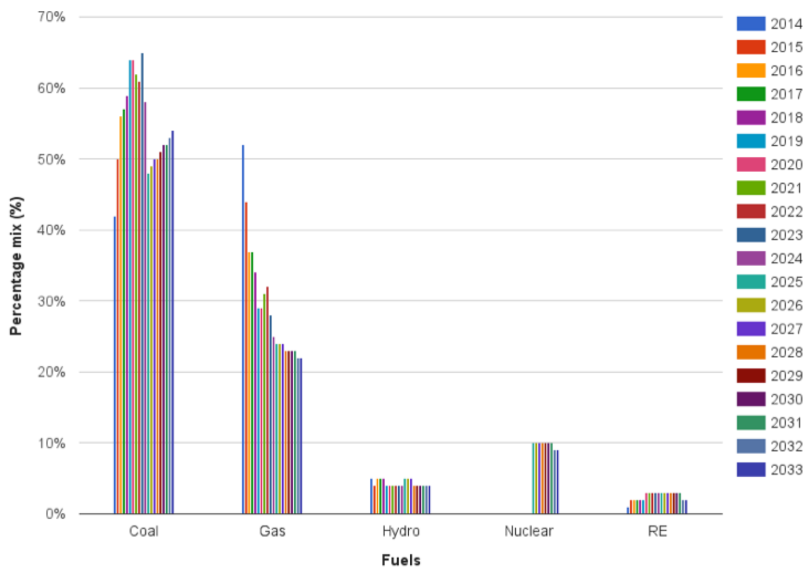


Figure 11. Projected generation mix for Malaysia's primary fuels (2016-2033)

Energy Acts, Policies, and Programs

There are vital needs for Malaysia to have greener technologies, cleaner fuels, and low carbon emission as it currently has very high carbon dioxide emissions, fuel depletion, and energy security issues. The largest contributors of GHG emission 1990-2007 in the country are the energy and transportation industries. Approximately 80-90 % of the total worldwide energy consumption is from fossil fuels while the energy demand in Malaysia is expected to increase from 2,000 PJ to 4,013 PJ around the 2009-2030 period.

The National Energy Policy established in 1979 has the primary role of guiding the development of the nation's energy sector in the coming years with principal energy objectives that cover the supply, utilisation, and environmental aspects of energy in Malaysia. Malaysia became a non-Annex I Party to the United Nations Framework on Climate Change in 1993 and the National Steering Committee on Climate Change (NSCCC) was formed in 1994.

The Intergovernmental Panel on Climate Change (IPCC) has proven time and again that anthropogenic GHG emissions, mostly carbon dioxide produced from energy production, cause global warming. Global nations have come together through the United Nations Framework Convention on Climate Change (UNFCCC) Conference of the Parties (COP) from the 1997 Kyoto Protocol in Kyoto, Japan to the latest 2014 COP 20 session in Lima, Peru in order to address the problems of climate change.

Malaysia ratified the Kyoto Protocol following the establishment of the National Committee Clean Development Mechanism (NCCDM) in 2002. The CDM is a flexible mechanism under the Article 12 of the Kyoto Protocol that mostly focuses on Renewable Energy (RE) and Energy Efficiency (EE) Projects.

At the United Nations Climate Change Conference 2009 in Copenhagen, Denmark and again at the UN Climate Summit in New York on 23 September 2014, Malaysia has declared its commitment towards reducing the carbon emission intensity of its Gross Domestic Products (GDP) in 2020 by 40% of its 2005 levels. Unfortunately, the recent 2014 update of the Malaysian Environmental Quality (Clean Air) Regulations does not specifically bring up the issues on carbon dioxide emission.

Malaysia has put in effort to incorporate several measures in terms of policies, acts, and programs as given below and they can be the starting platforms for formulating policies and regulatory actions that will specifically support and protect the fuel cell and hydrogen industries:

- National Green Technology Policy in 2009;
- National Renewable Energy Policy and Action Plan (NREAP) in 2010;
- Green Technology Financing Scheme (GTFS) 2010;
- Sustainable Energy Development Authority Act 2011 [Act 726];
- Renewable Energy Act 2011;
- Renewable Energy Feed-in Tariff (FiT) program in 2011; and
- Sustainability Achieved Via Energy efficiency rebate program (SAVE) in 2011.

The Economic Planning Unit (EPU) and the Implementation and Coordination Unit (ICU) under the Prime Minister's Department are tasked with formulating and overseeing the energy policies in Malaysia. The development of energy policies plays an important role in:

- Ensuring energy security, not just at the national level but also in all of the region;
- Encouraging the transition from energy based on fossil fuels to clean and renewable energies;
- Creating a platform for dialogues where experiences and best practices can be shared;
- Building appropriate energy frameworks; and
- Promoting overall industrial competitiveness

The Final Energy Demand was used as the EE Indicator and Malaysia aims for 8.6% reduction from business as usual by 2020 (Renewable Energy and Energy Efficient Partnership 2012). According to the Malaysian Prime Minister in his address to the 2014 United Nations Climate Summit, the country has achieved a reduction of up to 33% in emissions intensity of its GDP despite the lack of support from developed countries. Therefore, the remaining gap can be filled by developing the fuel cell and hydrogen industries.

Energy Agencies

A strong government commitment must be provided by the institutional setup and participation of relevant agencies shown in Table 1 with their specific roles in the energy policies and implementations in Malaysia.

Their important roles make them vital stakeholders that must play significant roles in establishing Malaysia's fuel cell and hydrogen industries.

Agency	Role
Ministry of NaturaL Resources and Environment (NRE)	• Appointed by the Cabinet as the Malaysian Designated National Authority (DNA) • Responsible for conservation and management of environment and shelters as well as natural resources management
Ministry of Energy, Green Technology and Water (KeTTHA)	• Monitors and facilitates energy programmes to ensure affordable energy for domestic consumers and to enhance green technology competitiveness
Business Council for Sustainable Development in Malaysia	• Promotes the business and industrial communities to be active participants in environmentally-driven projects
Energy Commission of Malaysia	• Promotes RE utilisation and non-RE conservation
Energy Development Authority of Malaysia (SEDA Malaysia)	• Promotes the competitiveness of sustainable and RE industries as well as be responsible for all the functions bestowed on it under the Renewable Energy Act 2011
GreenTech Malaysia	• Formerly known as Pusat Tenaga Malaysia (PTM) and now a non-profit organisation overseen by KeTTHA • Set up and maintains the RE database • Provides facilities and services in three main areas (advisory and consultancy, energy management, and training) in the effort to realise the national green technology agenda
Malaysia Electricity Supply Industry Trust Account (MESITA) fund	• Contributes financial assistance for rural electrification, energy efficiency and RE projects
Renewable Energy Fund	• Administered by SEDA Malaysia • Available under the Feed-in-Tariff (FiT) program
Environmental Research and Management Association of Malaysia (ENSEARCH)	• Provides training in various environmental areas
Centre for Education, Training and Research in Renewable Energy and Energy Efficiency (CETREE)	• Funded by KeTTHA • Conducts awareness programs regarding energy efficiency and RE for the public and specifically stakeholders in the energy community • Producing RE and EE modules for schools and universities

Achievements

The Malaysian fuel cell and hydrogen energy R&D community has published over 250 world-renowned scientific articles on fuel cells and hydrogen energy in high impact international journals. Malaysia's fuel cell experts have also delivered international keynote lectures and international invited lectures in various countries including Japan, Russia, and Iran. More than 50 patents in fuel cells technology and hydrogen energy had been filed and granted.

The Malaysian fuel cell teams have also garnered numerous international and invention awards in the fuel cells and hydrogen energy categories. However, the Malaysian industry is relatively slow to follow in the effort to develop the fuel cell and hydrogen industries due to the country's small domestic market reach and under-developed manufacturing capabilities.

1.1 HYDROGEN INFRASTUCTURE

State of the Art

Hydrogen is a viable alternative fuel source to fossil fuels and was introduced in the Eighth Malaysia Plan. Hydrogen is an odourless and colourless gas in its pure form. It is an energy carrier, like electricity, and not an energy source. Therefore, it does not produce energy but can be used to store and deliver energy that is later converted to usable forms.

It acts as fuel in power generation or transport by utilising fuel cells. Widespread use of hydrogen as a clean energy carrier can potentially be a real solution to problems regarding climate change, such as global warming, carbon emission and energy security. Table 2 shows some of the known advantages and disadvantages of hydrogen.

Table 2. Advantages and disadvantages of hydrogen

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 to form compounds, such as water
Contains more energy per weight compared to other energy carriers	Has relatively much less energy by volume
Generated from several domestic energy resources using various methods, and hence can be producedat large generation plants	Hydrogen produced from fossil fuels at the plants require sequestration and carbon capture technologies to reduce GH 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
May be stored as a high-pressure gas, a liquid, 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 energy, which has a great promise of zero emission, is unfortunately constrained by its high costs and low durability. Public perception also remains an obstacle regarding safety issues on hydrogen transport and storage despite it being vouched by safety professionals as safer than the liquefied petroleum gas (LPG) used in the kitchen and gasoline or petrol used in vehicles in terms of risk of explosion from a leakage. This is due to its buoyancy and ability to rapidly disperse when released in air. There are two considerations for hydrogen infrastructure:

1. Hydrogen as fuel for transportation; and
2. Hydrogen used for electricity generation

Methods of hydrogen production from fossil fuel sources include; steam methane reforming, coal gasification, and water splitting by electrolysis. The fastest way of using hydrogen would be through hydrogen-adapted combustion technologies, and major companies that produce energy or power technologies are looking into using hydrogen for combustion in gas turbine or other combustion-related technologies. Table 3 gives the conversion of various feedstock to 1 kg of hydrogen, which is the amount of hydrogen that can potentially displace 4.35 kg of gasoline (Milbrandt & Mann 2009) and is described as 1 gallon of gasoline equivalent (gge).

Table 3. Conversions for hydrogen production from various feedstock

Feedstock	Hydrogen production (1 kg)
Coal	7.6 kg
Natural Gas	4.5 m^3
Water	11.36 kg (average)

Natural gas can be utilised as the feedstock before the changeover to renewables-based hydrogen is completed. Coal is a cheaper alternative for feedstock. However, Malaysia import 90% of its coal because of the high cost of extraction for coal sourced domestically due to the remote locations of the reserves, making coal gasification for hydrogen production unfeasible in Malaysia. Coal gasification also generates twice the amount of carbon emissions compared to natural gas reforming. The current preferred method by the industry to produce industrial grade hydrogen is steam methane reforming (SMR) from natural gas (NG). The following three hydrogen production options are considered commercially viable due to cost and technological considerations. The location is off-site when hydrogen needs to be delivered to the refueling station and on-site when hydrogen is produced at the refueling station:

I. Steam methane reforming (SMR) technology with carbon dioxide capture and storage (CCS) method

- Resource required: natural gas. Location: on-site and off-site. Storage method: liquid and gaseous hydrogen on-site.

The SMR method currently produces almost 48% of worldwide hydrogen and is the most economical and commercially available method for hydrogen production. It is still used mainly as feedstock for chemical synthesis in chemical plants or upgrading of crude oil quality in refineries. Some advantages of the SMR method:

- Natural gas has a high hydrogen content;
- Natural gas distribution network already in existence; and
- Hydrogen production costs can be managed by planning out the production scale.

The map of gas utilisation network and in the Peninsular and the distribution network in Sarawak are shown in Figure 12(a) for the off-site hydrogen production considerations. The map of refueling stations for natural gas vehicles (NGV) by states is given in Figure 12(b) for the on-site hydrogen production considerations. The number of existing NGV refilling stations in operation is quite low, i.e., 177, with most of them located in the Klang Valley and only 5 stations are available on the east coast of the Peninsular Malaysia. PETRONAS is the sole operator of these stations and its wholly owned subsidiary PETRONAS NGV Sdn. Bhd. (PNGV) supplies natural gas for the NGV. However, the low regulated pump price due to subsidy still incurs negative margin and drives other suppliers away from the NGV market.

SMR mainly consists of two steps and the equipment required for the process must be taken into consideration when planning the hydrogen production facility at the on-site and off-site locations:

i. **The first step** is the methane reforming, which is an endothermic reaction. The catalyst, usually nickel (Ni), is used at elevated temperature of 500-900°C and pressure of 30 atm to produce carbon monoxide (CO) and hydrogen (H_2): $CH_4 + H_2O \Leftrightarrow CO + 3H_2$; $\Delta H = +206$ kJ/mol.

ii. **The second step** is the water gas shift reaction (WGSR), which is an exothermic reaction. CO reacts with steam (H_2O) to produce H_2 and carbon dioxide (CO_2): $CO + H_2O \Leftrightarrow CO_2 + H_2$; $\Delta H = -102$ kJ/mol.

The purification process can be commercially carried out with a pressure swing adsorber (PSA) to obtain nearly 99.99% pure hydrogen. A production capacity of 10.7 x 1010 kg of hydrogen is estimated to deliver about 410 TWh at full utilisation.[1]

1 *This is equivalent to 660 thousand barrels of crude oil or 1.4 trillion cubic feet of natural gas per day (US EIA 2008).*

Due to the carbon dioxide by-product, the SMR method requires the carbon sequestration method, or CCS, to reduce its carbon emissions by storing them in underground geologic formations. Although it adds to the cost of hydrogen, a reduction in atmospheric carbon emissions of around 85% is possible with CCS technology (Board on Energy and Environmental Systems 2014).

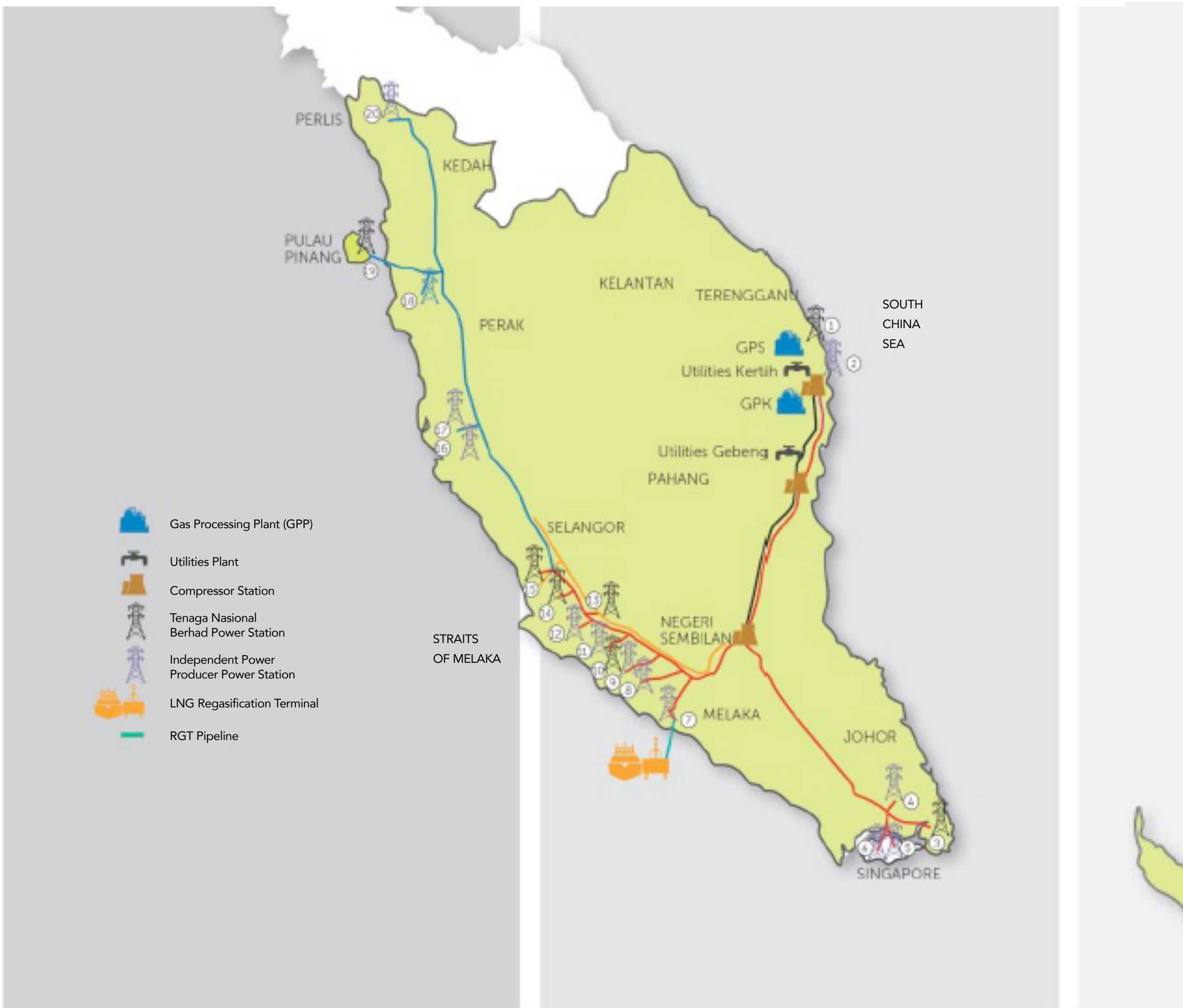
Large incremental investments for deploying CCS, especially for the initial CCS projects, are high and depend on factors such as the type of capture technology and fossil fuel used, location of the geologic storage, and percentage of captured carbon dioxide. The high capital and operating costs are due to the additional carbon capture equipment, while the additional amount of useful electricity required by the capture equipment can decrease the net power output of the plant considerably.

A 2010 data from the National Energy Technology Laboratory (NETL) shows that the cost of CCS for leveled cost of electricity (LCOE) of a newly build 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- USD46.12 per metric ton, while the Environmental Protection Agency gives an estimate of USD15 per metric ton for the long-term average cost of carbon transportation and storage.

Around the world, there are currently 14 large-scale CCS projects listed as in operation with 8 still under construction, which represent a total carbon capture capacity of around 40 million tonnes per annum. Various CCS projects are under development in several countries with a total carbon capture capacity of around 64 million tonnes per annum. However, Malaysia is not yet in this list. CCS is still a relatively expensive technology. Captured carbon dioxide can potentially bring in revenue from enhanced oil recovery (CO2-EOR) projects, as has been done in West Texas, US for more than 30 years. The CO2-EOR activities may offset the high costs and lessen the financial risks for early adopters of CCS projects (Global CCS Institute 2015). One of the ongoing Malaysian EOR projects, and one of the largest in Southeast Asia, which can participate in future CO2-EOR studies is the Tapis project led by ExxonMobil in partnership with Petronas.

Hydrogen production can be in a centralised or distributed mode. For the centralised mode, decarbonising the hydrogen production process is the main question when industrial hydrogen is produced at a large scale from fossil energy sources. The CCS method has not been commercially proven successful for this purpose and a lot of R&D effort must still be expended for it in terms of hydrogen purification and gas separation. Large market demand of hydrogen and pipelines for carbon dioxide storage are also required. Renewable-based sources are also considered, as they are sustainable carbonless alternatives for hydrogen production.

Both natural gas and water electrolysis processes can contribute to the distributed mode. Their existing infrastructure, i.e. natural gas and hydro, can also be utilised and this reduces the initial investment required for the transportation or distribution aspect in the hydrogen infrastructure. An underground system of (10 x 3 x 3) meters may be an optimum option to produce hydrogen of up to 500-700 Nm3/hr. However, this large space required to produce hydrogen is considered as relatively unfavorable (OECD & IEA 2006).

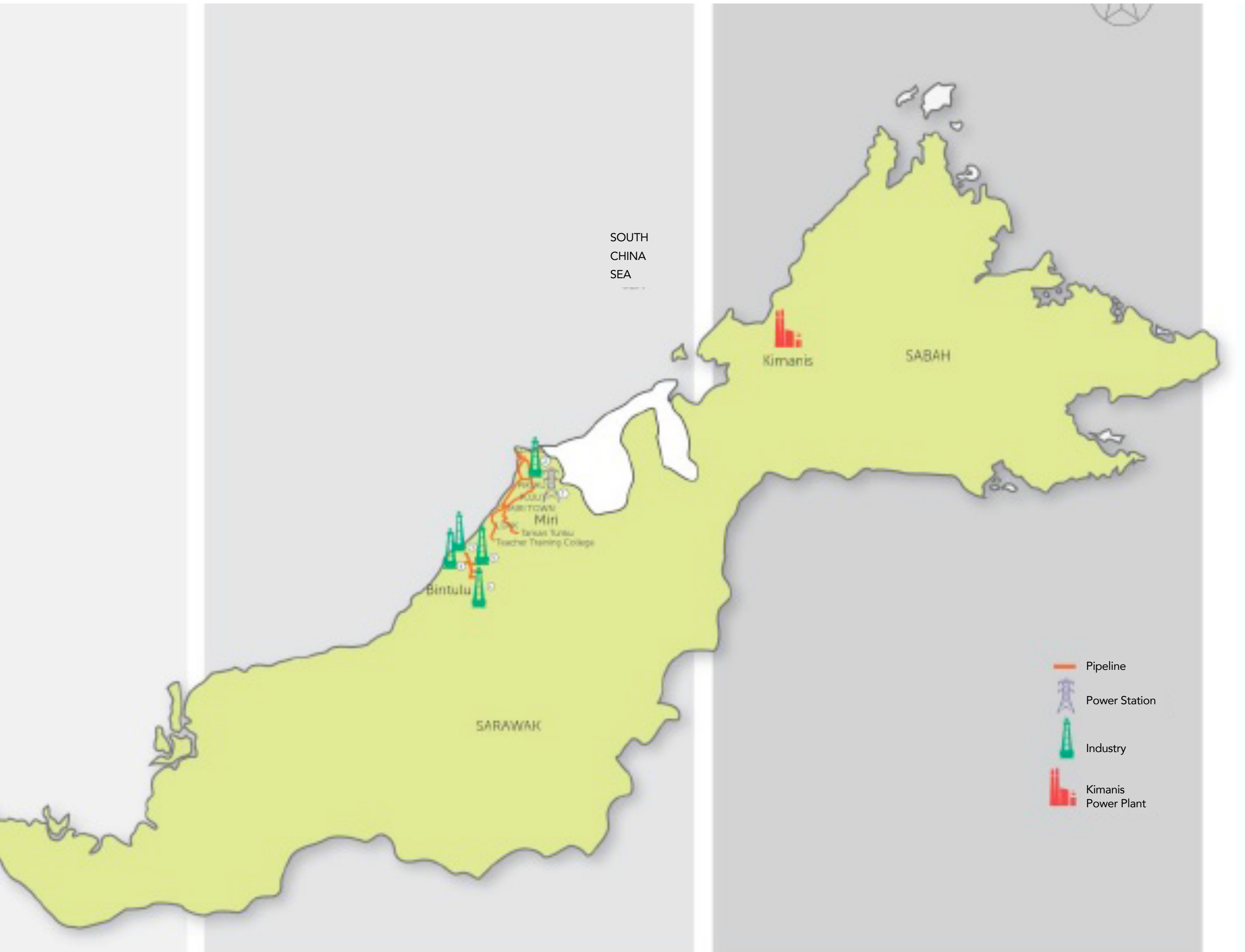


PGB Total Pipeline Length (In operation)	
Main	1,658 km
Lateral	374 km
C2, C3 and C4	357 km
GPP Interconnect	116 km
Sarawak	45 km
RGT	33 km
Total	**2,583 km**

Complex	GPP	Capacity mmscfd
GPK	1	310
	2	250
	3	250
	4	250
GPS	5	500
	6	500
	Total	**2,060**

Sales Gas Customers

1. TNB Paka
2. YTL Paka
3. TNB Pasir Gudang
4. YTL Pasir Gudang
5. Senoko Energy
6. Keppel Gas
7. Pahlawan Power Tg Kling
8. Panglima Power Teluk Gong
9. Powertek Teluk Gong
10. TNB Tuanku Jaafar
11. Port Dickson Power
12. Genting Sanyen Power
13. TNB Serdang
14. TNB Connaught Bridge
15. TNB Kapar
16. GB3 Lumut
17. Segari Energy Ventures
18. Prai Power
19. TNB Gelugor
20. Powertek Tenaga Perlis Consortium



Main Pipeline	
PGUI 32 km	
Kerteh - Teluk Kalong	1984
PGUII 685 km	
Sector I : 233 km Teluk Kalong - Segamat	1991
Sector II : 241 km Segamat - Kapar	1991
Sector III : 211 km Segamat - Singapore	1991
PGU III 450 km	2001

Main Pipeline	
Sector I : 384 km Meru - Lumut	1996
Sector II : 176 km Lumut - Gurun	1998
Sector III : 90 km Gurun - Pauh	1998
Loop 1 265 km	
Kertih - Segamat	1999
Loop 2 226 km	
Segamat - Meru	2001

Sales Gas Customers

1. SESCO Miri Power Station
2. Sarawak Gas Distribution System
3. Bintulu Edible Oils Sdn Bhd
4. Syarikat Sebangun Sdn Bhd
5. Sime Darby Austral Sdn Bhd
6. Bulkers Sdn Bhd

Figure 12(a). Map of Gas Utilisation Network in the Peninsular and Distribution Network in Sarawak

Figure 12(b).
Number of NGV Stations by States
Source: Malaysiangas.com

II. Recovery of hydrogen from oil refinery off-gas

- Resource required: oil. Location: off-site. Delivery method: tanker-truck liquid hydrogen delivery to the hydrogen refueling station. Storage method: gaseous hydrogen.

According to the Hydrogen Analysis Resource Center of the US Department of Environment (D.O.E), Malaysia's capacity of refinery hydrogen production is consistently at 147.2 MMSCFD for 2005-2014. In 2011, the Oil & Gas Journal reported that with an annual crude oil production of more than 650,000 bpd, Malaysia's total crude oil refining capacity was estimated at about 722,000 bpd (Malaysiaoilrefinery.com 2013). In Malaysia, large tonnes of hydrogen are emitted in refineries such as the ones in Port Dickson, Melaka, Kerteh, Tanjung Pelepas, and Pengerang. Hydrogen is also a by-product in petrochemical operations such as ethylene and propylene productions.

Table 4 shows the location of existing and operational oil refineries in Malaysia. Hydrogen in oil refineries is produced by: (a) large hydrogen plants that source from natural gas or other hydrocarbon fuels and (b) hydrogen generated during the refinery process itself[2]. An oil refinery contains several units that contribute to making up the refinery off-gas (ROG). A Fluidised Catalytic Cracking Unit (FCC) is used to break the long chain hydrocarbon molecules into lower molecular chains, i.e., lighter hydrocarbon components. The typical FCC composition for the hydrogen component in ROG is 10-50 mol% (Malik & Slack 2009).

Hydrogen is converted using off-gases from various refinery unit operations and purity of 99.9% or higher can be extracted using a PSA unit. Impurities contained in the off-gases, such as sulfur and arsenic, can be removed by adsorption method using high capacity sorbents as they can poison the catalysts used in the conversion. A low steam to carbon ratio design (typically 2.5 mol H2O/C-atom or lower) for a hydrogen plant can result in smaller equipment size, which reduces the capital cost, and in a more energy-efficient plant, lowers the operating costs (Rostrup-Nielsen & Rostrup-Nielsen 2001).

For an industrial hydrogen unit that works about 80% of the time, it is expected to produce 420,000 kg/day of pure hydrogen for usage[3]. To reduce transportation and storage costs, construction of the hydrogen plant can be co-located with the end users.

2 Hydrogen is used in refineries to desulfurise fuels such as diesel (hydrodesulphurisation process). From a 2010 data, an oil refinery was estimated to consume a total of 12.4 billion standard cubic feet hydrogen per day (or 12,400 million standard cubic feet per day = 10,529,477,821.01 kg (petrol) per hour), i.e., an average hydrogen consumption of 100-200 standard cubic feet per barrel of oil processed (Xebec Adsorption Inc.2015

3 By assuming that a hydrogen purity of 99.99% can be obtained using the PSA method, a flow rate of 3733.86 kg-mol/hr refinery off-gas is required as feed into an industrial hydrogen unit to obtain 21,000 kg/hr of hydrogen using the SMR reactions (Bal 2013).

Table 4. Location of Oil Refineries in Malaysia

OIL REFINERIES	LOCATION	BARRELS PER DAY (NPD)
Petronas Penapisan (Terengganu) Sdn Bhd	Kertih, Terengganu	440, 000
Petronas Penapisan (Melaka) Sdn Bhd	Tangga Batu, Melaka	
Malaysia Refining Company Sdn Bhd	Tangga Batu, Melaka	
Shell Refining Company (FOM) Bhd	Port Dickson, Negeri Sembilan	156, 000
Petron Malaysia Refining & Marketing Bhd	Port Dickson, Negeri Sembilan	88, 000
Kemaman Bitumen Refinery	Telok Kalong, Terengganu	25, 000

Source: Malaysian Investment Development Authority (MIDA) 2013

III. Hydrogen production from renewables (OTEC, wave/tidal/current, and solar power

- Resources required: water and solar
- Location: on-site and off-site
- Storage method: gaseous hydrogen on-site and liquid hydrogen off-site

Purified hydrogen can also be used in fuel cells for major applications such as portable (laptop & mobiles), stationary (UPS & small homes), smart grid connection (distributed power), and transportation (cars & buses) applications. However, the fuel cell and hydrogen supply chain can be made more attractive by eliminating carbon emissions with sustainable hydrogen from renewable sources, such as ocean thermal energy conversion, wave/tidal/ current, and solar.

i. Ocean thermal energy conversion (OTEC) energy

The difference in heat energy between warm surface water and cold deep-sea water of the ocean, i.e., about 20°C temperature difference, is utilised in the OTEC process. Very large pipes, i.e., about 1 km long with diameter of a few meters, 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: $2H_2O \rightarrow 2H_2 + O_2$ (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 plantship. Hydrogen is then delivered to the facilities at the port in liquid form to be used primarily as transportation fuel (Vega 2010, 2013). The surface seawater may potentially be evaporated and turned into fresh or potable water of high quality.

ii. Wave/tidal/current energy

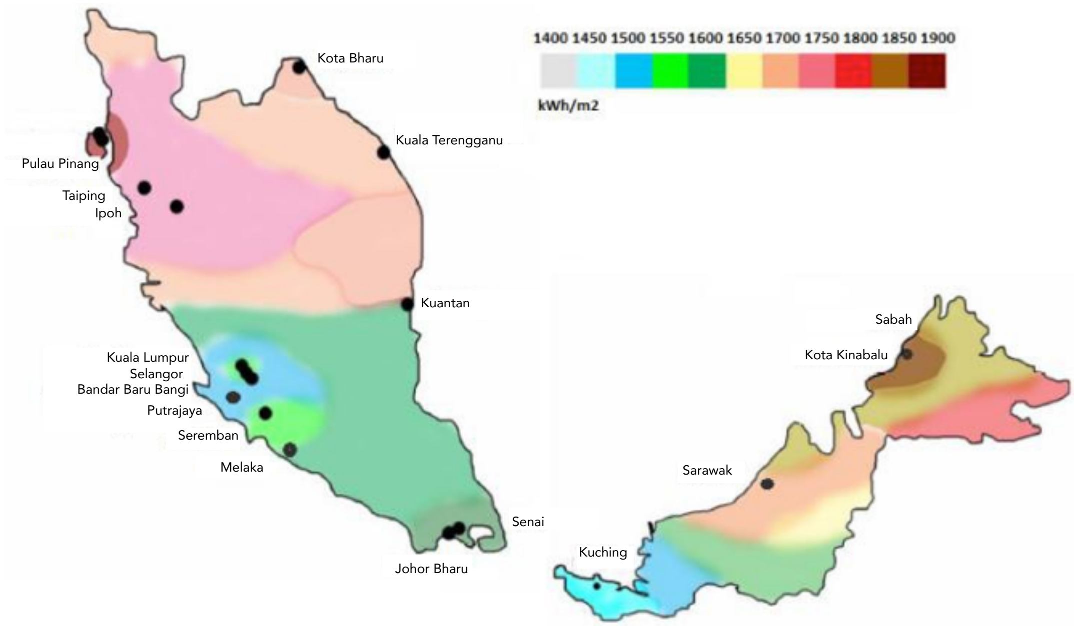
A barrage, such as a dam, is built to block the incoming and/or outgoing wave/tidal/current of water, which is then channeled through a turbine and converted into electricity using a generator. The electricity produced is then used in an electrolysis process to generate hydrogen. Wave/tidal/current energy 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.

iii. Solar energy

Solar conversion techniques to produce hydrogen mainly uses these processes:

- Thermal (thermolysis): thermochemical reactions to produce hydrogen driven by the heat produced from concentrated solar power (CSP);
- Photoelectrochemical (photolysis): biological or electrochemical reactions that produce hydrogen using solar photons; and
- Electrolytic (electrolysis): water electrolysis using electricity and is capable of producing pure hydrogen of 108.7 kg of hydrogen from 1 m3 of water.

Figure 13 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 electrolysers. 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 can run about 16000 km/yr with their 6 kW solar panel system (Crosse 2014).



(a)

Town/Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Average
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	764.	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

(b)

Figure 13. Solar energy potential in Malaysia:
(a) Solar irradiance map of Malaysia and
(b) Average yearly solar irradiance, kWh/m2 per day

Sources: Hussin et al. 2012; Akorede et al. 2012

The technical barriers faced in the hydrogen infrastructure development are in terms of the production, delivery, storage, and customer interface. While on the vehicle side, on-board hydrogen storage remains a significant challenge to overcome. Road Transport Act 1987, i.e., with amendments up to 2006, says that the Minister charged with responsibility for transport will regulate the use of any type of fuel for propelling motor vehicles, and this will include hydrogen when it is used as fuel for fuel cell vehicles (FCVs) in the future. Therefore, local policies, regulations, and safety mechanisms and measures that are compatible with global standards need to be realigned and formulated.

A vital building block in the hydrogen infrastructure for transportation is the hydrogen refueling station. Figure 14 shows the map of hydrogen refueling 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 refueling 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 14. Map of hydrogen refueling stations in Asia

Source: Netinform.net 2015

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

i. Equipment: hydrogen production (on-site), purification, safety, as well as mechanical and electrical operations; and

ii. 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 add a significant amount to the capital investment due to the production equipment.

In the transportation sector, hydrogen used as fuel for light-duty vehicles (< 3,000 kg) or heavy-duty vehicles (> 3,000 kg) can be supplied to the fueling stations by the following methods:

I. Tanker-truck delivery

A preliminary study on the potential usage of hydrogen as fuel for light duty vehicles (LDV) in the Peninsular was carried out in 2009 by mapping the existing fossil fuels delivery chain, i.e. petrol and diesel, onto hydrogen (Kamarudin et al. 2009).

Basing the hydrogen demand on fuel supply surveyed from local petrol stations was deemed more accurate than assuming it as a function of total vehicle numbers, average total distance traveled and vehicle fuel economy. Table 5(a) shows the projected daily demand of hydrogen for every state in the Peninsular and 18 hydrogen plants[4] throughout the Peninsular will be required to meet this demand.

The cost of the hydrogen network for type of production plant, storage unit and transportation mode is shown in Table 5(b). The water electrolysis method of producing hydrogen is much more costly than the SMR method due to the electrical power it requires. Compressed hydrogen gas is less costly to produce than liquid hydrogen due to the expensive dilution process. However, liquid hydrogen is less costly to be transported due to the much larger capacity of a tanker-truck, which requires less trips for delivery. The cost index calculated for Malaysia using this model is very high at USD384 x 1010 as the technology to develop and sustain the hydrogen infrastructure need to be imported. However, this cost can be significantly reduced when Malaysia has successfully developed strong ties with the global hydrogen network in the future.

4 The total amount of fuel capacity supplied daily by local petrol stations was recorded as 8.54 x 106 L/day for petrol and 4.16 x 103 L/day for diesel, while the production capacity of a hydrogen plant was assumed to be 150 x 103 kg/day

Table 5. Projection in the transportation sector for: (a) daily demand/target of hydrogen for every state in the Peninsular and (b) costs for production and storage to fulfill the hydrogen network demand

State	Population/state	Population/total population	Demand (kg/day)
Johor	3,029,300	0.1487	396,543
Kedah	1,813,100	0.089	237,339
Kelantan	1,479,700	0.0726	193,697
Melaka	700,100	0.0344	91,645
Negeri Sembila n	929,600	0.0456	121,687
Pahang	1,399,500	0.0687	183,198
Perak	2,225,000	0.1092	291,258
Perlis	221,200	0.0109	28,956
Pulau Pinang	1,442,800	0.0708	188,866
Selangor and Putrajaya	4,613,900	0.2265	603,971
Terengganu	990,600	0.0486	129,672
W.p Kuala Lumpur	1,529,000	0.075	200,150
Total	**20,373,800**	1	2,666,983

(a)

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

(b)

Source: Kamarudin et al. 2009

II. Pipelines specific for hydrogen

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 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 vaporised 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, for example, using the 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 300-30 psi is estimated to cost from USD0.3-1.3 per kg hydrogen for a 10% hydrogen blend.

III. On-site production

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

Therefore, 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 their plans to provide 'a fully-integrated hydrogen fueling infrastructure' in order to support Toyota's fuel cell electric vehicle (FCEV) entry into the northeast United States. It was claimed that the stations will have a fueling 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 is 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.

Initiatives in Malaysia

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 order to contribute to the required GHG emissions reduction that the country aspires to. Table 6 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 6. Transition steps towards Hydrogen Economy

Issues	Transition steps
Transportation	• National and international codes and standards for hydrogen use • Safety issues regarding hydrogen usage
Technical know-hows	• 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 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.

In an effort to take up this challenge, Pusat Tenaga Malaysia released the document "Roadmap for Solar, Hydrogen and Fuel Cell Research and Development Directions and Markets in Malaysia" in 2005 on behalf of the Ministry of Energy, Water, and Communications, Malaysia for the Government of Malaysia. This effort was assisted by the then Chairman of the National Solar, Hydrogen and Fuel Cell subcommittees and funded by the Malaysia Electricity Supply Industry Trust Account (MESITA). Figure 15 shows the first half of the 2005 roadmap, which focuses on hydrogen.

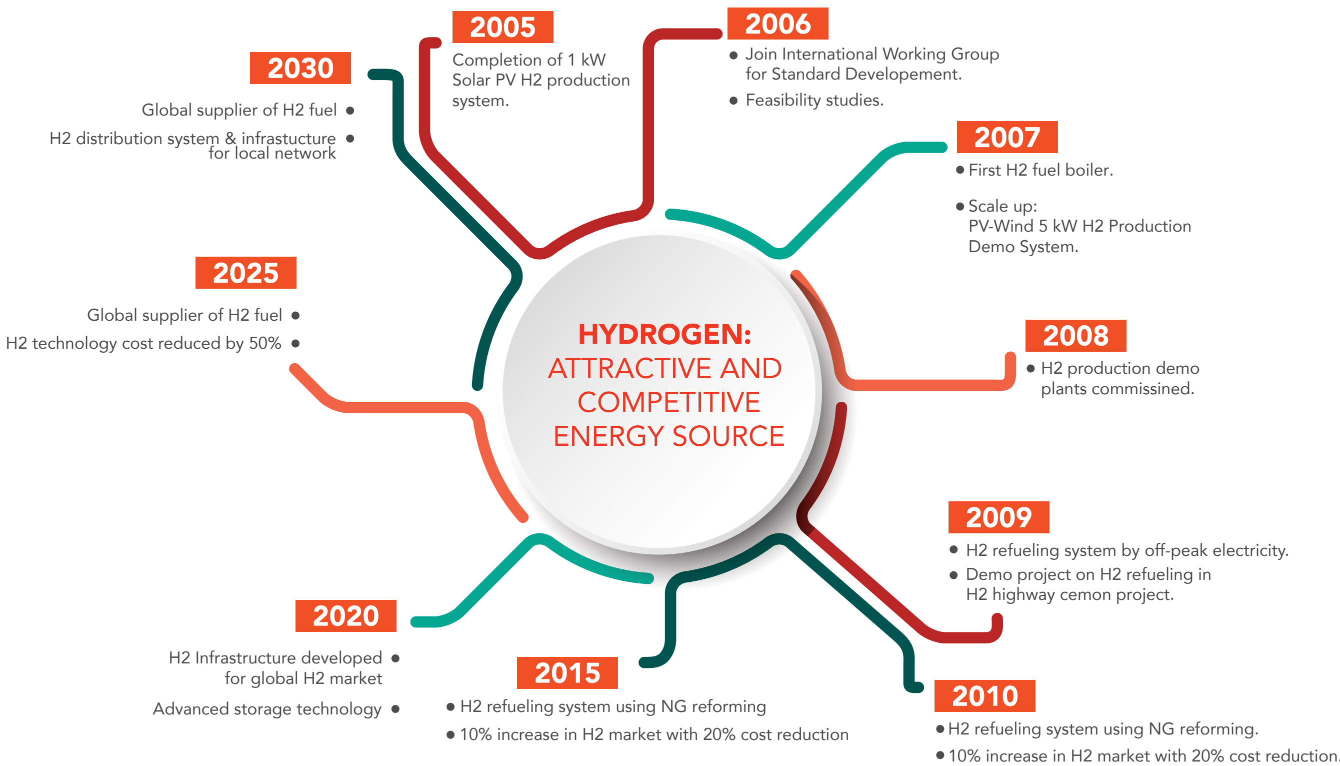


Figure 15. Malaysia's hydrogen roadmap 2006

Source: Daud 2006

The Roadmap assesses the role of hydrogen, solar and fuel cell in future renewable energy system and some recommendations have been successfully included for the policy in the Ninth Malaysia Plan. The policy specifies that activities such as technology development and knowledge sharing regarding solar, hydrogen and fuel cells will be put into effect while exploring financing mechanisms.

Pioneering work was carried out by Malaysia's researchers on process system engineering of a fuel cell system with balance of plant that include hydrogen production by steam reforming of methanol or natural gas, hydrogen purification using partial oxidation, pressure swing adsorption, membrane gas separation and humidification of feed air and hydrogen. Proto-types of the hydrogen-fuelled PEMFC stacks and demonstrations of fuel cell powered motorcycle and air-condition system for buses were also produced. Mechanisms, tools, and equipment were developed to support the work on PEMFC, for example, efficient catalysts were studied for the steam reforming process. A new solar hydrogen eco-house with solar photovoltaic cells and PEM electrolyser for hydrogen production was also demonstrated, along with nano-porous ceramic membrane reactors for steam reforming of methanol and methane.

The hydrogen infrastructure considerations certainly require major investments; however, such investments are absolutely 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, an exceptional level of relentlessly coordinated and sustained commitment by a myriad of stakeholders, which will comprise industry practitioners and technical experts from private and public organisations, who share a common vision for the hydrogen economy is imperative.

1.2 FUEL CELLS APPLICATIONS

State of the Art

The Ministry of Science, Technology and Innovation (MOSTI) and other relevant agencies have recognised Fuel Cell as an important field of study and awarded grants to universities and companies in Malaysia to conduct critical works in the field. At the national level, fuel cell applications are currently seen as important energy conversion devices with a considerable potential in the Malaysian future energy structure.

Fuel cells are highly efficient static electrochemical devices that convert the chemical energy from a fuel directly into electrical energy with low or zero carbon emission. They have been attracting more and more attention worldwide in recent decades due to the depletion of fossil-fuel resources, energy security and high demand in energy, and the adverse impacts that anthropogenic greenhouse gas (GHG) emission has on climate change. There are currently four main geographic regions of fuel cell adoption shown in Figure 16: Asia, Europe, North America and the Rest of the World (RoW).

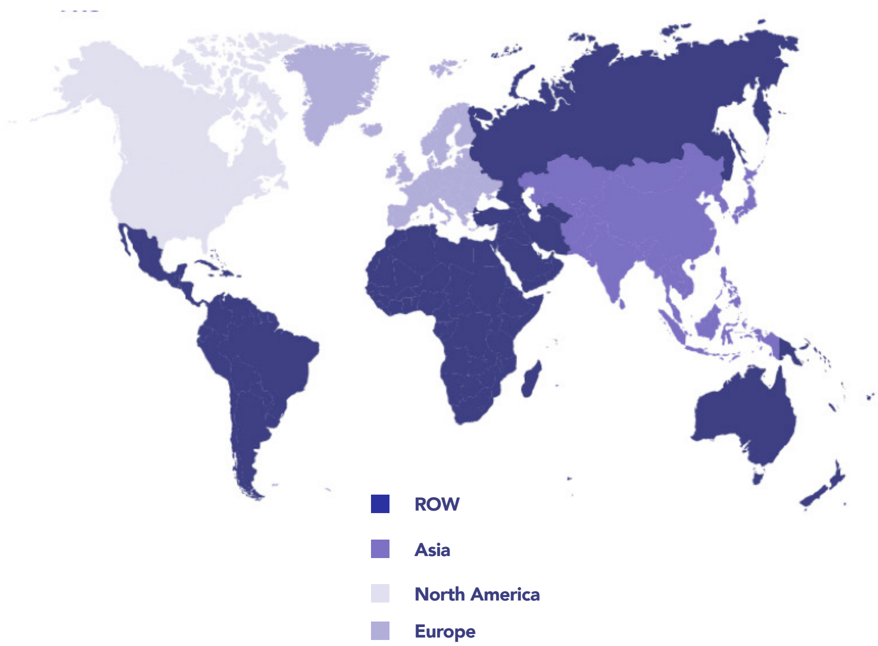


Figure 16. Main geographic regions of fuel cell adoption

Source: E4tech. 2014

There are three major markets for fuel cell industry applications, as given in Table 7, and different fuel cell applications dominate different market segments. Figure 17 shows the global market according to fuel cell types in the year 2009-2014. Polymer Electrolyte Membrane Fuel Cell (PEMFC) and Direct Methanol Fuel Cell (DMFC) are currently attracting interest in terms of R&D and commercialisation due to their high efficiency. The type of polymer electrolyte membrane used determines the operational temperature of PEMFC from a temperature range of 60-100°C up to 120 -140°C, while DMFC usually operates at ambient temperature of up to 120°C. PEMFC is typically used in the stationary sector such as stand-alone backup power units and residential micro-CHP systems at 700 W and 1 kW of power, while transport applications use 80-100 kW PEMFC units. It is currently the leading type shipped by number of units in 2014.

The 50-100 W DMFC unit shipments are typically in the portable and backup and off-grid applications such as mobile phones and laptops. Molten Carbonate Fuel Cell (MCFC) and Phosphoric Acid Fuel Cell (PAFC) types, with power of up to 300 kW, have already been commercialised as large stationary systems for prime power or Combined Heat and Power (CHP) at multi Megawatt scale. Solid Oxide Fuel Cell (SOFC) is made of ceramic and can operate at up to 1000°C with very high efficiency in CHP. As it can use fossil fuel such as such as synthesis gas, natural gas (NG), or even petrol directly, it can also function as a reformer. SOFC unit shipments are mainly for the residential micro-CHP segment in Japan and Europe.

In terms of market segment, Asia gives the largest shipment in 2009, whereas the US shipment has fluctuated due to change in policies. However, the US represents the biggest Megawatts by application due to the implementation of stationary central power, while Asia and Europe have employed fuel cells largely for small applications. The highest growth in 2013-2014 for the US is in material handling equipment and vehicles for large warehouses of giant retailers, whereas the deployment of fuel cells in the European market is for consumer electronics, backup power and stationary CHP units, along with fuel cell buses and cars. Germany leads the market and promises to increase the numbers of hydrogen refueling stations in the future.

Table 7. Major markets for fuel cell industry applications

Major MarketsM	ain Types	Operation
Stationary power • Operated at a fixed location to supply electricity or heat.	PEMFC	• High operating temperature up to 120-140°C • Applications such as auxiliary power units (APU) and CHP at 0.7 kW-1 kW
	PAFC	• Operates at temperature of up to 200°C • Supply power at ~ 400 kW
	MCFC	• Operating temperature is ~ 650°C • Used in large stationary systems such as for unit power for homes at 0.5-5 kW and CHP at ~ 300 kW
	SOFC	• High operating temperature of up to 1000°C with very high efficiency in CHP • Applications such as distributed generation or central power plant at ~ 5 kW-10 MW • Ceramic-based technology and can directly use fossil fuel resources such as natural gas and petrol as fuel. It can also function as a reformer.
	AFC	• Operates at ~ 23-70°C up to 100-250°C • Used for space and submarine applications
Portable power • Applications with fuel cells that are impermanent installation or with the fuel cells installed permanently in mobile devices.	DMFC	• Operates at ambient temperature of up to 120°C • Used in applications, such as mobile phones and laptops at 0.05 kW-2 kW
	PEMFC	• Low operating temperature of 60-100°C
Portable power • Powering vehicles, additional power unit on/off the highway, and for specific vehicles.	PEMFC	• Used in applications, such as materials handling vehicles, fuel cell electric vehicles (FCEV), and buses of up to 500 kW

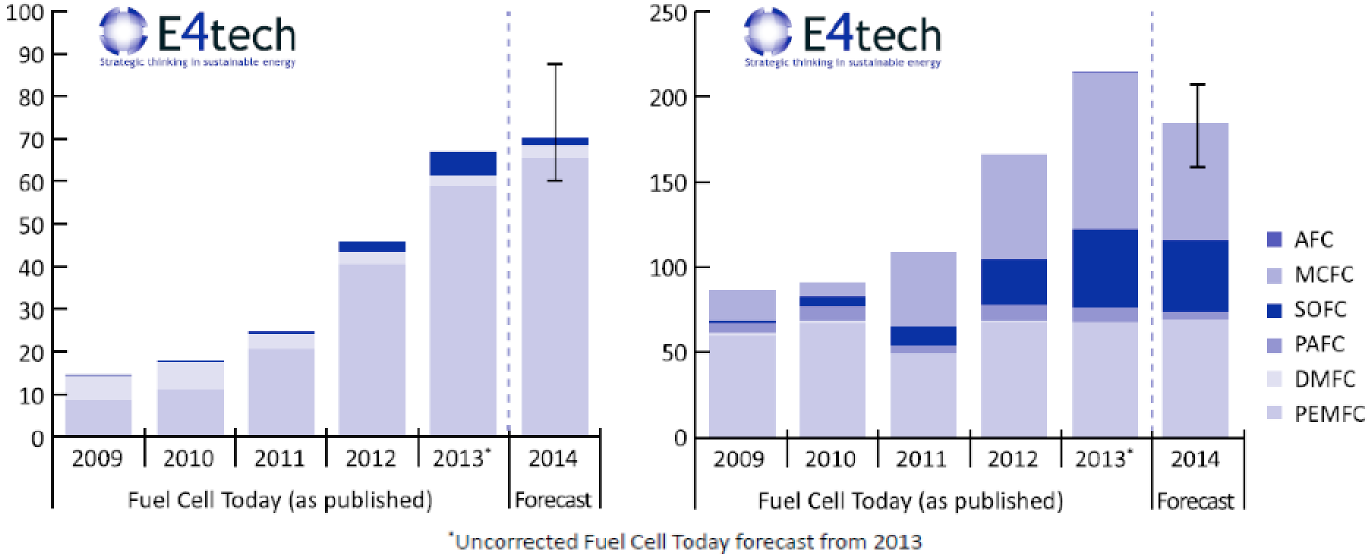


Figure 17. Market according to fuel cell type 2009-2014: (a) shipments by application and (b) megawatts by application adoption

Source: E4tech. 2014

In the US, several utility companies, which traditionally rejected distributed power from fuel cells, have expressed interest in 2014 to install fuel cell stationary power in their facilities. For example, the Delaware's Delmarva Power currently runs the largest fuel cell station with 30 MW of natural gas-powered Bloom Energy at two substations, which is enough to power 22,000 homes. There are many other examples of successful deployment of fuel cells to be used in the stationary, portable, and transportation applications, and Malaysia must seize the opportunity at this early stage to be an immediate adopter of the technology in the fuel cell and hydrogen energy community, especially in ASEAN.

In Europe, Fuel cell technologies and hydrogen energy are regarded as equally important with wind and solar technologies. Fuel Cells and Hydrogen Joint Undertaking (FCH JU) is an innovative public-private partnership that joins the European Commission, private sector businesses (New IG2) and Europe's research community (N.ERGHY3). It was established with a funding of €500 million for the first phase to promote 150 privately-led projects in transportation, stationary power and heat, early market products such as backup and portable power, hydrogen production, and 'cross-cutting' projects that support regulations, codes and standards development, and market evaluations.

In 2014, the Fuel Cells and Hydrogen Joint Undertaking (FCH 2 JU) has entered phase two with funding of about €650 million for over seven years. The two innovation pillars supported by cross-cutting projects are transportation and electricity generation. Plans to accelerate fuel cell bus commercialisation in more European cities, as well as increasing demonstration of fuel cell cars and hydrogen refueling stations, are being carried out. It also supports micro-CHP projects by introducing micro-CHP fuel cells in Europe's power and heating markets.

The leading countries in Asia are Japan, Korea, and China, where Japan has increased the 1-5 kW CHP shipment from 55% in 2013 to 88.5% in 2014. The shipment for Korea reached up to 100MW in 2014 for prime power in dedicated fuel cells-powered parks. In ASEAN, Indonesia has embraced hydrogen energy and deployed thousands of backup power for Telco towers using Canadian-made PEMFCs, supported by Pertamina. Unfortunately, industries in Malaysia are yet to be actively committed to fuel cell and hydrogen energy efforts.

Japan is very aggressive in its hydrogen energy efforts to retain Japan's commitment to reduce carbon emissions, especially after the Fukushima disaster, with the approval of its 4th Strategic Energy Plan in 2014 that minimises the reliance on nuclear energy. Imports of shale gas and coal from the US have temporarily been increased to buy time for the much-needed shift to renewable and distributed energy. A 'new' energy model has been introduced that emphasises on resilience through distributed power, and open access and consumer choice. They can choose to use the energy harnessed by solar energy in their homes or hydrogen energy with fuel cells, and then sell the excess electricity to the grid. Alternative fuel vehicles are actively promoted, where 50%–70% of the new car fleet should be "new generation vehicles" by 2030, which include natural gas, battery and hydrogen fuel cells. Hydrogen refueling stations are being built with 100 stations being targeted by 2015, while fuel cells are also promised to be showcased at the 2020 Olympics. Japan is also committed to promote cost reduction, modify codes and standards, and infrastructure deployment support. Government subsidy is also essential in the success of the 2012 EnE-Farming program with plans to provide 1.4 million residential fuel cell units by 2020 and 5.3 million units by 2030.

The world's currently largest fuel cell park, the 59 MW Gyeonggi Green Energy in Hwasang, Korea, was built by the Fuel Cell Energy company for POCSO in 2014 with 21 MCFC units running on natural gas. There is also a fuel cell park in Pyeongtaek city owned by POSCO, Doosan and Korea Gas Corporation with multi-hundred MW fuel cell units to be operated in 2018. Smaller installations using AFCs and PEMFCs have also been proposed. Table 8 gives the cost breakdown of a PEMFC system for 2007-2012 and the key assumptions of the cost analysis for 2013 while Figure 18 shows the modeled cost of an 80-kWnet PEMFC system based on projection to high-volume manufacturing (500,000 units/year). The 2013 system cost becomes higher due to the adjusted cost estimates that takes into account the higher platinum price, the realigned compressor and expander efficiencies, as well as the newly introduced Q/ΔT requirement. For a PEMFC system used in an FCV, the ultimate cost target is USD 30/kW.

Table 8. Key Assumptions of Cost Analyses and Resulting Cost (2007-2013)

Characteristic	Units	2007	2008	2009	2010	2011	2012	2013
Stack power	kWgross	90	90	88	88	89	88	89
System power	kWnet	80	80	80	80	80	80	80
Cell power density	mWgross/cm2	583	715	833	833	1,110	984	692
Peak stack temperature	°C	70-90	80	80	90	95	87	97
PGM loading	mg/cm2	0.35	0.25	0.15	0.15	0.19	0.2	0.15
PGM total content	g/kWgross	0.6	0.35	0.18	0.18	0.17	0.2	0.23
PGM total content	g/kWnet	0.68	0.39	0.2	0.2	0.19	0.22	0.25
Pt cost	USD/troz.	1,100	1,100	1,100	1,100	1,100	1,100	1,500
Stack cost	USD/kWnet	50	34	27	25	22	20	27
Balance of plant cost	USD/kWnet	42	37	33	25	26	26	27
Sys. Assy. and Testing	USD/kWnet	2	2	1	1	1	1	1
SYSTEM COST	**USD/kWnet**	**94**	**73**	**61**	**51**	**49**	**47**	**55**

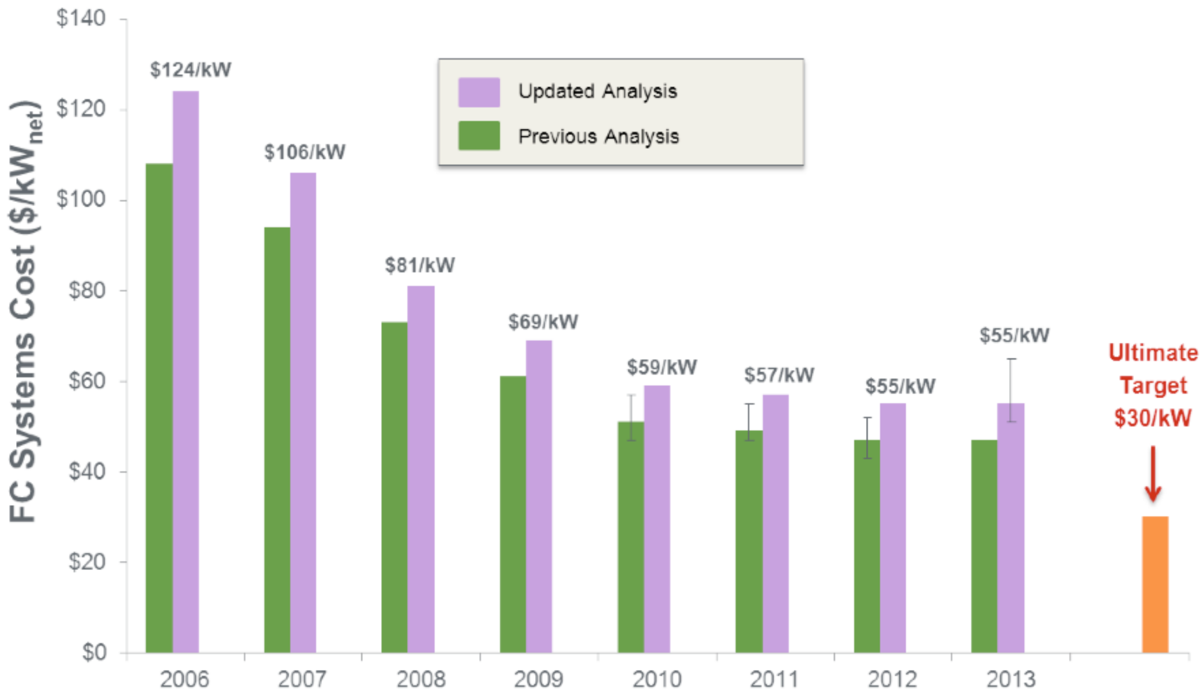


Figure 18. Modeled cost of an 80-kWnet PEM fuel cell system based on projection to high-volume manufacturing (500,000 units/year)

Source: DOE Fuel Cell Technologies Office Record 2014

The highest contributor to CO_2 emission is fossil fuel and 30-40% comes from transportation. Some of the major initiatives to reduce carbon emission in transportation are the large scale introduction of FCVs in 2015 by market and technology leaders in automotive such as Daimler, Ford, GM/Opel, Honda, Hyundai-KIA, Toyota, and Alliance Renault- Nissan, as well as the more stringent environmental legislations on greenhouse gas emission and climate change.

The future FCV scenario will see a portfolio of energy sources being used in the transportation industry, including hydrogen. The ICE and hybrid vehicles will still be in the market, along with the FCVs, but these technologies will have to reduce their carbon emission, for example through carbon sequestration. FCVs qualify to be categorised as Green Transportation as it fulfills all the criteria of Green Transportation. FCV has a higher efficiency of fuel cell (60%) that is three times that of ICE (20%) and twice that of HV (30%), a shorter hydrogen refueling time (3-4 minutes) compared to longer battery charging time (4-6 hours), and a longer operating time by hydrogen refueling compared to limited operating time of battery for every full charge.

Well-to-wheels GHG emissions of FCV based on hydrogen production processes concludes that there will be more carbon emission compared to coal gasification with sequestration if it uses NG as the source and less if the source is electrolysis and biomass. In Malaysia, hydrogen conversion from NG at petrol stations is possible because it is easy to find NG supply as it is distributed nationwide. The international industry-led FCV has solved the problems of driving range (500 km), efficiency (60%), cold start (from -30°C) and refueling time (3 min) in 2010. However, it is yet to solve the durability problem with the target being 5000 hr and the achieved result is still at 2500 hr. The target for transportation applications is 40000 hr and it has achieved only 10000 hr. The price remains high, with high-volume manufacturing cost achieved still at 35% reduction to USD51/kW, whereas the target is at 50% reduction to USD30/kW.

Several well-established foreign companies have been identified as potential fuel cell investors in Malaysia, as listed in Table 9. Major efforts need to be expended in order to attract overseas investors to Malaysia in order to create and maintain a sustainable fuel cell and hydrogen market environment. This will help develop the domestic fuel cell market as well as to promote and encourage local businesses to get involved in the fuel cell and hydrogen industries. The current initiative by Gas Malaysia Berhad to expand into the energy business by teaming up with Tokyo Gas' Energy Advance Co Ltd to develop the Combined Heat and Power (CHP) system can also be utilised to promote and encourage the technological development in SOFC-CHP systems for energy-efficient buildings.

Table 9. Business and the companies targeted as fuel cell investors

Business	Companies	
Transportation	• Cars: Toyota, Honda, and Hyundai • Buses and trucks: Mercedez-Benz	
Fuel cell solutions	• Asia Pacific Fuel Cell Technologies Ltd. • Hydrogenics Corporation • Aisin Seiki Co. Ltd. • Ceres Power Holdings PLC • AFC Energy	• Doosan Corporation • Kyocera • Panasonic Corporation • Plug Power Inc. • Toshiba Corporation.

Initiatives in Malaysia

Development efforts in establishing fuel cells and hydrogen technology in Malaysia started in 1995, when the first single cell proton exchange membrane fuel cell (PEMFC) was built and advanced materials for polymer composite bipolar plates were developed. R&D undertakings began in 1996 when a consortium of researchers from Universiti Kebangsaan Malaysia (UKM) and Universiti Teknologi Malaysia (UTM) proposed the first large scale fuel cell research project in Malaysia to the Intensification of Research in Priority Areas (IRPA) scheme at Ministry of Science Technology and Environment (MOSTI) in the Seventh Malaysia Plan.

Figure 19 gives an illustration of the hydrogen and fuel cell supply chain envisioned in the future while Table 10 shows the well-to-wheel and tank-to-wheel emissions, as well as fuel consumptions of different fuel vehicle combinations for future reference and comparison purposes. The WTW results show a better range for the hydrogen-fuelled FCEV compared to the petrol- and diesel-fuelled conventional vehicles, whereas the FCEVs do not produce any local emissions despite displaying a high carbon footprint due to the hydrogen production from natural gas. The more efficient method for hydrogen production is by central reforming, as suggested by its lower emission value.

A national fuel cell project, which was a joint effort by UKM and UTM, led by UKM from 2002 to 2007. From year 1995 to now, MOSTI has given a total sum of RM41 million to fund the domestic fuel cell project. Funding for the project was utilised for learning the fundamentals of fuel cells technology and developing it further with the aim of reducing fuel cell costs by reducing the catalyst loading in the electrodes and replacing the Nafion membranes with cheaper home-grown membranes. Hydrogen production technology from natural gas and methanol was also explored.

Fuel cell was later introduced in the Eighth Malaysia Plan 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 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 from now until 2050.

During the Tenth Malaysia Plan, a zero-emission vehicle powered by fuel cells using hydrogen energy was developed. The project mainly involved the prototyping of a new water-cooled 5 kW 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 in Malaysia. Figure 20 shows the second half of the 2005 roadmap, which focuses on fuel cells.

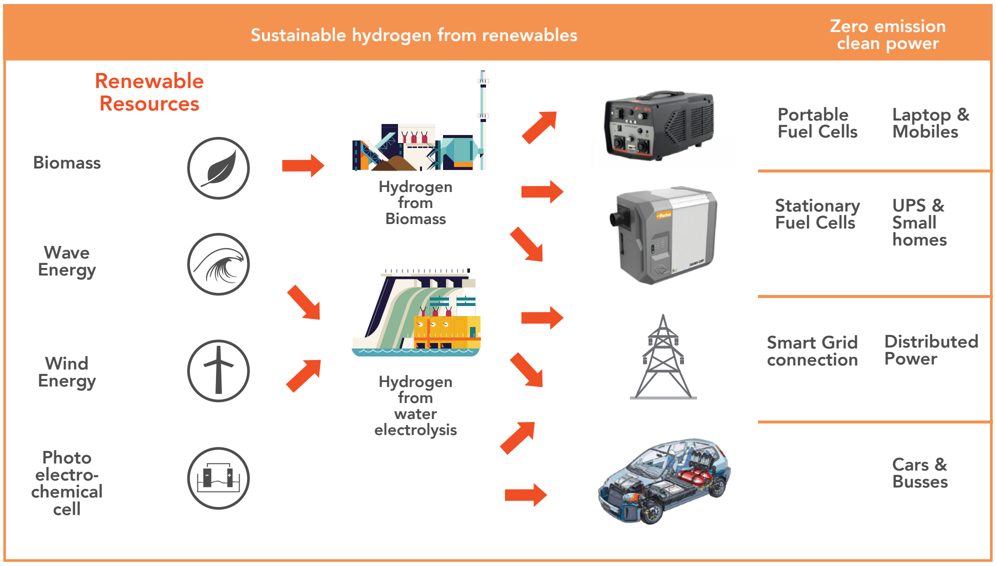


Figure 19. Hydrogen and fuel cell supply chain
Source: Daud 2015

Table 10. Well-to-wheel emissions, tank-to-wheel emissions, and fuel consumptions for different fuel-vehicle combinations

Fuel-vehicle combination	Fuel consumption (l.gas.eq/100 km)(		Emissions g.CO2.eq/km)	
	WTW	TTW	WTW	TTW
Conventional vehicles :				
Petrol-ICE vehilcle	6.00	5.10	144.00	121.00
Diesel-ICE vehicle	4.70	3.90	113.00	93.00
Compresed natural gas:				
NGP-FCEV	4.94	4.09	88.52	67.34
Hydrogen:				
HNO-FCEV[5]	4.53	2.21	83.66	0.00
HNC-FCEV	4.00	2.21	74.21	

Source: Ramachandrana & Stimming 2015

5 Petrol-ICE: conventional vehicles with internal combustion engine using petrol as fuel ; NGP-FCEV: fuel cell vehicles with hydrogen fuel produced using natural gas through the pipeline; HNO-FCEV: fuel cell vehicles with hydrogen fuel produced using natural gas (on-site reforming method); HNC-FCEV: fuel cell vehicles with hydrogen fuel produced using (central reforming method)

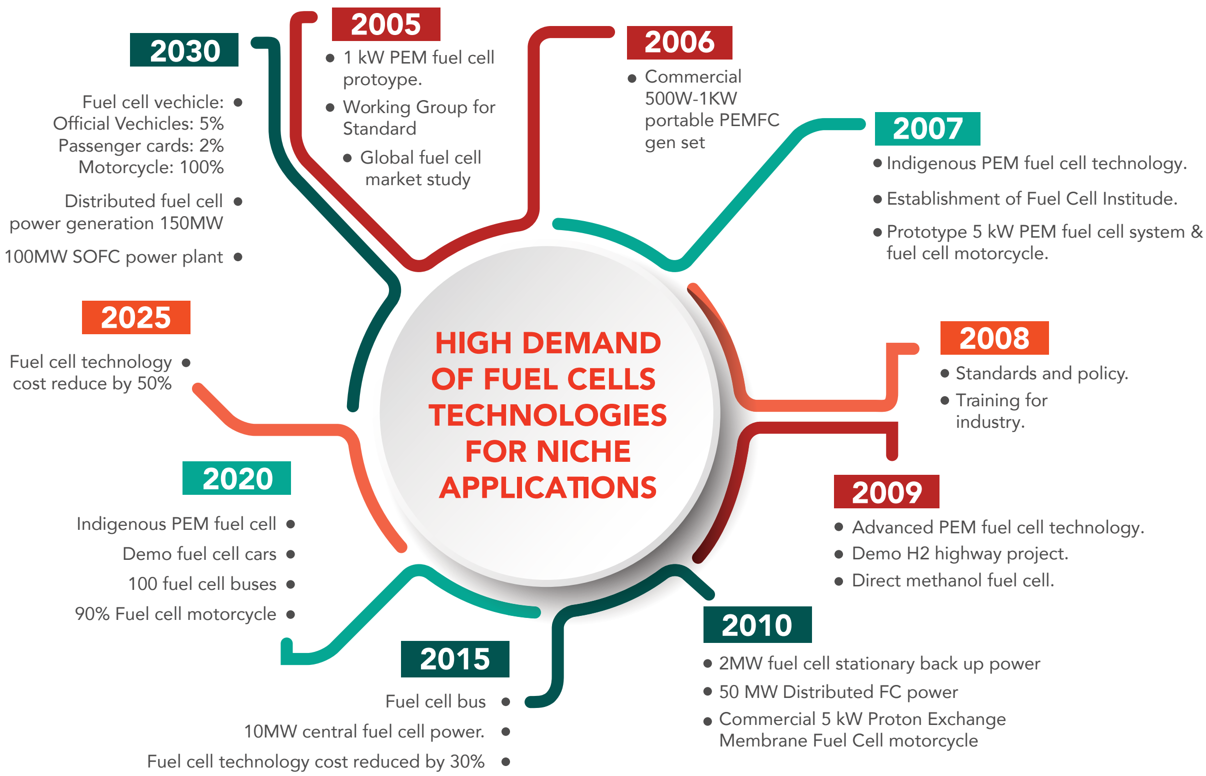


Figure 20. Malaysia's fuel cell roadmap 2006

Source: Daud 2006

Domestic PEMFC technology in Malaysia has currently reached the design and fabrication stage from 200 W, 1 kW, and up to 5 kW maximum power and the balance of plant to go with it. Table 11 shows the predicted large-scale PEMFC and SOFC units required to produce the electricity demand for Malaysia. The PEMFC stack can be used in uninterruptible power supply (UPS) or backup power system and in small portable power generation set. It also offers the full range of R&D support for the manufacture of the PEMFC stacks including material formulations and manufacture of membrane electrode assemblies and bipolar plates as well as the assembly of the stack or "stacking" to form a complete PEMFC stacks. PEMFC integration into existing electric or hybrid power trains was also developed for fuel cell-powered motorcycle demonstrator prototypes and a buggy vehicle, 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 for low and intermediate temperature electrode and electrolyte materials.

Table 11. The predicted PEMFC and SOFC units required for Malaysia's electricity demand

Year	2020	2035	2050
Total target (GWh)	200	3000	50000
PEMFC[6] unites required (80% supply)	73	274	2609
SOFC[7] unites required (20% supply)	51	7	163

The fuel cell market in Malaysia is still quite small and a 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 molding of polymer composites and the MEA can be manufactured using battery electrode making technology. Only 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 five 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 UAV fuel cell system), telecommunication sector (Telco BTS for primary power), military (AEROPAK military power pack), hydrogen generation (electrolyser 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 UAV 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 have the full support of Malaysia's green technology corporations. FCV specifications have reached maximum power of 114 kW for Toyota Mirai, while others are still at 100 kW, and the range is highest for the Hyundai Tucson at 650 km, while the shortest one is 385 km 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.

6 The basis is a PEM fuel cell module that contains 12 stacks of 75 cells, where each is electrically connected in series and with initial power output of 50-70 kW (at high hydrogen conversion efficiency of 53-57%, respectively). The plant operation has an uptime > 90% and peak output power of 120 kW. The unit has delivered more than 2 GWh after 40,000 hours of operation on the local grid (Nedstack.com 2015).

7 5,266 BTU (or 5.266 cubic feet) of natural gas required to make 1 kWh of electricity using SOFC (Weimar et al. 2013), while Malaysia's dry natural gas production for 2012 was 2,176.19 billion cubic feet of natural gas (IndexMundi 2015)

1.3 EMERGING FUEL CELL TECHNOLOGIES

State of the Art

Fuel cells have yet to be sufficiently cost-effective enough to rival conventional energy technologies and various stages of RD&D are being actively worked on and implemented in order to fulfill that objective. There are many promising future technologies for established types of fuel cells such as PEMFC, DMFC, and SOFC, as well as for relatively new types of fuel cells such as microbial fuel cells (MFCs). MFCs are being developed as suitable separators for nano-composite membranes and ceramics, and nano-composite and nano-structured cathodes and bio cathodes, as they combine wastewater reduction and power as well as produces electricity directly from waste. However, limitations in the microbial systems hinder further progress in terms of design and fabrication and the technology still shows low efficiency. The performance is improved using cheaper polymer electrolytic membrane nanocomposites, which is impermeable to oxygen and nanostructured electrodes, and able to form more stable biofilm for microorganism to transfer electron to anode easily. Maximum power density of a MFC that uses the less costly CNT/ polypyrrole is found to be close to Pt/C.

Hydrogen production from renewable fuels such as OTEC and solar is also being studied and deployed in many developed countries, particularly in the US, Europe, and Asia Pacific. Photo-electrochemical (PEC) technique for hydrogen production by water splitting is being looked into; however, the large band gap for electrolysis (1.6 eV) and electrode corrosion are primarily the challenges faced by this technology. The major barriers still exist for PEC commercialisation such as having electrode instability and an efficiency as low as 8%. Efficiency and stability of photo-electrodes in a photo-electrochemical cell are being improved with developments of new bi-metallic organic dyes and nanostructured metal oxide photo-electrodes.

Table 12 shows the ongoing RD&D efforts for some the components of fuel cells and hydrogen technologies. Cost and durability are the main challenges for fuel cell commercialisation, especially in the automotive sector. Market-driven targets set for technical specifications of fuel cells must be met concurrently in order to reduce cost and improve durability. In the automotive sector, the targets for the fuel cells used (PEMFCs) are as follows:

- Cost: achieved up to 2015 = USD55/kW
  2020 target = USD40/kW
  Ultimate target = USD30/kW

- Durability: achieved up to 2015 = 3,900 hr
  2020 target = 5,000 hr
  Ultimate target = 5,000 hr

- Efficiency: achieved up to 2015 = 60%
  2020 target = 65%
  Ultimate target = 70%

Table 12. Ongoing RD&D efforts on some components for fuel cells and hydrogen technologies

Component	Advances
Carbon nanotubes (CNT)	a. CNT has excellent mechanical properties (Young's Modulus 1 TPa with tensile strength 60 GPa), and larger surface areas (1315 m2g-1) compared to carbon black (240 m2g-1). b. Single-walled carbon nantotubes (SWCNT) with armchair, zigzag and chiral structures as well multi-walled carbon nanotubes (MWCNT) with 3 structures of shell having differing chirality. c. Oxygen reduction reaction catalyst for PEMFC uses CNT doped with nitrogen (NCNT), such as aniline-NCNT, ethylene diamine (EDA)-CNT, and diethylacetamide (DEA)-CNT. d. With 1 M methanol, the methanol oxidation and performance of a DMFC that uses PtRuFeNi/MWCNT is better than PtNi/MWCNT and PtNi/MWCNT
Carbon nanofibres (CNF)	a. Nanofibers have advantageous structures such as herring bone, platelets, spiral, and ribbon. b. With 2 M methanol, the methanol oxidation and performance of a DMFC that uses Pt-Ru on CNF is better than Pt-Ru on carbon black with CNF and Pt-Ru on carbon black.
Graphene	a. Graphene has excellent mechanical properties (Young's Modulus 1 TPa with tensile strength 130 GPa), and larger surface areas (2630 m2g−1) compared to carbon black. b. A defective single-layer graphene may successfully produce a membrane with a one-atom thick layer channel for proton transfers.
Nanostructured membranes	a. Performance of a PEMFC that uses the nanostructured membrane Nafion/silicon oxide/phosphotungstic acid nanocomposite membrane is found to be superior to Nafion. b. DMFC performance and reduction in MeOH crossover is better with Nafion/Pd-SiO2 nanofiber composite membrane than Nafion.

Cost can be reduced by improving performance using new nanostructures, nanomaterials, and nanosystems that increases efficiency 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 reduces degradation such as good proton conductivity and water diffusion in PEM to prevent drying as well as prevention of 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 (Papageorgopoulos 2015):

- Stack components: catalysts, electrodes, electrolytes, MEAs and single cells, gas diffusion media, seals, and bipolar plates;
- Performance and durability: mass transport, durability, and impurities; and
- Systems and balance of plant (BOP): BOP components, fuel processors, stationary power, auxiliary power units (APUs), and early markets.

Initiatives in Malaysia

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 solid oxide fuel cells (SOFC), have been successfully developed. Other fields of interest are photo-electrochemical devices for splitting of water to produce hydrogen and a scale-up version of a system that produces biohydrogen using palm oil mill effluent. Developments of novel materials for improving fuel cell performance include:

- A 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 TiO2 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; and
- Nano-materials 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.

2.0
METHODOLOGY OF THE FUEL CELL ROADMAP DEVELOPMENT

2.0 METHODOLOGY OF THE FUEL CELL ROADMAP DEVELOPMENT

The methodology implemented for this project utilises the information gathered from the existing legislative and industrial reports as well as literature relevant to the Malaysian environment. Stakeholders' discussion in a 1-day Workshop on Fuel Cell also provides valuable data to analyse the fuel cell and hydrogen industries in order to derive the required recommendations and conclusions using the following tools:

1. Logical Framework Analysis (LFA)
2. Problem Tree Analysis
3. SWOT Analysis

2.1 Logical Framework Analysis (LFA)

The Logical Framework Analysis (LFA) is used as the tool for planning, designing and managing the Blueprint project. The data is laid out systematically in a tabulated form to give a succinct and unambiguous presentation. The LFA is developed by covering the following topics:

- Focus Areas - each of these three areas received particular attention from their respective stakeholders group, namely Hydrogen Infrastructure, Fuel Cell Applications, and Emerging Fuel Cell Technologies
- Drivers - principal trends, people, knowledge, and conditions that the participants believed contribute to the market development and growth
- Main Problems - internal and external obstacles or setbacks associated with the fuel cell and hydrogen industries
- Proposed Recommendations/Action Plan - proposals are given regarding the steps to be taken by the stakeholders towards achieving the project objectives
- Strategies - plans are laid out to accomplish the short term (2020), middle term (2035) and long term (2050) goals

2.2 Problem Tree Analysis

This analysis was conducted by the relevant key groups to take into account the interests and views of the concerned stakeholders. It is a vital process as it addresses the current and future needs of the respective groups in order to come up with solutions based on an accurate and full evaluation of the situation at hand. After the LFA has been carried out, three important steps in the Problem Tree Analysis must be taken before any practicable objectives can be formulated along with the necessary strategies to attain them:

1. Problems Analysis

The problems faced by the fuel cell and hydrogen industries are clustered together to identify and relate between the core, main, and secondary problems. They are summarised in a negative way and presented in a visual display that is easily understood by anyone, i.e., the Problem Tree. The core problem is stated at the top of the tree followed by the problems that have been identified as the main causes of the core problem.

2. Backcasting

This is a concept that is the opposite of 'forecasting' as it works backwards and connects the problems faced by the fuel cell and hydrogen industries in the current situation to the desired future where those problems have been solved. Stakeholders used this concept by inverting the negative statements in the Problem Tree to positive ones.

3. Objectives Analysis

Positive statements from the Backcasting step are expressed as realistic objectives in a comprehensible visual display, i.e., the Objective Tree, that summarises the vision of the future where the desired solutions have been achieved through new or alternative institutions and structures proposed by the stakeholders.

Figure 21 shows the relationship between the 'problem-tree' analysis and 'objective-tree' analysis The strategies arising from the objectives are sorted by the stakeholders into suitable timeframes for the purpose of roadmap development: Short Term (5 years), Medium Term (15 years), and Long Term (beyond 15 years). The strategies and their respective timeframes should be linked with the Malaysia Plan in terms of the national development to promote focus and easier implementation in commercialisation as the end goal.

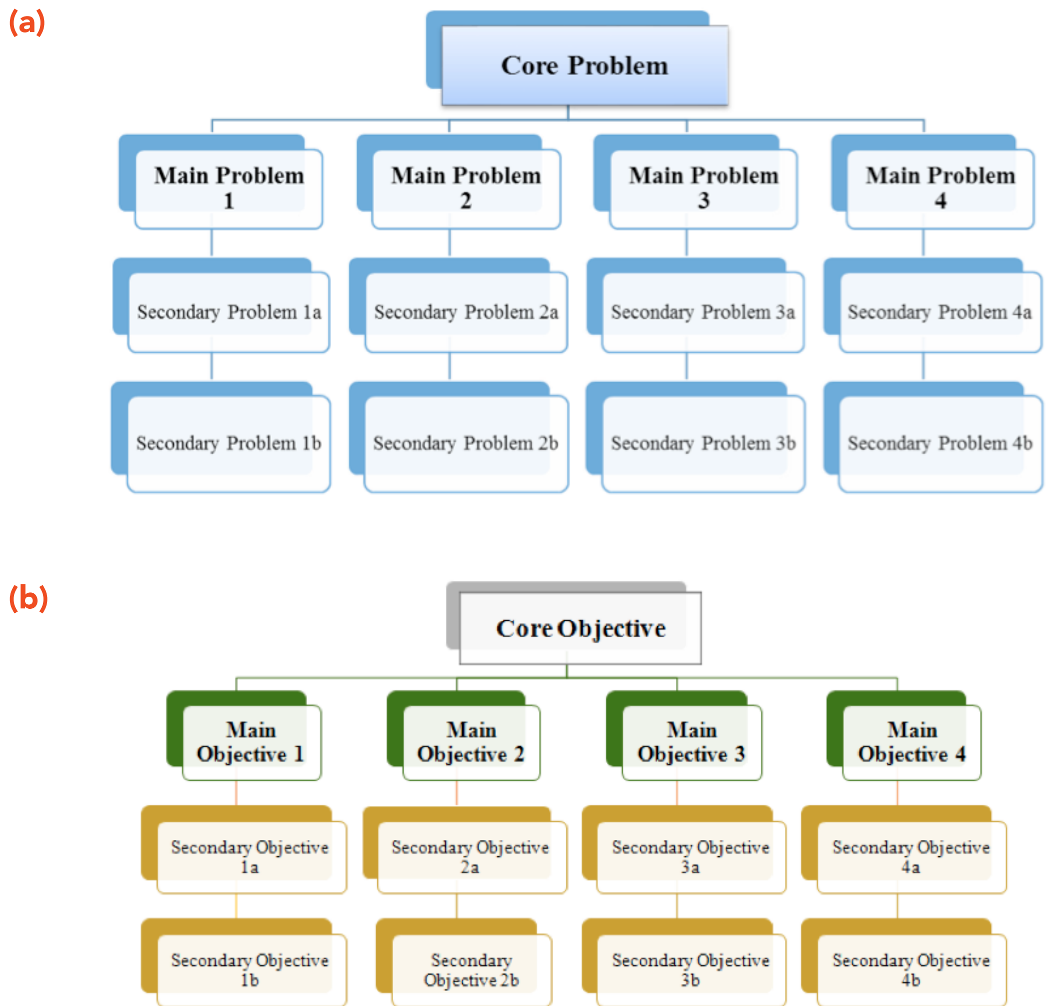


Figure 21. The relationship between the (a) 'problem-tree' analysis and (b) 'objective-tree' analysis

2.3 SWOT analysis

Modern SWOT analysis is an analytical method organised in a 2x2 matrix grid to help the decision-making process by delivering a presentation that facilitates a clear understanding of the project to enable the stakeholders in assessing the collected data with a subjective manner. General assumptions and habitual reactions are eschewed while proactive thinking is encouraged by ways of deliberating, conceptualising, formulating strategies, and coming together for the common goals.

The SWOT analysis should be viewed as a dynamic part of the project management and development process for the fuel cell and hydrogen sectors. The impacts of past developments and programs along with the current energy updates in Malaysia on the technological, economic, and societal fields are taken into account when presenting the current state of the sectors.

Three important segments are used in the analysis: Science and Technology (S&T), Market and Industry (M&I), and Policies and Measures (P&M). The SWOT template is presented as a grid according to a logical order of four dimensions, one section for each of the SWOT headings:

1. Internal factors

- Strengths - resources and capabilities that are advantageous in developing the sectors, promote a sustainable business practice, and improve its service capacity management.

- Weaknesses - lack of resources and capabilities that are capable of bringing substantial setbacks and causing failures for the sectors

2. External factors

- Opportunities - surrounding variables with potential benefits, opportunities, and anticipated trends for the sectors

- Threats - surrounding variables that pose obstacles, bring negative changes in relevant technology and job market, and effect financial predicaments in the sectors

3.0
THE FUEL CELL ROADMAP

3.0 THE FUEL CELL ROADMAP

The main drivers crucial to the development of the Fuel Cell & Hydrogen Industries in Malaysia have been identified as:

- Global climate change - Malaysia has pledged in the National policy to reduce 40 % carbon emission by 2030 based on the 2007 intensity level
- Petroleum dependency - fossil fuel is experiencing depletion and alternative sources of energy need to be developed
- Subsidy rationalisation on the current power generation scheme - hydrogen can be made into a more attractive fuel for local users

The strategies laid out below is presented in the Problem Tree and Objective Tree format along with the time period required to fulfill them.

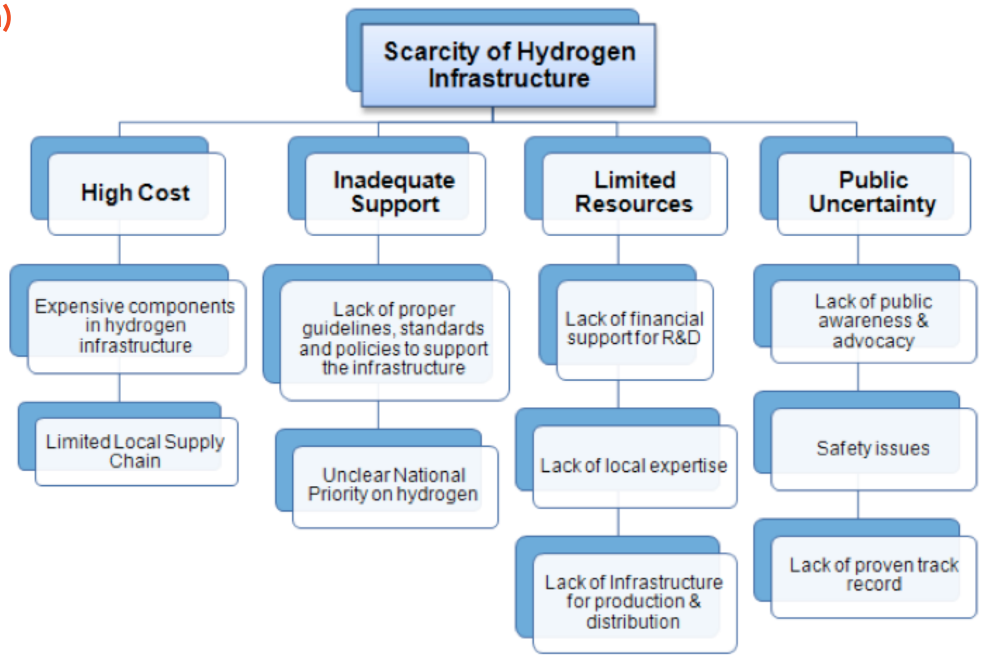
3.1 Hydrogen Infrastructure

The Hydrogen Infrastructure focuses on issues regarding production, delivery, and storage of hydrogen as fuel for the fuel cells. Relevant matters that are pertinent to the discourse include refueling, distribution systems, multi-fuel reforming, and low-cost renewable hydrogen generation were also of interest to the stakeholders. Figure 22 shows the Problem Tree and Objective Tree for Hydrogen Infrastructure.

Four main problems have been identified as barriers in the hydrogen infrastructure development are high cost of fuel cell deployment and hydrogen infrastructure development, lack of Malaysian standards and policies regarding fuel cells and hydrogen, insufficient resources, and low consumer confidence regarding fuel cell capabilities and hydrogen safety.

From the backcasting step, the corresponding objectives derived are decrease cost by utilising technological advancements from hydrogen R&D efforts, establishing robust governmental policies and National Priority regarding hydrogen, ensuring the sustainability of hydrogen infrastructure, and increase of public acceptance through a series of high profile measures.

(a)



(b)

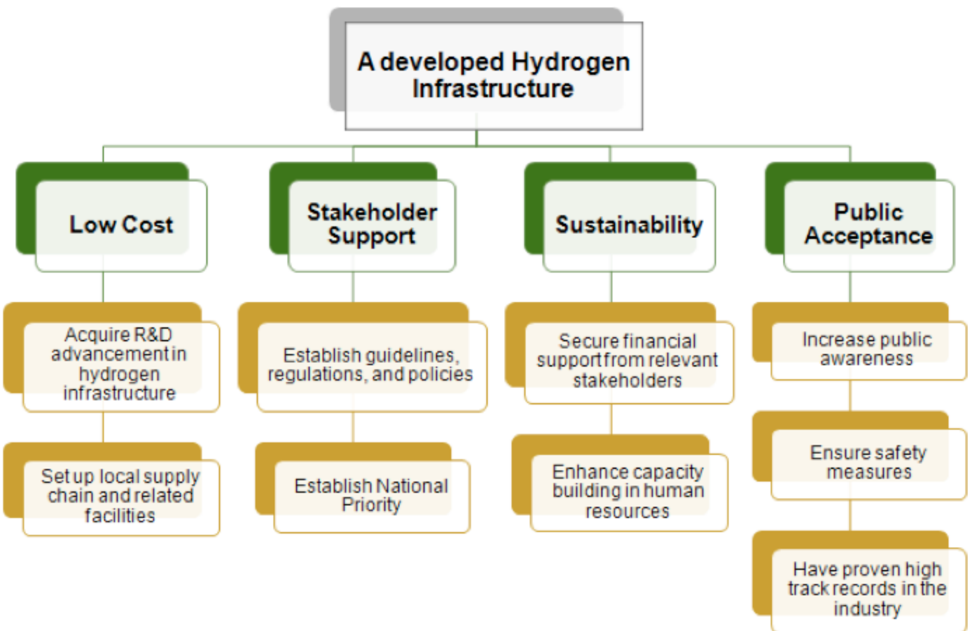


Figure 22. Hydrogen Infrastructure: (a) Problem Tree and (b) Objective Tree

3.2 Fuel Cell Applications

The focus is mainly on fuel cell power generation and supply for vehicles (transportation, materials handling, military, and unmanned), stationary applications (large, small, and micro), and portable applications (military devices, auxiliary power units, portable products, personal electronics, education kits and toys).

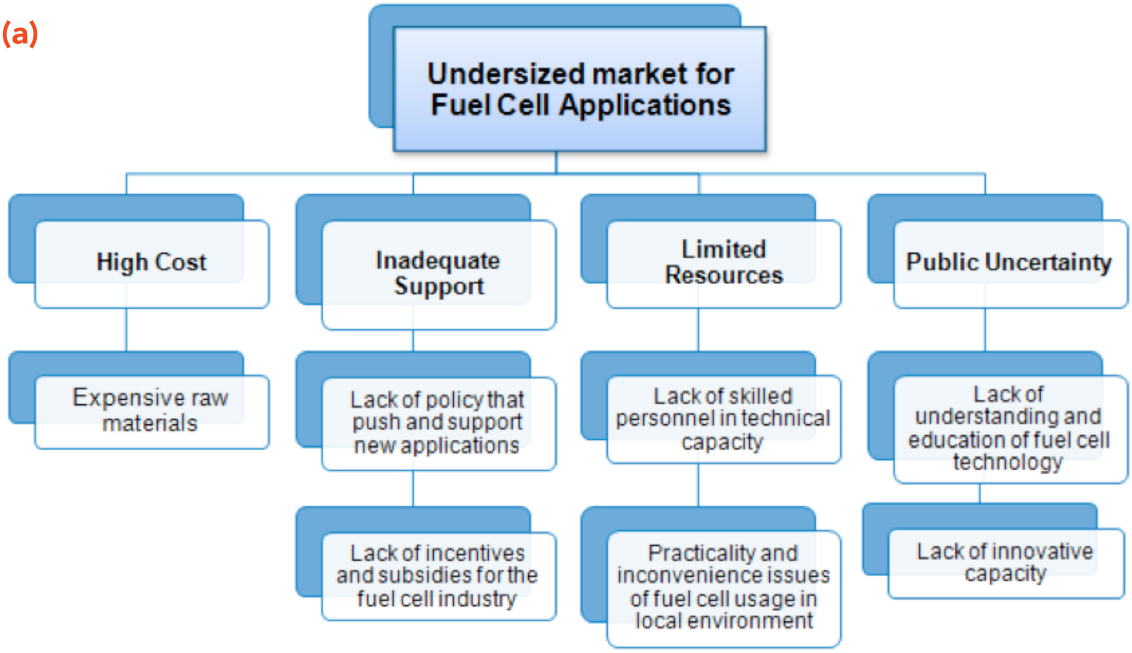
Other applications of interest are distributed power for homes and buildings, micro combined heat and power (mCHP), backup power for remote facility and shipboard, and expeditionary applications as well as their market penetration. Projects that are being looked into in Malaysia include remote sensing, generator set replacement, backup power solutions for power process systems (PPS) at telecommunication sites, and lightweight soldier packs for military applications.

Development of hydrogen fuel cell as an alternative energy is currently the responsibility of the Regulatory and Industry Development Division, which is a division under the Energy Sector in the Ministry of Energy, Green Technology and Water (KeTTHA). This division is also the one tasked with the legislation, planning, and implementation of Renewable Energy development policies, programs, projects, and activities as well as the promotion of energy efficiency and conservation in all economy activities at domestic and international levels. However, there is no mention of hydrogen or fuel cell in the Tenth Malaysia Plan (10MP) despite its growing global market and the importance of hydrogen as fuel in Malaysia's energy mix with fuel cell as an alternative energy source having a higher efficiency than the ones from fossil fuels.

The problems that have been identified in this key group are high cost of fuel cell components and parts, lack of understanding, education and awareness of the fuel cell technologies among the public, the relevant ministries, and to some extent the university communities. Lack of local policies that support new application and insufficient capacity in terms of innovation, technical know-hows, and fuel infrastructure such as distribution, storage, and refueling facilities, and high cost of deployment and inconvenient application practicalities are also obstacles that need to be overcome.

Figure 23 shows the Problem Tree and Objective Tree for Fuel Cell Applications. By backcasting these problems into objectives, some recommendations and strategies for future actions proposed are organising awareness campaigns for the public to realise the advantages of fuel cell technology, awarding incentives for tax benefits with the involvement and endorsement by the relevant ministries, intensifying efforts in human capacity building, and developing pilot projects or a model city powered by fuel cell technologies as have been carried out in other countries such as Japan and Korea.

(a)



(b)

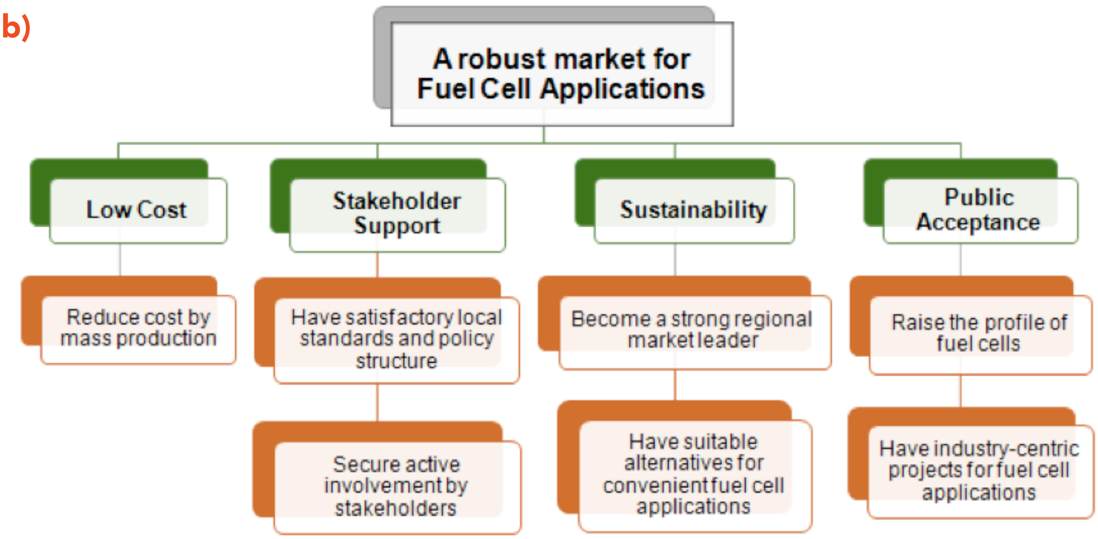


Figure 23. Fuel Cell Applications: (a) Problem Tree and (b) Objective Tree

3.3 Emerging Fuel Cell Technologies

Emphasis is put on issues regarding fuel cell components such as the technological barriers for the fuel cell systems and deployment of the technologies in terms of cost reduction, durability, efficiency, validation, and sustainability. The champions or enablers for developing the emerging fuel cell technologies have been identified as:

- Relevant ministries and agencies such as the Ministry of Energy, Green Technology and Water Malaysia (KeTTHA), Ministry of Science, Technology and Innovation, Ministry of Natural Resources & Environment (NRE), and Energy Commission of Malaysia; and

- Technology users such as telecommunication companies, Ministry Of Defense (MINDEF), automakers, and Tenaga Nasional Berhad (TNB)

The problems faced by the emerging technology that have been outlined are high cost due to several reasons including small market demand and expensive raw material, lack of various resources including technically-skilled human capacity building, and lack of awareness due to the scant amount of R&D enablers and non-existent national blueprint specific to fuel cells.

Figure 24 shows the Problem Tree and Objective Tree for Emerging Fuel Cell Technologies. Several important objectives derived from backcasting these problems contain important elements in deliberation such as the replacement of expensive components by utilising new low cost local components, improvement of the component and system designs along with the integration of various fuel cell types for relevant applications, employment of advanced hydrogen storage materials, implementation of technologies that are more suited to the local environment, promotion of studies on socio-economic impact and assessment of fuel cell deployment, clear identification of target market segments by the industries and relevant agencies, and setting up a monitoring body to align the research works between learning institutions, government, and industry.

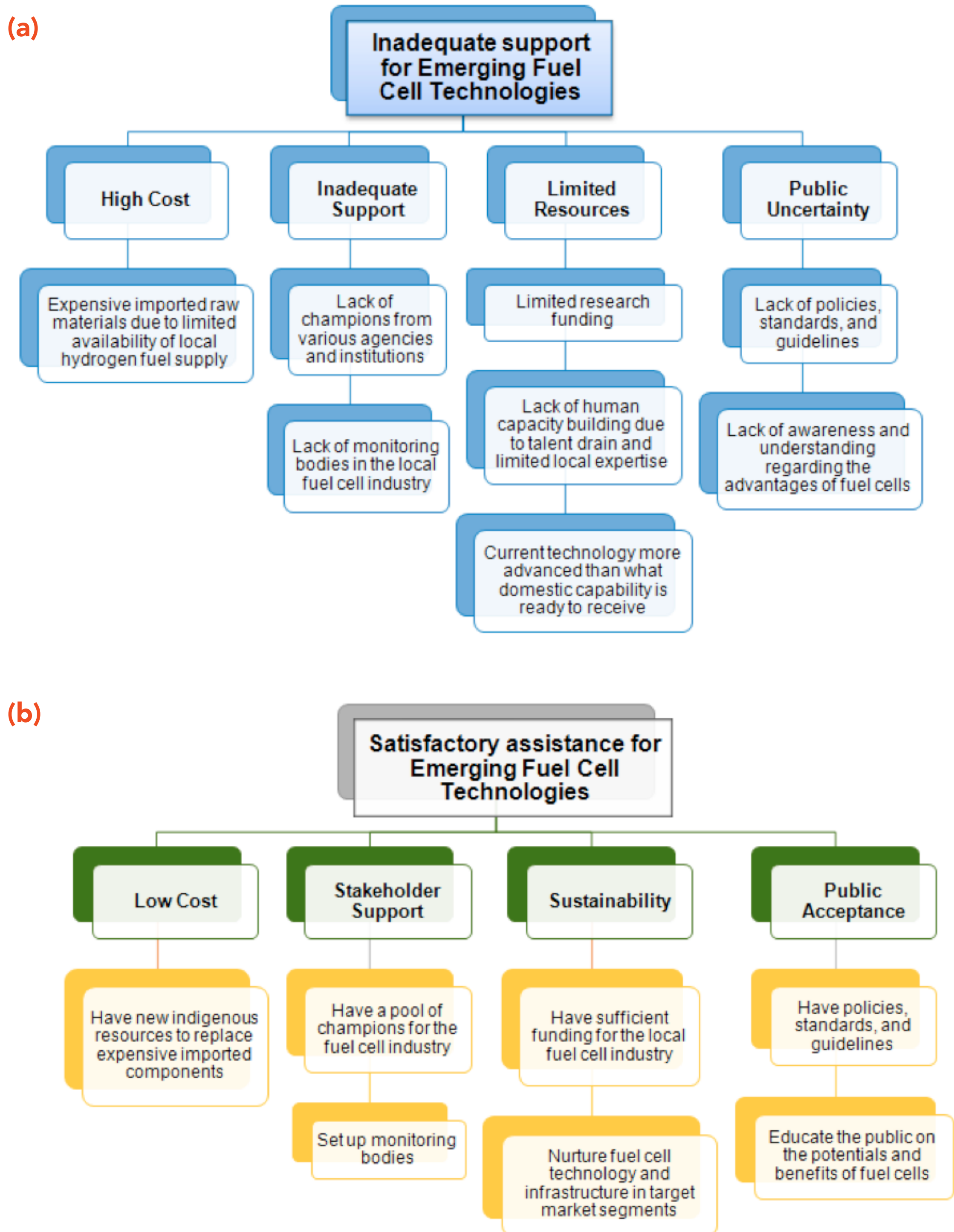


Figure 24. Emerging Fuel Cell Technologies: (a) Problem Tree and (b) Objective Tree

3.4 SWOT Analysis to Overcome Challenges

The three focus areas reveal similar items in each of the four dimensions for the SWOT analysis in Table 13 - Table 15, which shows that there is a need to have crosscutting themes and interaction between the groups must be encouraged.

Table 13. SWOT Analysis for Hydrogen Infrastructure

	Strength	Weakness
S&T	• Existing local automotive manufacturing Industries • Availability of local experts and R&D facilities in the Hydrogen field	• Expensive to develop facilities for hydrogen production, distribution network and storage.
M&I	• Availability of indigenous raw material supply for hydrogen production from oil and gas industries. • Existing pool of skilled labor. • Hydrogen fuel attractiveness due to oil price fluctuations	• Limited resources and raw materials biomass, for renewable and cleaner Hydrogen. • Low consumer confidence due to lack of proven track record in the local industry, insufficient knowledge, and safety issues
P&M	• Government Policy for Clean Air Regulation 2014 (full implementation In 2016)	• Lack of local Standards and Policies specifically on hydrogen fuel
	Opportunities	**Threat**
S&T	• Introduce the onboard Hydrogen system for easy storage handling	• Competition from other Renewable and Alternative Energy industries
M&I	• Hydrogen can be produced from local renewable and fossil fuel resources • Create local hydrogen manufacturers to reduce the cost of hydrogen production	• Slow regulatory actions and non-globe standards to create market banner
P&M	• Host demonstration trials to promote stake holders and public awareness	• Stakeholders does not prioritise hydrogen as potential energy near future • Government does not give full support to drive the hydrogen industry • Environmental and safety concern regarding infrastructure development operation of hydrogen plants • Fear of industrial accidents over known safety concerns

Table 14. SWOT Analysis for Fuel Cell Applications

	Strength	Weakness
S&T	• Abundant source of natural source and bio-mass • Competent and capable researchers/engineers to develop the technology	• Inadequate source of energy to generate hydrogen • Lack of hydrogen distribution infrastructure
M&I		
P&M		• No institutional framework to support the import and export/trading of fuel cell technology
	Opportunities	**Threat**
S&T		
M&I	• Become the main regional exporter of hydrogen supply • The integration of regional market - ASEAN	• No domestic market/demand for local products • Threat from Japan and China establish produces of modular stand-alone system at commercial level
P&M		• No government policy to support/protect the industry

Table 15. SWOT Analysis for Emerging Fuel Cell Technologies

	Strength	Weakness
S&T	• Existing research infrastructure • Availability of local experts in the R&D sector • Local experience in managing fuel cell research projects	• Inadequate, limited access and outdated infrastructure that is not centralised • Lack of technical staff • High cost of hydrogen fuel extraction
M&I	• Existing supporting industries and R&D, e.g., nanotech, biotech, gas technology • Availability of natural resources as raw material	• Lack of local Standards and Policies specifically on hydrogen fuel
P&M		• Lack of funding and support • Lack of national coordination especially for research programs and direction
	Opportunities	**Threat**
S&T	• Collaboration with international facilities	• Neighboring countries have better high-tech infrastructure
M&I	• International funding • Develop collaborations industrial partners/private sectors • Abundant raw material from natural resources and industries	• Countries with better funding schemes will spearhead fuel cell projects • Unstable global and domestic economy environments • Regional competitions
P&M	• Ongoing human capacity building in all the relevant sectors • Promotion by government to utilise natural resources • Development of a fuel cell technology park	• Better job opportunities overseas • Protests from NGOs regarding protection of environment • Expensive imports of fuel cell components and products

The crosscutting themes are as given below:

Strengths

- Raw materials - there is an abundant supply of natural sources and biomass that can be utilised for the hydrogen production, as well as from oil and gas industries;
- Local champions - there are relatively low cost skilled labour, i.e., competent researchers and engineers in the hydrogen sector to develop the technology and experienced in managing fuel cell research projects;
- Existing research infrastructure from supporting technologies in the industry such as nano, bio, and gas technologies; and
- 2014 Clean Air Regulations introduced in Malaysia and is to be fully implemented in 2016.

Weakness

- Lack of adequate hydrogen infrastructure with limited access and outdated decentralised facilities. Hydrogen extraction process and equipment are costly and with insufficient sources of energy from renewables, e.g. biomass to generate hydrogen;
- Limited amount of technical staff with lack of coordination in terms of direction for the various research programs and insufficient funding and monetary support;
- No institutional framework that specifically supports the import and export or trading of fuel cell technologies compounded by the lack of government standards and policies on hydrogen; and
- Low consumer confidence due to lack of proven track record from the local fuel cell industry and no widespread knowledge on hydrogen safety issues.

Opportunities

- As main exporter of hydrogen supply due to the diversity of renewables from natural resources available and promoted by the government, as well as clean hydrogen production from fossil fuel. Onboard Hydrogen system can be introduced as it has an easier storage handling system;
- Human capacity building by creating local hydrogen manufacturers that will reduce cost of hydrogen production, integrating the local market with the regional (ASEAN) market, raising awareness among stakeholders and the public through hosting demonstration trials, and collaborating with international facilities for R&D and commercialisation purposes; and
- International funding and collaborations available with industrial partners and private sectors can be utilised to develop a pilot project or technology park powered entirely by fuel cells.

Threats

- Countries like Japan and China have already actively produced modular/stand-alone systems at a commercially competitive level. They also have more funding and will likely be better positioned to spearhead fuel cell-related projects. Indonesia, for example, is rich in renewable resources and is getting actively involved in alternative energy industries. Neighboring countries such as Singapore have a better-equipped high-tech infrastructure and can give more attractive job offers to skilled workers in the fuel cell industry. There is little to no local market or demand for goods and services or job opportunities and most commercial fuel cell are imported from overseas;
- There is a less than stable economic environment with no government policies that specifically support and protect the industry while regulatory actions are slow and cannot be expected to drive the hydrogen industry. Therefore, stakeholders do not prioritise hydrogen as the potential energy in the near future; and
- Environmental and safety concerns regarding the operation of hydrogen production plants due to lack of awareness may give rise to protests from NGOs against the hydrogen infrastructure development.

3.5 Business Case for Fuel Cells

Fuel cells do not need to compete with other power technologies as they complement the electric power industry due to the inimitable assortment of benefits that they offer. The utilisation of fuel cells as sources of power to generate electricity is attractive due to its clean energy as it produces little or no toxic emissions at the site. The fuels used for different types of fuel cells can either be hydrocarbon fuels such as natural gas or renewables such as hydrogen. This also promotes local renewable resources and allows the country's production of electricity to rely less on foreign energy imports. The fuel cell device can be combined with other renewable technologies such as solar and wind power for energy storage purposes or packaged as a hybrid fuel cell-battery system.

It is a reliable and highly efficient power supplier as its operation can be independent of the national power grid and thus less prone to grid problems such as electrical blackouts and power surges. Therefore, it can be used in situations such as during emergencies, for critical applications, and at remote locations. The design can be flexible as it is possible to separate and recombine the components of a fuel cell system to provide modularity and scalability, or be made more lightweight and rugged to suit the environment in which it is installed. Along with its characteristic quiet operation and exceptionally low or even zero GHG emissions, investments in fuel cells can be expected to yield significant returns for applications in a wide range of market sectors.

In the US, which has a reasonably developed fuel cell and hydrogen energy industry, many companies such as Walmart, AT&T, and Verizon have participated in fuel cell demonstrations as well as installed fuel cell systems to power their vital operations. Many satisfactory repeat sales, where bigger purchases of fuel cells for larger megawatts were made for other facilities owned by existing customers, have been recorded (Curtin & Gangi 2014). This shows that fuel cells systems are trusted by their users to deliver a reliable performance that is resilient, profitable, and cost-saving. In developing the country's fuel cell and hydrogen energy industry, Malaysia can follow these successful examples that have been practiced by companies in the US, South Korea, Japan, and China:

- The modular fuel cells are manufactured to be sold to utilities with revenues expected from the sales, installation, monitoring, and maintenance of the fuel cell equipment;

- High quality fuel cell systems are sold at a competitive price with sufficient volume secured to reduce payback time and increase return of investment after 3 years;

- Substantial subsidy mechanisms are installed by the government to replace the existing conventional power systems with fuel cells in the residential and commercial sectors;

- Project consulting is made available to customers from the conceptual planning stage to the turnover stage with financial perks such as special low-interest loans and grants offered by the government to promote purchase;

- The purchasing, installation, and operating stages are sufficiently assisted by skilled personnel for troubleshooting at any time where damage to any of the fuel cell component and/ or failure due to unexpected technical error may occur;

- Renewable hydrogen used in fuel cells for electricity generation must be included in the current list of renewable energy qualified for the Feed-in-Tariff (FiT) program for electricity generation and the power is traded into the national power grid; and

- Individual power purchasing agreements (PPA) to secure financing are activated by the effective collaboration between the fuel cell manufacturing company, the power utility company, and the customer/user.

Early adopters for the fuel cell and hydrogen industry may consist of commercial businesses and government-funded agencies/institutions that require a continuous supply of electricity or emergency power-backup systems, including:

- Corporate buildings and data centers;
- Municipal facilities such as wastewater treatment plants, landfills, banks, post offices, police stations, and community centers;
- Public recreational areas such as gardens, parks, and zoos;
- Local government offices and public buildings in every state;
- Critical government agencies such as fire departments and law enforcement buildings;
- Transportation sites and facilities including airports, ports, train stations, bus stations, roadways, and railroads;
- Hospitals and healthcare facilities such as the Operating and Emergency rooms, blood refrigeration equipment, and heating and cooling systems;
- Educational institutions such as public schools and universities; and
- Public and commercial vehicle such as transit buses, delivery vehicles, cars, trucks, forklifts, and refrigerated trailers.

The total cost of modifying an existing battery-powered 4 seat passenger buggy car into a vehicle powered by an in-house 3 kW hydrogen fuel cell is RM76, 000. The high cost due to the expensive Platinum catalyst was offset by the availability of patented indigenous technologies developed by the Universiti Kebangsaan Malaysia fuel cell team. This cost will inevitably decrease when the industry reaches the stage of mass production. The challenges for the stakeholders in the industry are to develop an efficient manufacturing process in order to produce high-performing fuel cell systems with a supply chain that is cost-competitive for all the market sectors involved.

4.0
STRATEGIES & ACTION PLANS

4.0 STRATEGIES AND ACTION PLANS

The strategies and action plans for the three key groups, or focus areas, are categorised under the following main objectives, as given in Table 16:

1. To create and develop local safety measures, guidelines, regulations, policy structure, and monitoring bodies by integration with existing international standards.
2. To spread and raise education, awareness, and industry profile.
3. To continuously work towards obtaining better financial deals for the industry in terms of cost-saving, funding, financing, and marketing.
4. To develop intensive programs for capacity building towards creating and increasing skilled personnel and industry champions.
5. To develop relevant advanced R&D and technology at fundamental and commercial levels.
6. To create, develop, and maintain a sustainable supply chain and infrastructure for the industry.

Table 16. The strategies and action plans formulated for each focus area within the timeframe of 2020, 2035, and 2050

Focus Area	Objective	Strategies	Action Plan	Time
Hydrogen Infrastructure	Utilise advances in R&D on hydrogen infrastructure	Improve components in the fuel cell and hydrogen industries	1. Complete the development of the relevant sectors for components in hydrogen production, purification, and in alternative raw materials 2. Fully source hydrogen from existing local hydrogen producers and resources 3. Complete the identification of research, development, and deployment (RD&D) needs and priorities in targeted pilot projects for fuel cell applications	2020
	Establish guidelines, regulations, and policies	Develop comprehensive guidelines, regulations, and policies according to global standards	1. Enhance management skills in commercialisation relevant to the fuel cell industry 2. Demonstrate the capabilities of hydrogen fueling facilities for light-duty vehicles with R & D activities included in the development, testing, and training stages of the operators and personnel involved 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. Include renewable hydrogen (used in fuel cells for electricity generation) in the current list of renewable energy qualified for the Feed-in-Tariff (FiT) program at SEDA	2020
	Raise public awareness	Hold public awareness & advocacy campaigns	1. Successfully raise more market awareness relating to fuel cells through relevant channels and media 2. Successfully raise the nation-wide awareness campaigns on domestic and international career opportunities in 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. Successfully lower the perceived risk of indigenous fuel cell and hydrogen technology through improved public understanding 5. Successfully raise awareness by encouraging fuel cell-based project learning in public education curriculum and work towards developing fuel cell courses at selected schools and universities	2020

Focus Area	Objective	Strategies	Action Plan	Time
Hydrogen Infrastucture	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 data base for 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 high priority by reference to Hydrogen Codes and Standards as well as the accompanying codes and standards 6. Demonstrate and conduct R & D in safe handling of hydrogen used for fuel cells to the public	2020
		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 fuel for light-duty and heavy-duty vehicles through the International Standards Organization (ISO) and Technical Committee (TC197)	2020
	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	2035
	Set up local supply chain and related facilities	Develop local supply chain and specific market penetration	1. Develop Malaysia-based supply chains by adapting 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	2035
	Enhance capacity building in human resources	Build adequate capacity building in human resources for the hydrogen industry	1. Develop training and certification programs 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	2035
	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 in 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 fuel cells in Malaysia by securing high level political buy-in	2050
	Have proven high track records in the industry	Obtain proven high track records of involvement in hydrogen energy industries	1. Successfully 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 refueling 3. Successfully involve fuel cells in the Malaysian market by utilising high profile infrastructure development plan	2050

Focus Area	Objective	Strategies	Action Plan	Time
Fuel Cell Applications	Have satisfactory local standards and policy structure	Establish a policy structure that supports 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 useful 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	2020
	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	2035
	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 Malaysian market environment 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	2035
	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 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	2035
	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 fuel cell industry and technology in Malaysia 2. Successfully develop collaborative high-profile 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 publicise milestone achievements to stakeholders and markets as soon as they are accomplished 5. Formulate a business model that is capable of selling fuel cell at a discount but with sufficient volume secured to reduce payback time and increase return of investment after 3 years	2050
	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 publicly accessible hydrogen refueling stations for the fuel cell transport sector	2050
	Have industry-centric 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 refueling station capabilities 3. Install mechanisms to support deployment of fuel cell vehicles and refueling of hydrogen fuel in Malaysia	2050
		Develop a model city powered by fuel cell technology	1. Execute Distributed Generation (DG) projects by communicating the benefits of DG and adapting 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 4. Provide heat and power using stationary fuel cells to the household and commercial installations 5. Power all security lighting (crime-prevention lamps) and street lamps with fuel cells 6. Plan urban development as a whole, including the next generation transportation system, lifestyle and business opportunities 7. Install subsidy mechanisms to replace the residential power system with fuel cells in order to reduce GHG emissions in the residential sector	2050

Focus Area	Objective	Strategies	Action Plan	Time
Emerging Fuel Cell Technologies	Have 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 programs that can help offset high upfront purchase costs 3. Import management personnel already skilled in technology commercialisation	2020
	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 cost	2035
	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. Successfully collaborate with fuel cell champions on a regional Government - Industry Roadmap in developing commercial-scale infrastructures 3. Successfully 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	2035
	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 at the global setting	2035
	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	2035
	Educate the public on the potentials and benefits of fuel cells	Plan for education programs in higher education institutions	1. Execute a multi-disciplinary approach with a fuel cell focus to various scientific and engineering disciplines 2. Support the development of appropriate skilled and advanced workers for appropriate sectors of fuel cell in Malaysian Universities 3. Run co-op/internship university programs 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	2035
	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	2050

5.0
CONCLUSIONS

5.0 CONCLUSIONS

It is prudent and timely for Malaysia to continue incorporating fuel cell as an alternative energy source and hydrogen as fuel in the Fuel Diversification Strategy in the effort to obtain energy security, reliability and maintenance of the ecological state of the nation. A more focused R&D efforts in fuel cell and hydrogen technologies 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. Substantial investment and support by the government must continue for the development of the fuel cell and hydrogen energy flagship programme by effectively implementing research, development and deployment in Malaysia until 2050 and beyond.

REFERENCES

Abdul Rahman Mohamed and Lee Keat Teong, Energy Policy for Sustainable Development in Malaysia. *The Joint International Conference on "Sustainable Energy and Environment (SEE)*", Hua Hin, Thailand, 1-3 December 2004, pp. 940-944.

Ahmad, N.A. and Abdul-Ghani, A.A. 2011, *Towards Sustainable Development in Malaysia: In the Perspective of Energy Security for Buildings,* Procedia Engineering, 20: pp. 222-229.

Air Liquide, *2014. Air Liquide plans network of new hydrogen filling stations in the United States,* https://www.airliquide.com/media/air-liquide-plans-network-new-hydrogen-filling-stations-united-states, viewed 30th November 2011.

Akorede, M.F., Hizam, H., and Ya'acob, M.E., 2012. *Enhancing the Solar Energy Potential in Malaysia using the Concentrated Photovoltaic (CPV) Technology,* https://connect.innovateuk.org/documents/3166454/3674505/Mudathir+Funsho+Akorede.pdf/1b00ca6a-3e2f-480d-ad14-9171b3a46397, viewed on 30th November 2011.

Amir Hakim Omar, 2013, Executive brief: *Malaysia Oil Refinery in Pahang, Malaysia,* http://www.malaysiaoilrefinery.com/company-profile/executive-brief, viewed on 30th November 2011.

Bal, P.K, *Production of 500 tons per day of pure hydrogen gas from refinery off-gas stream,* 2013.
Center for, C. and Energy, S. 2012, Carbon capture and storage, http://www.c2es.org/technology/factsheet/CCS, viewed on 30th November 2011.

Crosse, J., 2014, *Honda opens new hydrogen filling station in Swindon,* http://www.autocar.co.uk/car-news/industry/honda-opens-new-hydrogen-filling-station-swindon, viewed on 30th November 2011.

Curtin, S. and Gangi, J. 2014. *The Business Case for Fuel Cells 2014: Powering the bottom line for businesses and communities,* http://energy.gov/sites/prod/files/2015/02/f19/fcto_2014_business_case_fuel_cells.pdf, viewed on 30th November 2011

D.O.E., U. 2008, *The Impact of Increased Use of Hydrogen on Petroleum Consumption and Carbon Dioxide Emissions,* http://large.stanford.edu/courses/2010/ph240/usui1/docs/oiafcneaf(08)04.pdf, viewed on 30th November 2011.

Daud, W.R.W, 2006, *Hydrogen economy: Perspective from Malaysia,* http://www.un.org/esa/sustdev/sdissues/energy/op/hydrogen_seminar/presentations/09_ramli_malaysia.pdf, viewed on 30 November 2011.

Daud, W.R.W., *Fuel cell & hydrogen energy: An overview,* presented at the Workshop on Fuel Cell Energy in Malaysia, Academy of Sciences Malaysia, Kuala Lumpur. 3 March 2015.

Dessne, P. and Golmen, L. 2015 *OTEC Matters*, http://www.hb.se/Global/HB%20-%20externt/Forskning/bilder/OTEC%20MATTERS%202015%20webb.pdf, viewed on 30th November 2011.

E4tech 2014, *The Fuel Cell Industry Review,* http://www.fuelcellindustryreview.com/archive/TheFuelCellIndustryReview2014.pdf, viewed on 30th November 2011.

Economic Planning Unit (Prime Minister's Office), 2001, Eighth Malaysia Plan (2001-2005), Kuala Lumpur, Percetakan Nasional Malaysia Berhad.

Economic Planning Unit (Prime Minister's Office), 2006, Ninth Malaysia Plan (2006-2010), Kuala Lumpur, Percetakan Nasional Malaysia Berhad.

Economic Planning Unit (Prime Minister's Office), 2011, Tenth Malaysia Plan (2011-2015). Kuala Lumpur, Percetakan Nasional Malaysia Berhad.

Enerdata.net, 2015, *Natural Gas Subsidies in Malaysia: Current situation and outlook,* http://www.enerdata.net/enerdatauk/press-and-publication/energy-news-001/natural-gas-subsidies-malaysia_31973.html, viewed on16 April 2015.

Hussin, M.Z., Yaacob, A., Rahman, R.A., Zain, Z.M., Shaari, S., and Omar, A.M., 2012, *Monitoring results of Malaysian building integrated PV project in grid-connected Photovoltaic system in Malaysia.* Energy and Power. 2 (3): pp.39-45.

IndexMundi, 2015, Oil - proved reserves - country comparison, http://www.indexmundi.com/g/r.aspx?v=97, viewed 30 November 2011].

Kamarudin, S.K., Daud, W.R.W., Yaakub, Z., Misron, Z., Anuar, W., and Yusuf, N.N.A.N., 2009, *Synthesis and optimization of future hydrogen energy infrastructure planning in Peninsular Malaysia, International Journal of Hydrogen Energy.* 34 (5), pp. 2077-2088.

Lee, C., 2015, *How Does the Oil Price Decline Affect Southeast Asia?,* http://www.iseas.edu.sg/documents/publication/ISEAS_perspective_2015_05.pdf, viewed on 6 May 2015.

Malaysia Energy Information Hub, 2014, *Malaysia Energy Statistics Handbook 2014*, http://meih.st.gov.my/documents/10620/adcd3a01-1643-4c72-bbd7-9bb649b206ee, viewed on 6th April 2015.

Malaysia Productivity Corporation (MPC), 2014, *Reducing unnecessary regulatory burdens on business: downstream oil & gas*, http://www.mpc.gov.my/mpc/images/file/RR2014/Oil%20and%20Gas/Draft%20report.pdf, viewed on 16th April 2015.

Malik, Z.I. and Slack, J.W., 2009, *How to Treat Refinery Gases And Make Them Suitable to Recover Valuable Liquids*, http://www.lppusa.com/international/web/le/us/likeleuslbpp30.nsf/repositorybyalias/lpp_gpa_paper_2009/$file/2009_GPA_Paper_Treating.pdf, viewed on 30th November 2011.

Melaina, M.W., Antonia, O., and Penev, M., 2013, *Blending Hydrogen into Natural Gas Pipeline Networks: A Review of Key Issues*, http://www.nrel.gov/docs/fy13osti/51995.pdf, viewed on 30th November 2011.

Milbrandt, A. and Mann, M. 2009, *Hydrogen Resource Assessment: Hydrogen Potential from Coal, Natural Gas, Nuclear, and Hydro Power*, http://www.nrel.gov/docs/fy09osti/42773.pdf, viewed on10th May 2015.

Nadzri Yahaya (Deputy Secretary General of KeTTHA), 2014, *Malaysia's Energy Mix & Outlook*, http://mys.mofa.go.kr/webmodule/common/download.jsp?boardid=13837&tablename=TYPE_

National Research Council and National Academy of Engineering of the National Academies, 2004, *Carbon Capture and Storage: The rationale of carbon capture and storage from hydrogen production, pp. 84-90, In "The hydrogen economy: Opportunities, costs, barriers, and R&D needs"*, Washington, D.C.: The National Academies Press.

Nedstack.com, 2014, *Nedstacks PEM Power Plant passes 40,000 hrs of operation*, http://www.nedstack.com/about-us/nedstack-in-the-news, viewed on 30th November 2011.

Netinform.net, 2015, *Hydrogen Filling Stations Worldwide – H2-Stations*, http://www.netinform.net/H2/H2Stations/Default.aspx, viewed on 30th November 2011].

Papageorgopoulos, D, *"Fuel Cells Program," presented at the The US DOE's Annual Merit Review and Peer Evaluation Meeting*, Arlington, Virginia. 8-12 June 2015.

Ramachandrana, S. and Stimming, U. 2015, *Well to wheel analysis of low carbon alternatives for road traffic*, http://pubs.rsc.org/en/content/articlepdf/2015/ee/c5ee01512, viewed on 30th November 2011.

Renewable Energy and Energy Efficient Partnership 2012, Malaysia, 2012, http://www.reegle.info/policy-and-regulatory-overviews/MY, viewed on 19th April 2015.

Rostrup-Nielsen, J.R. and Rostrup-Nielsen, T. 2001, *Topsoe Technologies: Large-scale hydrogen production*, http://www.topsoe.com/sites/default/files/topsoe_large_scale_hydrogen_produc.pdf, viewed on 30th November 2011].

Spendelow, J. and Marcinkoski, J. 2014, *Fuel Cell System Cost - 2013*, http://energy.gov/sites/prod files/14012_fuel_cell_system_cost_2013.pdf, viewed on 30th November 2011.

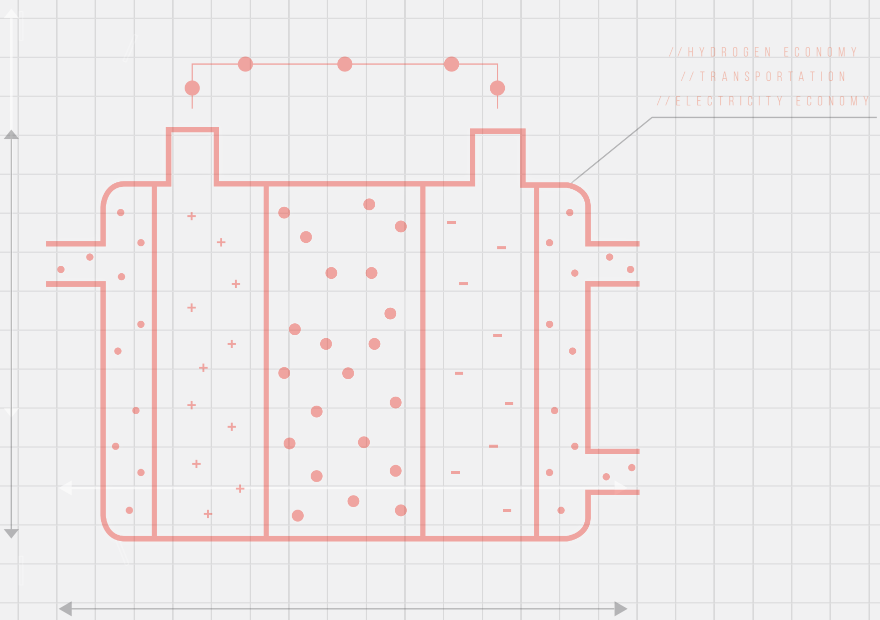
U.S. Energy Information Administration, 2014, Malaysia, http://www.eia.gov/countries/analysisbriefs Malaysia/malaysia.pdf, viewed on 13th April 2015.

Vega, L.A. 2010, *Ocean Thermal Energy Conversion*, http://hinmrec.hnei.hawaii.edu/wp-content/uploads/2010/01/Published-Article-OTEC-by-Vega-Aug-2012.pdf, viewed on 30th November 2011.

Vega, L.A. 2013, *OTEC overview*, http://www.otecnews.org/portal/otec-articles/ocean-thermal-energy-conversion-otec-by-l-a-vega-ph-d/ viewed on 30th November 2011].

Weimar, M.R., Chick, L.A., Gotthold, D.W., and Whyatt, G.A. 2013, *Cost study for manufacturing of solid oxide fuel cell power systems*, http://www.pnnl.gov/main/publications/external/technical_reports/PNNL-22732.pdf, viewed on 30th November 2011.

Worldbank.org, 2015, *The World Bank: Ease of Doing Business Index*, http://data.worldbank.org/indicator/IC.BUS.EASE.XQ, viewed on 7th May 2015.



Academy of Sciences Malaysia
Level 20, West Wing, MATRADE Tower, Jalan Sultan Haji Ahmad Shah,
off Jalan Tuanku Abdul Halim, 50480 Kuala Lumpur, Malaysia

Phone : +6 (03) 6203 0633
Fax : +6 (03) 6203 0634

www.akademisains.gov.my

ISBN 9789832915300

9 789832 915300