INDUSTRY TECHNOLOGY ROADMAP ON HYDROGEN PRODUCTION FROM THE OCEAN THERMAL ENERGY CONVERSION INDUSTRY IN MALAYSIA

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INDUSTRY TECHNOLOGY ROADMAP ON HYDROGEN PRODUCTION FROM THE OCEAN THERMAL ENERGY CONVERSION INDUSTRY IN MALAYSIA

ONG GUI XIAN

A thesis submitted in fulfilment of the
requirements for the award of the degree of
Master of Philosophy

Malaysia-Japan International Institute of Technology
Universiti Teknologi Malaysia

JUNE 2016

I declare that this thesis entitled " *Industry Technology Roadmap on Hydrogen Production for the Ocean Thermal Energy Conversion Industry in Malaysia* " is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

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To my beloved father and mother

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ABSTRACT

The purpose of this research is to propose an Industry Technology Roadmap on Hydrogen Production for the Ocean Thermal Energy Conversion (OTEC) Industry in Malaysia. This research seeks to leverage foresight approaches to discover critical elements in the OTEC ecosystem, which can support the development of the roadmap for the OTEC industry in Malaysia. This research will identify future market goals for the OTEC industry and provide various technological and other supportive industry-level solutions to achieve their goals. Ultimately, this will help OTEC companies and the whole OTEC industry to plan their future. This research adopted a qualitative approach, utilizing the case study method. Data was collected through semi-structured interviews and focus groups encompassed of experts in the related field, document analysis including the data gathered through an environmental scanning seminar. The scope of the study is limited to the context of Malaysia, and on a single OTEC product, which is hydrogen. The resulting roadmap provides the OTEC industry with information about enabling technologies, required properties, and the current landscape of the OTEC industry, which suggests that research should focus on biofouling of heat exchangers, corrosion, frequency instabilities in generator and violent out-gassing of cold seawater in condenser. This can help the OTEC industry to make informed investment into research and development, and contribute new knowledge for OTEC to be given due consideration as an alternative energy generation source for the hydrogen economy.

ABSTRAK

Tujuan kajian ini adalah untuk mencadangkan satu pelan Hala Tuju Teknologi Industri dalam Pengeluaran Hidrogen untuk industri *Ocean Thermal Energy Conversion* (OTEC) di Malaysia. Kajian ini menggunakan kaedah '*foresight'* dalam mengenalpasti elemen-elemen kritikal dan penting dalam ekosistem OTEC, yang boleh menyokong penggubalan pelan hala tuju ini bagi Industri OTEC di Malaysia. Kajian ini mengenalpasti matlamat pemasaran masa depan industri OTEC dan memberi pelbagai cadangan penyelesaian teknologi pada tahap industri untuk mencapai matlamat utama industri tersebut. Ini akhirnya diharapkan dapat membantu syarikat dalam industri OTEC secara kesuluruhannya membuat perancangan masa depan mereka. Kajian ini menggunakan pendekatan kualitatif, iaitu melalui kaedah kajian kes. Data kajian dikumpulkan melalui temubual separa berstruktur dan kumpulan fokus merangkumi daripada pakar-pakar dalam bidang berkaitan, analisis dokumen termasuk data yang dikumpulkan melalui satu seminar mengimbas persekitaran (*environmental scanning*). Skop kajian ini hanya terhad kepada konteks di Malaysia, dan produk OTEC tunggal, iaitu hidrogen. Pelan hala tuju yang terhasil dapat melengkapkan industri OTEC dengan maklumat yang komprehensif tentang teknologi kritikal, ciri-ciri yang diperlukan, serta landskap industri OTEC semasa secara menyeluruh yang menunjukkan bahawa penyelidikan perlu memberi fokus kepada *biofouling* penukar haba, hakisan, ketidakstabilan frekuensi dalam penjana dan *out-gassing* air laut sejuk dalam pemeluwap. Pelan hala tuju ini dapat membantu industi OTEC membuat pelaburan yang terarah dalam penyelidikan dan pembangunan, serta memyumbang ilmu baharu untuk mengigihkan OTEC sebagai salah satu sumber penjanaan tenaga alternatif ekonomi hidrogen.

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LIST OF ABBREVIATIONS

CAPEX	-	Capital Expenditure
COE	-	Cost of Energy
DSW	-	Deep Sea Water
EIA	-	Environmental Impact Assessment
EPCC	-	Engineering Procurement Construction and Commissioning
FIT	-	Feed-in Tariff
LCOE	-	Levelized Cost of Electricity
ODA	-	OTEC Desalination Aquaculture
OTEC	-	Ocean Thermal Energy Conversion
SDC	-	Seawater District Cooling
SWAC	-	Seawater Air Conditioning

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CHAPTER 1

INTRODUCTION

1.1 Introduction

The energy trilemma; energy security, energy equity and environmental sustainability is a growing concern which will contribute to a significant development of the new economy (World Energy Council, 2013; Quirapas, Lin, Abundo, *et al.*, 2015; World Economic Forum, 2012) Innovative technology solutions are needed to prepare for the projected growth in energy consumption and to ensure a sustainable future. Research and development exploration, technology development, analysis, as well the limiting challenges and barriers of an alternative energy solutions need to be understood and addressed (Ikegami, 2015; Kehoe, 2013). Comprehensive policies and guidelines, which may direct concerted technology development is needed to address the range of interconnected issues within the energy industry (Ocean Energy Systems, 2014).

This study examines the Ocean Thermal Energy Conversion (OTEC) industry, which has high potential to address a multitude of issues. OTEC is an emerging industry that can contribute significant value proposition to the Malaysian economy as well as provide energy security and sustainability (Aini Suzana Haji Ariffin, 2015; Akbariah Mohd Mahdzir & Marziah Hj. Zahar, 2015; Bakar Jaafar, Mohd Haris Abdul Rani, Aini Suzana Haji Ariffin, *et al.*, 2015). Though long neglected in development, the technological advancements in other fields and integration of crosscutting industry technology solutions now provide more feasible opportunities for the OTEC industry (Vega, 2015).

Strategic planning is necessary to facilitate the careful development of an emerging industry such as OTEC (Aini Suzana Ariffin & Ong, 2015). The strategic planning enables a systematic and comprehensive approach to developing the OTEC industry through: the establishment of key linkages between technology resources and business drivers; identification of important gaps in market, product and technology intelligence; technology strategy and planning initiatives; and communication between technical and commercial functions (Phaal, Farrukh & Probert, 2001).

One method to facilitate the strategic planning of an emerging industry is through a foresight activity. This activity leverages information across industries and stakeholders, as new knowledge and ideas may be triggered to create new technology, markets or improve its current technologies so it meets the rapid change and customer needs. The importance of communication among various stakeholders and willingness to share their information is imperative to catalyze progressive development of an industry. The main goal of the foresight is to anticipate and shape the futures, which are strategic for the organization. These areas include the organization's ability to anticipate emerging opportunities and threats in the environment, identify dependence paths (networks), and success factors (drivers) (Ejdys, 2013). Foresight has been used at various industry levels to provide numerous benefits and impact on policy and decision making (Calof & Smith, 2012)

The OTEC related companies, industry associations, and academia have already shown interest in the development of a commercial OTEC plant. In order to successfully implement the first OTEC pilot plant in Malaysia, various factors must be considered and critical requirements need to be fulfilled. A strategic planning activity, which adopts the foresight methodology may provide an Industry Technology Roadmap for the OTEC industry, which could serve as a clear direction for future development.

Besides providing a comprehensive future path, The Industry Technology Roadmap for the OTEC industry may also serve as a communication tool for industry members particularly, to help improve and create knowledge, initiate partnerships, and focus resources. The discovery of technology alternatives may identify ways to leverage research and development investment through coordinating research activities and trigger financial or infrastructural support from the government. In addition, this study will also be beneficial in providing inputs for the formulation of technology policies and strategies that will guide the development of the technological infrastructure in Malaysia. This research will also support the OTEC industry to provide support to innovation, incentives and assistance to various parties in the domain of technology management and technology transfer, leading to enhanced competitiveness and growth. Finally, the research may also serve as a benchmark for the use of Industry Technology Roadmapping as an effective technology management tool.

1.2 Statement of the problem

Energy is the cornerstone of societal needs and economic growth. The issue of energy security is paramount to meet the fast rising energy demands (Asia Pacific Economic Cooperation, 2013; Tabakoglu & Lymberopoulos, 2008; World Energy Council, 2013). The International Energy Agency (2015) defines energy security as uninterrupted availability of energy sources at an affordable price. The long-term energy security mainly deals with timely investments to supply energy in line with economic developments and environmental needs. This calls for an exploration, development and promotion of alternative energies, in face of the declining fossil fuel reserves (Hoel & Kverndokk, 1996; Höök & Tang, 2013)

The changing global landscape has spurred a renewed interest in OTEC at various parts of the world (Tellado, 2008). The main drivers for this includes the rising cost of fossil fuels, and the increasing environmental impact concerns (Plocek, Laboy, Associates, *et al.*, 2009). Oil prices are projected to rise steadily from $92 per barrel in 2013, to $128 per barrel by the year 2035 (International Energy Agency, 2013). The effects of global warming is a prevalent concern, and the emissions of greenhouse gas from combustion of fuels (from renewable or non-renewable sources) needs to be managed (Chong & Lam, 2013). The exploitation of clean and renewable energy alternatives may be used as a solution to safeguard the environment. A potentially viable option is OTEC, since it does not use fossil fuels or nuclear energy, and has the highest potential (estimated 300 exajoules (EJ) per year or 90% of the global ocean energy potential) when comparing all ocean energy technologies, and as many as 98 nations and territories have been identified to have viable OTEC resources (Lewis, *et al*., 2011). Studies by Rajagopalan and Nihous, (2013) suggest that total worldwide power generation capacity could be supplied by OTEC, and that this would have little or no impact on the ocean's temperature profiles. Furthermore, numerous island states in the Caribbean and Pacific Ocean have OTEC potential within 10 km of their shores (IRENA, 2014). OTEC seems especially suitable and economically viable for remote islands in tropical seas where generation can be combined with other functions e.g., air-conditioning and fresh water production (Magesh, 2010). In short, OTEC offers attractive alternatives in finding the solution to energy security issue, as it is economically feasible and environmentally friendly.

Reviewing the recent developments of OTEC around the world, several countries are actively pursuing large-scale initiatives on OTEC, such as mapping the strategic direction of OTEC development. For example, companies and governments in France, Japan, the Philippines and South Korea have developed roadmaps for OTEC development (DCNS, 2013; Ikegami, 2015; Marasigan, 2012; Kim & Yeo, 2013). Indonesia is mapping its OTEC potential (Achiruddin, 2011), and the Philippines has been considering feed-in tariffs for OTEC (National Renewable Energy Board, 2012).

For the case of Malaysia, a new law on ocean thermal energy development is being proposed (Jaafar, 2013). The press release by MIMA (2013) indicated itself as a strong proponent for the OTEC as an alternative energy source for the future. In the year 2011, approvals were granted from the Malaysian government for the Ocean Thermal Energy Corporation to conduct a study to generate electricity from the deep sea in Sabah, Malaysia (Bernama, 2012). However till the year 2015, there are lacks reference guidelines and technical inputs to inform much needed policy formulations, gauge readiness, and support investment decisions.

In order to address this need in strategic direction, as from the outset of any emerging technology study, Technology Roadmapping may be adopted. This approach is beneficial to suggest development prioritizations (Lin, Chan & Ien, 2013). The use of technology foresight for OTEC development will significantly facilitate strategic planning; therefore a technology roadmap should be developed and implemented in planning for the OTEC industry. Roadmapping, in the context of OTEC is urged by Kehoe, (2013) who reiterates that a:

> "—multi-national vision, strategy and collaboration is needed to; conduct fundamental and applied OTEC research, develop a stable market structure for OTEC, identify areas suitable for development, perform in situ environmental studies, build a trained OTEC workforce, contracting services and infrastructure, improve performance and reduce costs, and resolve grid integration issues."

Although it is commonly agreed that roadmapping is beneficial to set direction and determine research priorities (Cable, Tayler & Tindal, 2010; Ocean Energy Systems, 2014), an OTEC industry technology roadmap has not yet been developed in the context of Malaysia. This research may address this gap in knowledge that may hinder OTEC's development in Malaysia by leveraging on existing OTEC roadmaps of France, Japan, Philippines, and South Korea. This research attempts to provide an overview of the OTEC industry, including future product performance goals, opportunities, challenges, and technological solutions for achieving the goals at the industry level. This is based on the synthesized insights of various sources, including an environmental scanning seminar, focus group discussions, interviews, patent analysis, and the current literature available on OTEC.

According to Frow and Payne, (2011) only less than 10 percent of firms have managed to successfully develop and communicate their value propositions. Such may be developed through this research, since a roadmap also serves as a communication tool for industry members firstly, to help improve and create knowledge, initiate partnership and focus resource. The proposed roadmap is hope to be able to assist in the identification of specific topics on which to focus R & D on, hence able to assist in funding strategies. Hopefully, it will assist in identifying the areas of strategic research and the cross cutting technologies that will generate highest economic revenue and create value to society. It is hoped that the roadmap will also direct the ways to leverage R & D investment through coordinating research activities. This will further enhance the collaboration and knowledge exchange between research organizations and all OTEC related entities. The proposed roadmap will also be able to direct and inform business investment that can accelerate OTEC development, and most importantly will also be beneficial in providing inputs for the formulation of related policies and strategies that will guide the development of OTEC in Malaysia. Besides that, this research will support the OTEC industry to provide support to innovation, incentives and assistance to various parties in the domain of technology management and technology transfer, leading to enhanced competitiveness and growth. Lastly, the research may also serve as a benchmark for the use of Industry Technology Roadmapping as an effective technology management tool.

1.3 Purpose of Research

The purpose of this research is to propose the development of an Industry Technology Roadmap on hydrogen production for the OTEC industry in Malaysia. This research will identify future market goals for the OTEC industry and provide various technological and other supportive industry-level solutions to achieve their goals. Ultimately, this will help OTEC-related companies and the whole OTEC industry to plan their future ventures.

1.4 Research Objective and Questions

The objective of this research is to develop and propose an Industry Technology Roadmap on hydrogen production for the OTEC industry in Malaysia.

Two main research questions will be addressed;

i. What are the critical elements in the OTEC ecosystem that need to be considered in the development of the OTEC Industry Technology Roadmap?
   a. What are the key elements that play major role in ensuring the success planning, implementation, execution and monitoring in the OTEC ecosystem?
   b. How did the Malaysian energy and research community perceive OTEC future potential, particularly on hydrogen production?
   c. To what extent are the OTEC-related technologies readily available?
   d. How may the development of OTEC industry be hindered, in the context of Malaysia?

ii. What would be a feasible Industry Technology Roadmap to be adopted for the development of OTEC industry in Malaysia?

1.5 Conceptual Framework

The conceptual framework of this research links the theory of complexity with the technology roadmapping model as shown in Figure 1.1.

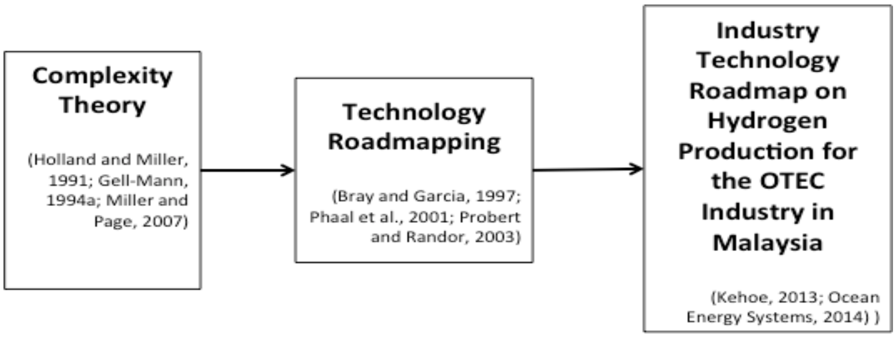

Figure 1.1 Conceptual Framework

The intricateness of technology roadmapping is reflective of the state of complexity of which various social structures and interlinking forces interact to create a dynamic system. This 'complexity' is difficult to account for by reducing each to its respective parts and components. Thus, when various components are combined or interlinked, a particular synergy occurs which gives rise to more formidable and dynamic creations. This type of organic interaction and resulting synergy (in the form of dialogue and discussions) is necessary for the development of an emerging industry, whereby the future is uncertain, resources limited, and knowledge relatively scarce.

Based on these premises, this research seeks the development of an Industry Technology Roadmap on hydrogen production for the OTEC industry in Malaysia. The theory of complexity provides sound grounding and is especially relevant since the OTEC industry is 'complex', with various by-products and sub-industries (including hydrogen).

Leveraging on the foresight approach to develop the Industry Technology Roadmap, it should be noted that the complex interlinking interaction process is also intrinsic in a foresight activity. The goal of foresight is to make every effort to shape and create the future, which allows the foresight practitioners to investigate and improve the interactions between people and the broader decision environment. Thus, humans play a significant role in adapting and responding to unexpected or unknown situations in addition to recognized situations. The foresight processes and tools facilitate people in their decision-making processes, especially in optimally promoting creative problem solving, adaptability and learning through collective thoughts.

The conceptualization of foresight through the lens of complexity theory can be explained as, "the whole being greater than the sum of its parts". This means that in the context of an intricate system with various interplaying components, it is difficult to reduce each to its singular functions and properties. The result of such interconnectedness is difficult to anticipate, and through concerted discussions, bring powerfully synergistic ideas into motion. This interlinking process is a foundation in foresight and attempts to express the complex workings of an industry. From these perspectives, the complexity theory may be used as theoretical underpinning to develop the Industry Technology Roadmap on hydrogen production for the OTEC industry in Malaysia, and may provide bearing to help fulfil the rising energy needs of society.

1.6 Operational Definition

From the outset, is helpful to illustrate definitions of pertinent foresight terms.

Foresight: A set of strategic tools that support government and industrial decisions, by availing sufficient time for societal preparation. This may include examination of geopolitical, socioeconomic, and strategic response from corporate managers (Calof & Smith, 2012).

Technology Foresight: The process involved in "systematically attempting to look into the longer term future of science, technology, the economy and society with the aim of identifying the areas of strategic research and the emerging generic technologies likely to yield the greatest economic and social benefits" (Martin, 1993).

Technology Roadmapping: A goal oriented technique for supporting technology management and planning (United Nations, 2005).

Industry Technology Roadmapping: A roadmap made at the level of the industry. "..At the industry level, technology roadmapping involves multiple companies, either as a consortium or an entire industry (industry technology roadmap). By focusing on common needs, companies can more effectively address critical research and collaboratively develop the common technologies" (Bray & Garcia, 1997)

Strategic foresight: A system used to support companies in endeavours to maintain sensitivity to their environment (Rohrbeck, Mahdjour, Knob, *et al.*, 2009). Strategic foresight seeks to; detect developments in the corporate environment, and align decision-making processes to support the results from on-going foresight activities.

Corporate foresight: A process of communication (within a private company) focused to build a mid-to long term vision of future markets, customer needs, and societal challenges (Will, 2008; Scheiner, Baccarella, Bessant, *et al.*, 2014)

Forecasting: Estimating in "unknown" situations (Cuhls, 2003).

Strategic planning: the process by which a system maintains its competitiveness within its work environment by determining where the organization is, where it wants to go, and how it wishes to get there (Katsioloudes, 2012).

Emerging industry: emerging industries are those where no clear or established value chain currently exists. These can either be those where a new technology exists and there is no clear market and therefore no route to market, or those where a market exists but the introduction of a new technology could rearrange or destroy the existing value chain or industry. (Lubik, Lim, Platts, *et al.*, 2013)

1.7 Limitations

The scope of study for this research is limited to OTEC development in Malaysia, in particular hydrogen production. Although the sample for this study was reasonably strong, because this research used purposive sampling, the results cannot be generalized to the entire population, and the resulting Roadmap may not be representative of the entire OTEC industry that includes its various spin-off products.

1.8 Summary of Thesis

As a background to this study, Chapter 2 addresses pertinent theoretical issues while Chapter 3 describes the methodology of the study. Chapter 4 outlines the Malaysia OTEC potential with the empirical foundation. Chapter 5 reviews the implications of the empirical findings and summarizes the main findings of the study. Each of the chapters is briefly reviewed as follows:

Chapter 1 - **Introduction**
Provides a brief overview of the research.

Chapter 2 - **Literature Review**
This chapter was designed to link technology foresight strategies with the complexity theory, as framed in the research model. The literature also reviewed developments in the OTEC industry including its advancements by region, value proposition, and cost factor. The need to develop an OTEC industry technology roadmap was proposed.

Chapter 3 - **Methodology**
This chapter details the procedures employed in gathering the empirical material for this study. It emphasizes that a qualitative approach, using the case study method was adopted for the study as it afforded more detailed understanding on the potential of OTEC. Data was collected through three phases; environmental scanning seminar, focus group, and semi-structured interviews. These were triangulated to produce valid and reliable results.

Chapter 4 - **Results and Interpretation**

The industry technology roadmap for OTEC in Malaysia is discussed in regards to the OTEC technology development, hydrogen product applications, and OTEC challenges.

The chapter argues that the Malaysian OTEC development will be greatly facilitated if it is grounded on strong government support.

Chapter 5 - **Conclusion**

This chapter provides a summary of the principal findings of this study including their managerial and policy implications. The main theme emitting from these findings, as well as throughout this study, is that government support matters and it is a prerequisite for success in research prioritization. An OTEC industry technology roadmap based on the findings of this study is presented. Some suggestions for future research are made.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

A review of literature is conducted to provide the theoretical and industrial context of this study. Firstly, the conceptual framework is discussed. This explains the theory of complexity, which provides theoretical underpinning for Technology Roadmapping. Next, a brief overview of the energy scenario is presented, including the global outlook, and the national outlook. Finally, the current state of the OTEC industry is outlined, encompassing the OTEC concept, regional developments, roadmaps, value propositions, and costs.

2.2 Conceptual Framework

The conceptual framework for this research is based on the theory of complexity (Holland & Miller, 1991; Gell-Mann, 1994a; Miller & Page, 2007). This theory may be used as theoretical underpinning for technology roadmapping (Bray & Garcia, 1997; Phaal, Farrukh & Probert, 2001; Probert & Randor, 2003), which is a strategic planning tool that is effectively used to chart an industry or organization's future direction. The conceptual framework is depicted in Figure 2.1 below. More specifically, the focus of this research is to provide an Industry Technology Roadmap on Hydrogen Production for the OTEC Industry in Malaysia, to help fulfill the growing energy needs of the nation.

Through the development of the Technology Roadmap for OTEC (Kehoe, 2013), the researcher may identify the critical elements that need to be considered in the OTEC ecosystem. This includes the extent of which the OTEC related technology is readily available, viable technology options, the perception of the OTEC future potential (particularly on hydrogen production), and some challenges that may be faced in its development.

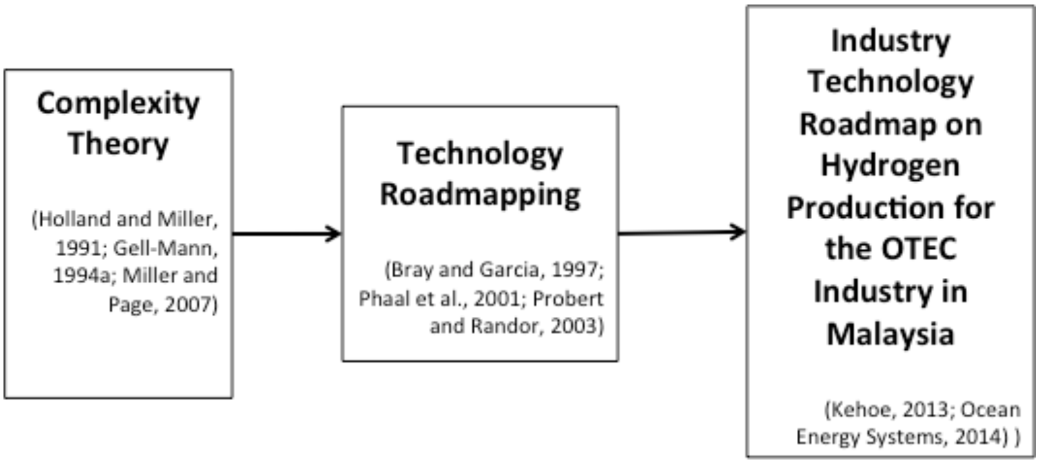

Figure 2.1 Conceptual Framework

2.2.1 Complexity Theory

The theory of complexity seeks to explain how the general output of a system is greater than the sum of its parts. It should be noted that the term ‘complexity’ refers to a particular behaviour that occurs from the interactions of complex adaptive systems (CAS) (Holland & Miller, 1991; Gell-Mann, 1994b; Miller & Page, 2007) and not to the system in itself.

A CAS is made up of partially connected agents (in moderately-structured systems) whose interaction result in the 'complex' behaviour that is representative of these systems (Gell-Mann, 1994a). Within a CAS, each entity acts individually, but also in affect and effect with the other agents, and the environment. These interactions constantly exist, in structured systems, moderately-structured systems, or less-structured systems. In more structured systems, the emergent behaviour of the interactions are more easily known or predicted, due to its highly observed regularities. A less-structured system too, may have dependable outcomes, based on the theory of randomness. However, Eisenhardt and Pienzunka (2011) argues that the moderately structured systems have rather uncertain interactions (that can neither be described by complete structure or randomness), thus highly unpredictable emergent behaviour, which may be termed as 'complex'.

Davis *et al.*, (2009) discusses the theory of complexity by highlighting two key aspects, which is the optimal amount of structure of a system, and the optimal amount of structure in relation to the environment. He states that the amount of structure in a system has a direct effect on the efficiency or flexibility of the system. In that regard, a higher amount of structure would allow for systems to be more efficient, but less flexible. Whereas, a lower amount of structure would allow for systems to be more flexible, but less efficient. These trade-offs function at the extreme, whereby a system may either be too 'loosely connected', and highly error prone, or too 'gridlocked' and lack adaptiveness. Thus, Kauffman, (1995), Langton (1990), and Gell-Mann (1994a) agree that the partially connected systems may offer greater benefits, at being both optimally efficient and flexible.

Further to the complexity theory addresses the optimal structure of the system in relation to the environment (Davis, Eisenhardt & Bingham, 2009; Eisenhardt & Sull, 2001). By this, the level of structure in a system may be adequately modelled on the level of environmental uncertainty. Following the logic previously highlighted by Davis *et al.*, (2009), the higher levels of environmental uncertainty would require a less structured system to allow for greater flexibility. The opposite is true for more known environment, with greater predictability. Therefore, the environmental uncertainty plays a vital role in planning for the optimal degree of structure in a system.

It is commonly agreed that moderately-structured systems are advantageous in allowing for more robust functions (Davis, Eisenhardt & Bingham, 2009; Eisenhardt & Sull, 2001). In these moderately-structured systems, exist a transition phase between stability and instability, or randomness and regularity, which is termed as the ‘edge of chaos’(Langton, 1990; Marion & Bacon, 2000; Pascale, 1999). According to Eisenhardt and Pienzunka, (2011), this is where ‘complex’ behaviour emerges. The edge of chaos may be described as a continually evolving equilibrium which requires inputs such as interactions, networks, structures and formalizations for it to continually function at this dissipative state.

Complex interactions of the systems or networks, is described as causal and non-linear (Andreaoni & Miller, 1995; Dent, 1999; Marion & Bacon, 2000). The effects of these interactions explain the crux of complexity theory, which is the concept of emergence. The emergence which results, is a function of synergism between the various interacting agents (Lansing & Kremer, 1993). However, it is important to note that a system’s emergent qualities may not necessarily be methodologically traceable to the characteristics of each agent, or internal component (Baas & Emmeche, 1997).

2.2.2 Strategic Planning and Foresight

Strategic planning is defined as, “the process by which a system maintains its competitiveness within its work environment by determining where the organization is, where it wants to go, and how it wishes to get there” (Katsioloudes, 2012).

For the context of this study, it is useful to establish the integration of foresight into strategic thinking. According to Zahra & Nambisan, (2012), strategic thinking consists of foresight and insight. This is also explained by Voros, (2003), stating that the foresight process provides input into the consideration of decisions and the implementation of actions, which outputs results in strategy. This is illustrated in Figure 2.2. In this concept, inputs inform the foresight phase incudes the analysis, interpretation, and prospection. The formulating of these outputs, which suggest “what might we need to do”, will serve as development of strategy, which answers the questions, “what will we do”, and “how will we do it?”

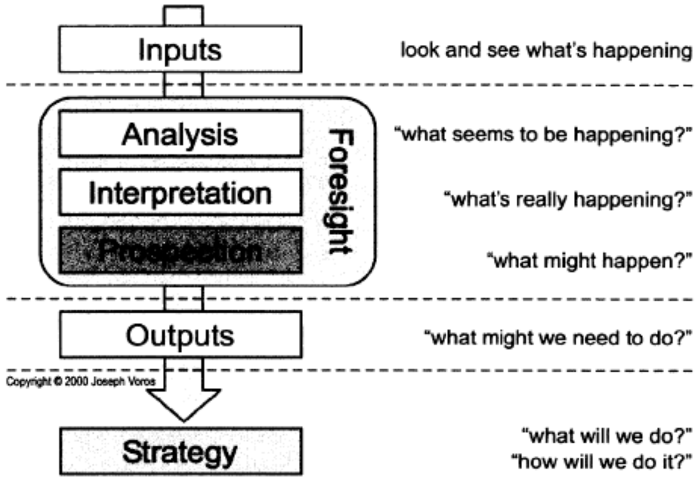

Figure 2.2 Generic foresight model, (Voros, 2003)

Strategic foresight, therefore is a system used to support companies in endeavours to maintain sensitivity to their environment (Rohrbeck, Mahdjour, Knob, *et al.*, 2009). Strategic foresight seeks to; detect developments in the corporate environment, and align decision-making processes to support the results from on-going foresight activities.

Slaughter (1995) asserts that foresight is something that is pervasively needed in today’s knowledge societies. On the whole, foresight activities imply a future orientation of the participating entities, and attempt to facilitate their ability to prepare for and manage change (Scheiner, Baccarella, Bessant, *et al.*, 2014; Amsteus, 2008).

The simplest definition of foresight is offered by Loveridge and Cox, (2013) who describe foresight as ‘the act of looking forward’. This is contrary to forecasting, whereby the end-point is a finite forecast, without guidelines or methods for how these will be achieved (Yu & Yu, 2006). Foresight on the other hand, seeks to identify technologies that have a strong influence on the future.

In greater detail, foresight is as defined by Martin (2010) as “a process by which one comes to a fuller understanding of the forces shaping the long-term future which should be taken into account in policy formulation, planning and decision-making”

There are various methods for foresight, which should be selected based on their suitability to achieve the activity goals and resources available. The different foresight methods can be surmised in Popper's (2008) foresight diamond model, as shown in Figure 2.3. This depicts the different methods according to their inclination level of creativity, interaction, evidence, and or expertise. These methods may be classified as qualitative, semi-qualitative, quantitative, or others.

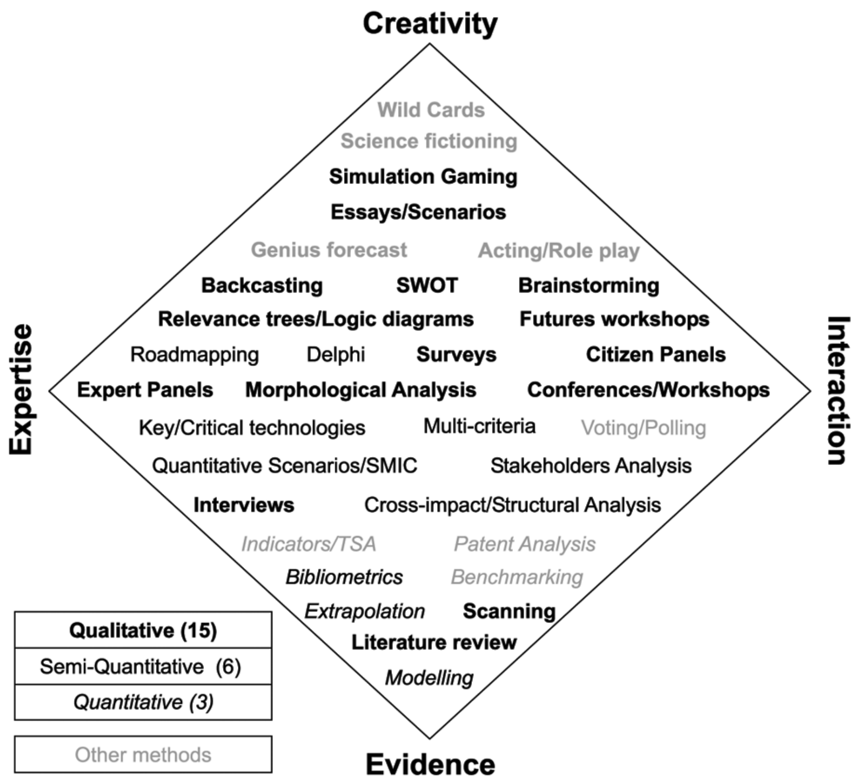

Figure 2.3 Foresight diamond (Popper, 2008a)

2.2.3 Technology Foresight and Technology Roadmapping

When foresight approach is targeted at the far-future implications of science and technology, the more specific 'Technology Foresight' activity is employed. Technology foresight is defined as

> "the process involved in systematically attempting to look into the longer term future of science, technology, the economy and society with the aim of identifying the areas of strategic research and the emerging generic technologies likely to yield the greatest economic and social benefits"
>
> (Martin, 1993).

One commonly used method of Technology Foresight is Technology Roadmapping (TRM), which is a goal oriented technique for supporting technology management and planning (United Nations, 2005). By this, some key areas are identified, such as the critical product needs of future markets, critical technologies, technology gaps, technology alternatives, and a time frame (Garcia & Bray, 1997; Probert & Randor, 2003).

It is important to differentiate technology forecast from technology roadmapping. Technology forecasting tends to ask, "Where is technology going?" or "When will technological change happen?", which focuses on the future uncertainty and providing alternative future states, thus contingency plans and perquisites or consequences of each. However, a technology Roadmapping seek to answer, "Where do we want to go?", "Where are we?" and "How can we get there?".

Technology Roadmapping is widely adopted in industry for firm planning and management (Willyard and McClees, 1987; Barker and Smith, 1995; Bray and Garcia, 1997; EIRMA, 1997 Groenveld, 1997; Strauss *et al*., 1998; Albright and Kappel, 2003; McMillan, 2003), and more recently, to support national and sector foresight initiatives (SIA, 2001; Phaal, 2002). The applications by sector and its focus or aims are shown in Table 2.1.

Table 2.1: Applications of Technology Roadmapping (United Nations, 2005)

Sector/Product	Focus/Aims
Industrial coding (3 applications)	Product planning
Postal services (10 applications)	Integration of R&D into business: business planning
Security/access systems	Product planning
Software	Product planning
Surface coatings	New product development process
Medical packaging (2 applications)	Business reconfiguration
Automotive sub-systems	Service development and planning
Power transmission	Business opportunities for new technology
Railway infrastructure (3 applications)	Capital investment planning and technology insertion
National security infrastructure	Research programme planning
Building environmental controls	New product/service opportunity: business reconfiguration
Road transport	Defining national research agenda: network development
Technical consulting (6 applications)	New service development
Automotive/aerospace	Corporate synergy
Academic (2 applications)	Strategic planning
Bio-catalysis	Research planning; network development
Satellite navigation	Research planning; network development
Food processing	Research planning; network development
Pneumatic systems	Innovation strategy
Emerging technologies	Research priorities
Automotive	Innovation opportunities
Retail (2 applications)	Business strategy and product planning
Off road vehicles	Global production strategy

Among some benefits of Technology Roadmapping (TRM), T-Plan "fast start approach" by Phaal *et al*. (2001) are:

i. Support the start-up of company-specific TRM processes.
ii. Establish key linkages between technology resources and business drivers.
iii. Identify important gaps in market, product and technology intelligence.
iv. Develop a "first-cut" technology roadmap.
v. Support technology strategy and planning initiatives in the firm.
vi. Support communication between technical and commercial functions

Technology roadmapping is an inherently flexible technique, in terms of:

i. The wide range of aims that roadmapping can contribute towards.
ii. The time frame covered by the roadmap (past and future).
iii. The structure of the roadmap, in terms of layers and sub-layers, which can be adapted to fit the particular application.
iv. The process that is followed to develop and maintain the roadmap/s.
v. The graphical format that is selected to present information and communicate the roadmap.
vi. The set of existing processes, tools and information sources in the firm which the roadmap and roadmapping process need to integrate with.

Figure 2.4 and Figure 2.5 provide a depiction of a generalized technology roadmap architecture, and also a roadmap integration of commercial and technological knowledge.

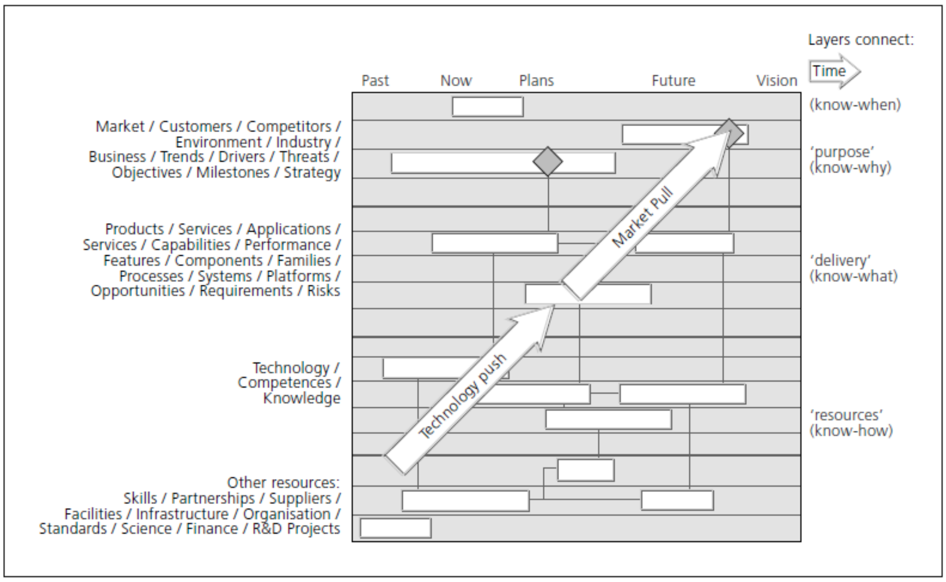

Figure 2.4 Generalized Technology Roadmap Architecture (Probert, Farrukh & Phaal, 2003)

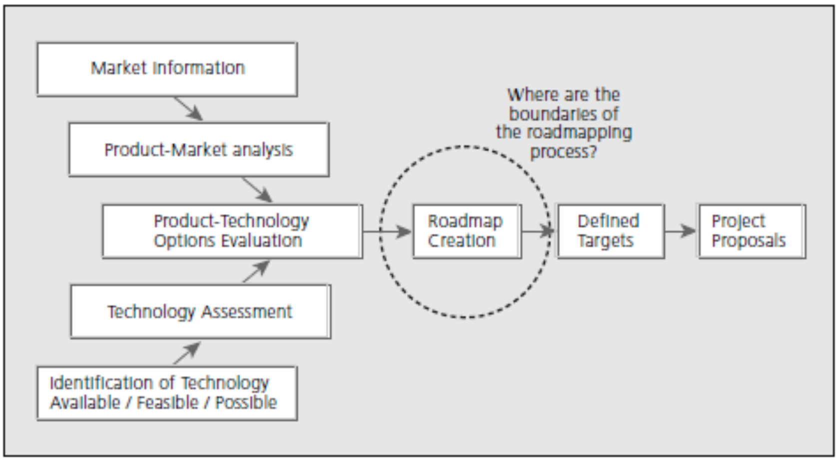

Figure 2.5 Roadmaps Integrate Commercial and Technological Knowledge (Probert, Farrukh & Phaal, 2003)

Formalized foresight practices are used in multinational firms, for its ability to capture value in various ways. This includes firstly, increasing its ability to perceive, understand and respond to change. Foresight also influences other actors, or the subunits within an organization. In addition, the foresight practice also increases organizational learning. (Rohrbeck & Schwarz, 2013).

Industry technology roadmapping is made in the level of industry. This type of roadmapping covers not only technological but also includes economic, institutional, and cultural factors at the industry, and sometimes cross-industry levels. This broad level information allows an industry and companies to plan a technological thrust as well as the competitive landscapes, such as the possible threats and opportunities in the business environment in achieving their future goals.

The information coverage provided by an Industry Technology Roadmap is much broader than that of the organization level roadmap, since it includes external company factors, such as the required infrastructure, regulations, international trade, etc. As asserted by Garcia & Bray (1997):

> "Some companies do technology roadmapping as one aspect of their technology planning (corporate technology roadmapping). However, at the industry level, technology roadmapping involves multiple companies, either as a consortium or an entire industry (industry technology roadmap). By focusing on common needs, companies can more efficiently address critical research and collaboratively develop the common technologies".
>
> (Garcia and Bray, 1997, p.11)

The total involvement of stakeholders is vital to the development of the industry technology roadmap. These stakeholders include organizations from within the industry, supply chain partners, potential users, research institutes, academia, government, which with their involvement, allows the collection of vital and reliable information (Bray & Garcia, 1997; Schaller, 2004).

Probert *et al*. (2003) explained that the Industry Technology Roadmap focuses on providing guidance on critical future technology areas as well as national and commercial research funding and infrastructure investment to enhance an industry's competitiveness. According to Probert & Randor (2003):

> "Industry roadmaps are generally created by bringing together firms from across the sector, research institutes, associations, etc. to project the pathway, rate of changes, requirements, or constraints on development in the sector… a key intent of industry roadmapping is to provide guidance on critical future technology areas and national and commercial research funding to enhance competitiveness" (Prober & Radnor, 2003, p. 29)

Prior Industry technology roadmaps constructed include the International Technology Roadmap for Semiconductors (ITRS), and the National Electronics Manufacturing Initiatives (NEMI) technology roadmap, which involve large numbers of stakeholders. The International Technology Roadmap for Semiconductors (ITRS) was developed in the year 2008, which involved over 900 respondents from value chains, research consortia, academia, government agencies, and laboratories from various countries. The NEMI technology roadmap was created in the year 1998, by more than 175 organizations (Schaller, 2004).

To surmise, foresight has vast benefits in facilitating a nation, industry, or organization, to anticipate, plan and create change. Various scholars have attempted to develop new theories regarding the implications of foresight; however the lack of a standardized language (within management disciplines) has led to a confusion that the foresight field is only at conceptual formation. Thus, it is recommended for future research to address a common nomenclature to describe foresight tools, methods and concepts. Further development of foresight may be established by associating or conceptualizing it, branching from other scholarly accepted theories.

2.2.4 Complexity Theory as a Lens for Conceptualizing Technology Foresight

The theory of complexity provides theoretical basis for the structuring and preparing of a foresight activity. This premise is supported by a number of researchers, who long argued that the increasing complexity makes it especially necessary to pursue long range planning (Rohrbeck & Bade, 2012; Jain, 1984; LoPresti, 1996; Samet, 2011).

Scholars agree that human interactions create complexity (Marion, 2008; McMillan, 2004; Stacey, 2010; Stenvall & Laitinen, 2012). Complexity emerges as societal interactions result from a ‘bottom-up’ approach. According to Epstein & Axtell (1996), social processes are only complex when each of their sub-processes cannot first be neatly decomposable into individual sub-processes, such as economic, demographic, cultural, and spatial processes and then aggregated to give an adequate view of the social process as a whole. In this view, most societal processes are in fact complex, which is being formed from the emergent interactions of various agents, or otherwise termed as a ‘bottom-up’ process.

The occurrence of social processes in reality is complex, and when processes are ‘truly bottom-up’, the value of investigations using ‘top-down’ approaches become questionable (Edmonds, 1999; Schilperoord, 2005). These occurrences however may be better explained by exploring the emergent quality of a ‘bottom-up’ complexity theory, vs. the reductionist approach of the ‘top-down’ process. In essence, complexity research deals with the concept of emergence, which is in contrast with the reductionist form of thinking.

The questions that are addressed in complexity studies seek to explore how emergent behaviours or phenomena unfold. For instance, in the context of scientific research, psychology and economics, the theory of complexity may seek to explain how water might phase into ice at lower temperatures, or the occurrence of learning from experience, and reasons for market crashes. The limited, linear, reductionist way of thinking however, is inadequate to explain these complexly emergent phenomena.

The reductionist approach is described by some scholars as the "whole being nothing but the sum of its parts" (Godfrey-Smith, 2013; Polkinghorne, 2002). Reductionism is strongly associated with causality and in the reductionist framework any phenomena can be explained wholly through different 'levels' of explanation, with higher levels reducible, if needed, to lower levels. On the fundamental level of the reductionist perspective, every item that exists is a sum item, and the emergent phenomenon does not exist principally, but merely being a description of a system (Silberstein & McGeever, 1999).

Therefore the theory of complexity offers a more nuanced view that the whole (system) will have features that some of the parts do not have. From the complexity perspective, if emergent behaviours or emergent phenomena are consequence of a bottom-up change process, hence the phenomena cannot be fully explained through a mere logical review of each agent. This means that the behaviour of each agent cannot be precisely reduced or its effect fully accounted for. For that reason, complexity research stresses the need to observe patterns in the behaviours of agents, which may contribute to a more adequate understanding of the entire phenomenon.

However, even though social sciences are inherently complex, its disciplines are obviously insular, with specific journals segmented to economics, demography, political science, etc. (Sichman, Conte & Gillbert, 2005). Therefore, to capture the emergent workings of an industry, interdisciplinary dialogs need to be practiced. This is a key characteristic of a good foresight activity. Foresight, or more specifically, roadmapping, integrates various sources of information leading to concerted understanding at multiple organizational levels, (Brown & O'Hare, 2001). The theory of complexity explains the moderately connected system interactions as operating on the 'edge of chaos'. According to Smith, (2005), identifying this state, or these points of interactions is deemed advantageous to a foresight activity.

Foresight is typically used to shape the future, but Sardar (2010) asserts that its activity also has a direct impact on the present, with the potential to change people's perceptions. This includes creating awareness on dangers or opportunities ahead, motivating people to do certain things, forcing people to innovate, encouraging people to change and adjust, galvanizing people to collective social movement, paralyzing people with fear, empowering people, marginalizing people, or influencing beliefs and cultures.

Notably, foresight processes are not just an emphasis on the extrapolation of existing patterns, but instead a recognition that the future is uncertain and the marked possibility or probability of seriously disruptive events.

Therefore grounded on the theory of complexity, the goal of foresight is not merely to prepare for the future, rather, to make every effort to shape and create the future. This type of situational awareness in foresight allows the planners to study and enhance the interactions between agents and the broader decision environment. Thus, this reshapes the collective behaviour of society, and the resultant approach of adapting and responding to unexpected or unknown situations as well as recognized situations. The foresight processes and tools may facilitate people in their sense making processes, especially in optimally promoting integrated problem solving, adaptability and absorptive capacity.

The impact of foresight through the lens of complexity theory can be conceptualized as, “the whole being greater than the sum of its parts”. This means that with many things, especially in the context of an intricate system with various interplaying components—it is difficult to reduce each to singular functions and properties. The result of such interconnectedness is difficult to anticipate, and through concerted discussions, bring powerfully synergistic ideas into motion. This interlinking process is intrinsic in foresight and is attempts to substantialize the complex workings of an industry. From these perspectives, the complexity theory may be used as theoretical underpinning to develop the OTEC industry roadmap in Malaysia, and provide bearing to help fulfil the ever-increasing energy needs of society.

2.3 Energy Scenario

Energy has immense impact on the economic system, and may be regarded as a "complex adaptive system", due to its tendency to grow and evolve in a self-organizing manner. Energy is central to the economy, thus it's planning in responding to new challenges will require a multi-faceted approach. The exact nature of what the changing energy demand will bring cannot be quantified to a certainty. Given the economic importance of energy, however, countries need to ensure that their energy policies and systems are robust enough and able to adapt to a range of possible energy scenarios. The global and national energy outlook is reviewed in the following.

2.3.1 Global Outlook

Energy demand is on the constant rise, in tandem with growing population and income growth. This is depicted in Figure 2.6, which shows the correlation between economic activity, population, and energy demand over the span of 4 decades.

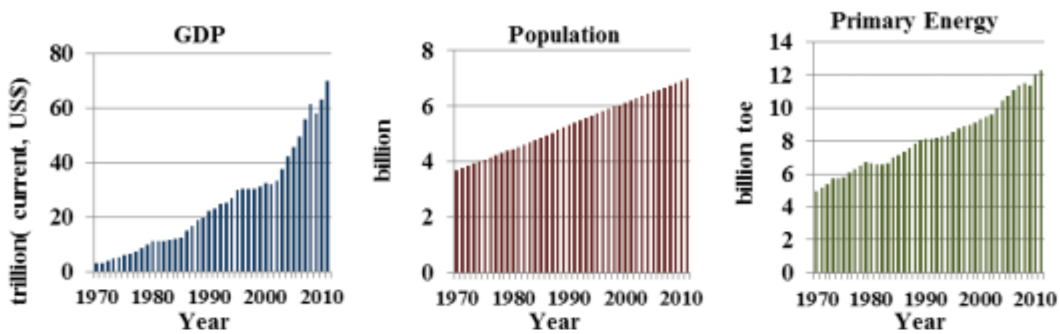

Figure 2.6 Correlation between economic activity, population, and energy demand between 1970-2010

The demand for primary energy is largely driven by the price of fuels, and technology used in supplying the energy. Therefore the energy demand is sensitive to fluctuations in energy price (relating to the types of fuels used at various sectors or industry, and the rate of technological change).

A survey of global energy consumption by primary fuel revealed that oil is the major consumption worldwide with 34%, followed by natural gas 22%, coal 26%, nuclear 6%, Biomass/Waste 9%, hydro 2% and other renewable 1% in 2010.

According to the International Energy Agency (2013), the global energy demand will increase by one-third, from the years 2011 to 2030. This is relatively within Exxon Mobil's (2014) projection of a 35 percent increase global energy demand, from 2010 to 2040, and British Petroleum's (2015) projection of a 37% increase from the years 2015 to 2035. The projections of International Energy Agency and British Petroleum have been statistically validated in terms of t-test and F-test by Aydin (2015) and deemed suitably used for future planning.

With these projections in consideration, a diverse, reliable and affordable fuel mix will be needed to provide energy that enables economic growth and societal advancements for the future. From the projections up to year 2040, oil remains the single largest source of energy demand until 2040. Demand growth is forecasted for all forms of energy; oil by 13%, coal by 17% (mainly before 2020), natural gas by 48%, nuclear by 66% and renewables by 77% (International Energy Agency, 2013). The projected demand by fuel type over time is shown in Figure 2.7.

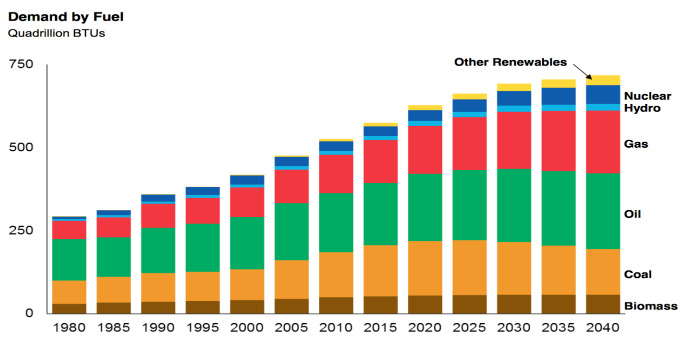

Figure 2.7 Projected fuel demand over time (International Energy Agency, 2013)

2.3.2 National Outlook

The Malaysian energy outlook may be reviewed by analyzing the final energy demand by types of fuel, and by sector. Table 2.2 shows the final energy demand by types of fuels. According to the Energy Commission, (2014), the most dominant fuel types are diesel and natural gas, accounting for about 40% of the entire fuel mix. Biodiesel fuels entered the fuel mix in the year 2011, and have been steadily contributing modest amounts since.

Table 2.2: Final Energy Demand by Types of Fuels (Energy Commission, 2015)

Year	Final Energy Demand by Fuel Type (ktoe)											
	Diesel	Fuel Oil	Motor Petrol	LPG	Kero sene	ATF and AV Gas	Non-Energy	Refinery Gas	Natural Gas	Coal and Coke	Electricity	Biodiesel
2000	7627	1875	6387	1362	131	1574	622	3	3863	991	5263	
2001	8116	1497	6827	1392	99	1762	626	4	4621	977	5594	
2002	8042	1590	6948	1542	92	1785	633	6	5644	1086	5922	
2003	8539	1256	7360	1436	93	1852	632	7	5886	1212	6313	
2004	9262	1463	7839	1542	86	2056	626	11	6490	1305	6642	
2005	8672	1954	8211	1509	82	2010	564	10	6981	1348	6943	
2006	8540	1901	7518	1520	79	2152	672	12	7562	1335	7272	
2007	9512	2203	8600	1475	76	2155	823	9	7708	1361	7683	
2008	9167	1963	8842	1475	75	2112	818	0	7818	1713	7986	
2009	8634	1291	8766	2506	30	2120	799	0	6800	1613	8286	
2010	8388	478	9560	2920	20	2380	657	0	6254	1826	8993	
2011	8712	414	8155	2892	19	2553	1178	0	8515	1759	9235	24
2012	8757	768	8919	2891	38	2522	739		10206	1744	10011	115
2013	9568	329	12656	2946	31	2998	662		10076	1539	10590	188

As shown in Table 2.3, throughout the years, the transport and industrial sectors record the highest energy consumption. The next largest sector is the residential and commercial sector, while the agriculture sector accounts for the lowest consumption. Therefore, future energy productions need to adequately provide for the industrial and transport sectors, which amount to more than 60% of the total national energy consumption.

Table 2.3: Final Energy Consumption by Sectors (Energy Commission, 2015)

Year	Final Energy Demand by Sectors (ktoe)				
	Industrial	Transport	Agriculture	Non-Energy	Residential and Commercial
2000	11406	12071	104	2250	3868
2001	11852	13138	98	2378	4049
2002	12854	13442	96	2511	4387
2003	13472	14271	98	2345	4400
2004	14913	15385	87	2183	4754
2005	15492	15384	101	2173	5134
2006	15248	14825	253	2809	5429
2007	16454	15717	281	2958	6196
2008	16205	16395	287	2876	6205
2009	14312	16119	211	3868	6336
2010	12928	16828	1074	3696	6951
2011	12100	17070	916	6377	6993
2012	13919	19757	1053	7494	7065
2013	13496	22357	1051	7277	7403

The national energy balance depicts that Malaysia produces almost double the energy consumed by the nation (see Figure 2.8, page 33).

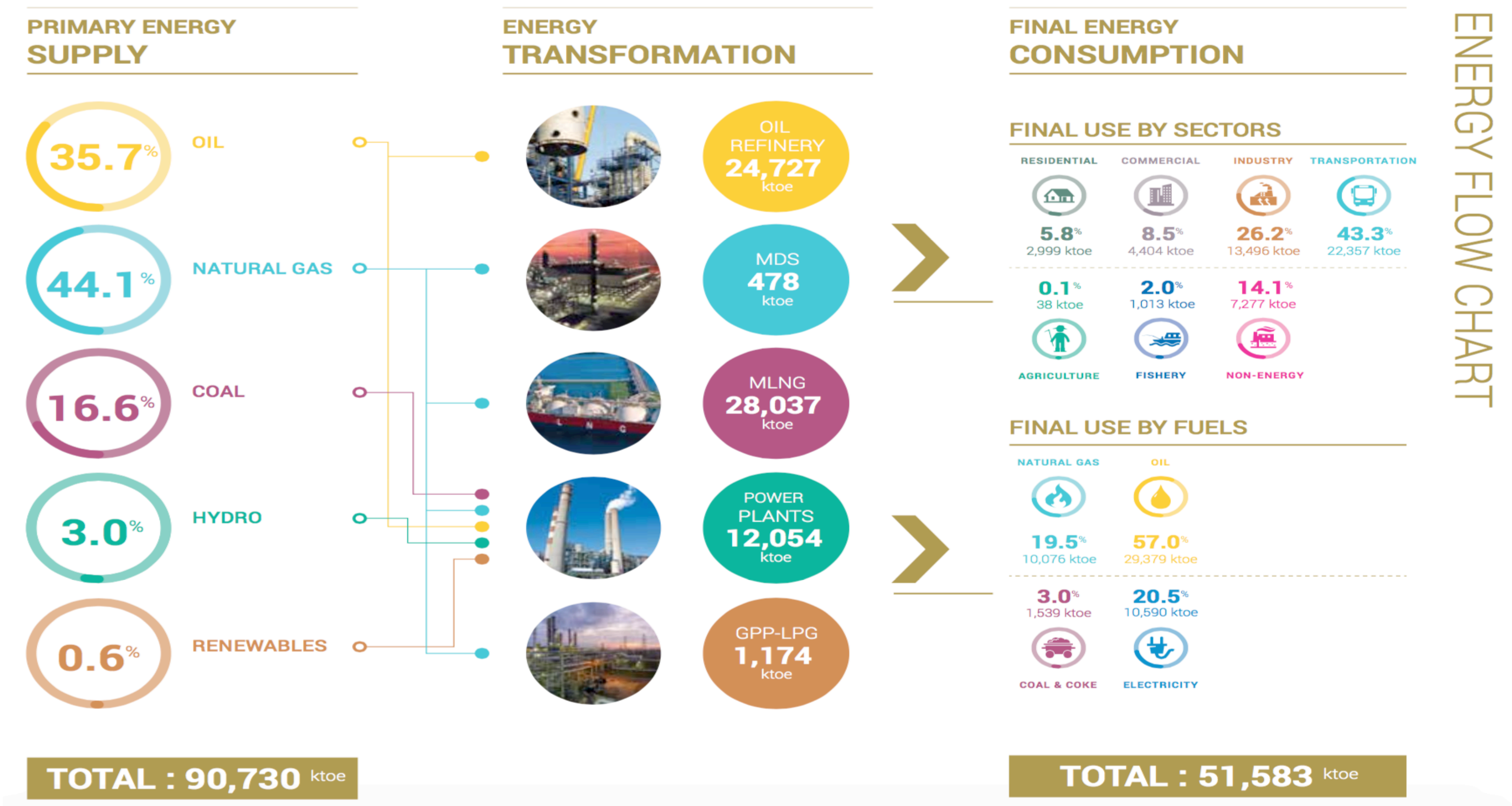

Figure 2.8 Malaysia Energy Balance Flows, year 2013 (Energy Commision, 2014)

2.4 Overview of OTEC Industry

Resurgent interest in the OTEC Industry requires a thorough review of its development. This section provides an overview of the OTEC industry, by outlining the OTEC concept, development by regions, value propositions, and OTEC cost estimates.

2.4.1 OTEC Concept

The Ocean Thermal Energy Conversion (OTEC) system makes use of the regular occurring differential temperature (of about 20°C) between the warm surface seawater and the deep ocean water to generate electricity. This is achieved through (the process of) evaporating and condensing a working fluid to power a turbine, much like the system of refrigerator. The depths of an OTEC plant reaches to about 800-1,000m below the surface, which are well within the operating depths of a typical oil and gas rig. (Vega, 2012; IRENA, 2014; Muralidharan, 2012)

The OTEC systems may be differentiated into the 3 types of cycles. This includes the open cycle, the closed cycle, and the hybrid cycle . The OTEC open cycle utilizes the ocean water as its working fluid, whereas an OTEC closed cycle typically uses ammonia. The OTEC hybrid cycle, on the other hand uses a mixture of ammonia and water. Various researchers are studying the alternative working fluids or refrigerants, as this may improve the cost and efficiency of the OTEC cycle (Lim, Lee & Kim, 2015; Norazreen Samsuri, 2015).

Another way OTEC systems may be differentiated is by the type of platform used. This may be floating platforms, land based platforms, or moored to the sea platforms. Theoretically, OTEC plants will channel the electricity generated via submarine power cables, or its excess to be converted into hydrogen as an energy carrier.

2.4.2 OTEC by Region

According to Lewis, Estefen, Huckerby, *et al.* (2011), OTEC has the largest potential among all ocean energy technologies, which is an estimated 300 exajoules (EJ) per year, or 90% of the global ocean energy potential. The total estimated available resources for OTEC is 14 terawatt (TW), and a more conservative scenario proposes global production of 7 TW, with little effect on the ocean temperatures (Rajagopalan & Nihous, 2013). Based on study by Ocean Energy Europe (2014):

> "The global potential for OTEC is a weighted installed base of 150 GW, with a priority market of 60 GW which will emerge first with islands and isolated areas for 9 GW total. By 2030, 1.5GW of OTEC should be installed."

There are various locations suitable for the development of OTEC, including least 98 nations and territories with access to OTEC resources within their 200 nautical mile exclusize economic zone (EEZ) (IRENA, 2014). According to Magesh (2010) and Vega (2010), the commercial future of OTEC plants are 100MW sized plants for industrialized nations, and smaller sized plants for less developed countries and Small Island Developing States (SIDS). Figure 2.9 highlights some feasible locations for OTEC plants.

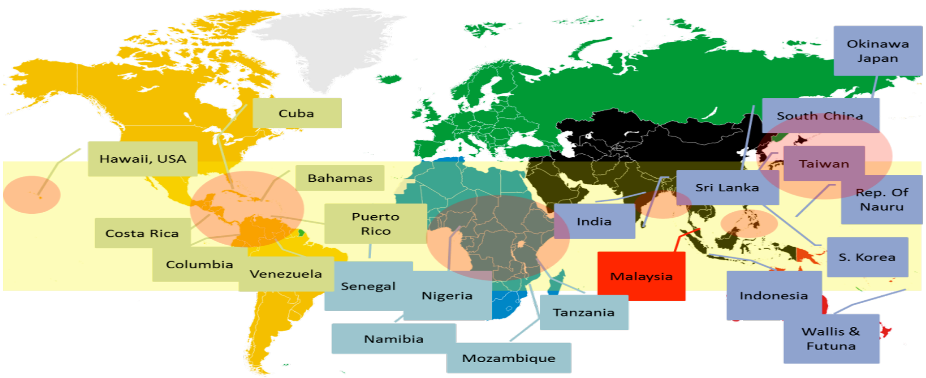

Figure 2.9 Feasible locations of OTEC plants (Bakar Jaafar, 2013)

Several nations that have embarked on OTEC research include France, United States, Indonesia, Philippines, South Korea, East Coast of India, Small Island Developing Nations, and Malaysia. The OTEC development of these nations is discussed in the following sub-sections.

2.4.2.1 France

Potential OTEC sites under the French jurisdiction include the French West Indies, Tahiti, New Caledonia, and Reunion and Comores Islands in the Indian Ocean (Charlier & Justus, 1993).

Throughout the years, France has shown variable interest in OTEC research and development (R&D). In the 1930s, one of the main research drivers for OTEC was the anticipated decline of fuel resources, which was coal at that time. This research was short-lived after World War 2, with the subsequent exploitation of oil. In 1973, the oil crisis emerged, revealing supply vulnerability and revived OTEC research in France. In 1986, the decrease of pressure in oil market (referring to the huge drop in crude oil prices) led the France government to re-examine the case for OTEC, thus abandoning OTEC R&D (Argonautes 2005).

After the French scientists, Jacques d'Arsonval proposed OTEC in 1881, his work was continued by IFREMER in the 1970s, and today extended by DCNS. The technology providers, DCNS decided to invest in OTEC because of the technical know-how and systems engineering competences required (Ernst & Young, 2012). In support of OTEC development, DCNS is equipped with 30 team members from thermodynamical engineering & system engineering, naval architects, heat exchangers, risers, mooring system, and ocean survey (Chino, 2013).

The first offshore 16 MW OTEC plant of commercial size is to be commissioned by the year 2020 off Martinique, the French Territory of the Caribbean region (Bouchet, 2015). Although, work on OTEC has begun since the year 2008, as shown in Table 2.4 (page 37).

Table 2.4: OTEC milestones by DCNS (Chino, 2013; Gautret & Labat, 2010; Offshore Wind, 2013; Ernst & Young, 2012)

Year	Activity
2008	Pre-feasibility study in Martinique
2009	Feasibility study in "La Réunion" regoin
2010	Tahiti feasibility studies
2010-2011	Contract for a land based prototype. Onshore small scale prototype will be installed by 2011 to test, to optimize and to validate the energy system of the OTEC (Gautret & Labat, 2010).
2011-2013	Memorandum of Understanding (MOU) with export utilities and Special Purpose Vehicles
(June) 2013	Ocean Thermal Energy PLD (OTEplc) and DCNS signed an MOU to for developing and building OTEC, among other systems in selected markets (Offshore Wind, 2013)
2014	First offshore OTEC project to be announced The aim is the installation in Reunion Island of the first World experimental offshore OTEC power plant in 2014. The project financial pool shall be defined by the end of 2010. (Gautret & Labat, 2010) Land-based testing on Réunion island of a 2.5 MWe OTEC-module, preparatory to constructing a 10 MWe ocean thermal pilot plant that was originally intended for operation off Réunion.
2015-2016	DCNS shifted the location of its proposed 10 MWe offshore OTEC plant from Réunion to Martinique, where it is scheduled to commence operation around 2020. This project is selected as one of thirty renewable energy projects being funded by a multi-billion-euro initiative sponsored by the European Commission (EC).
2020	DCNS's project in La Martinique is planned to connect to a pilot 10 MW OTEC plant, named 'New Energy for Martinique and Overseas' (NEMO) to the grid in 2020 (Ernst & Young, 2012).

In June 2013, a MOU was signed between Ocean Thermal Energy PLC (OTEplc) and DCNS to collaborate in an OTEC plant. In this arrangement, OTEplc will operate as the developer, whereas DCNS will serve as the Engineering, Procurement, Construction (EPCC) Contractor. In addition, there is to be a joint marketing council which will screen and select projects to be undertaken, as well as a shared technical and marketing expertise (Offshore Wind, 2013)

The initial selection of projects include a land based OTEC and SDC system in the US Virgin Islands (USVI), and a floating OTEC system in Asia. Current development includes the development of a 10 MW OTEC plant in Martinique, with key development phases depicted in Table 2.5.

Table 2.5: OTEC 10MW Pilot Plant by DCNS (Bouchet, 2015)

Description & targets	Demonstrate the Offshore OTEC technology via a first OTEC pilot plant of 10 MW in Martinique island, in accordance with the European Commission NER300 program
Location	Martinique
Partners	Acceptability and environmental study partners: Scientific committee and technical experts ARER, EGIS
Planning	2009: Pre-feasibility study on a 2.5 MW offshore OTEC plant 2010-2012: Feasibility study on a 10 MW OTEC pilot plant and Risk assessment plan including • On ground OTEC prototype (DOTP1) • Pipe design and development • Environmental measurements studies 2016: End of design 2019: Installation 2020: Commissioning and full operation
Contacts	DCNS/Marine energy incubator Tableau

2.4.2.2 United States of America

One of the earliest OTEC plant was undertaken in Hawaii. In the year 1979, it was an offshore demonstration 50kW closed-cycle plant which used up 32kW in running the plant and produced 18kW as the net output (Vega, 2012). The platform was moored by using a 13,500kg weight. Cold water at a temperature of 4.4°C was upwelled from a depth of 670m. Ammonia was used as the working fluid and the cold water pipe was made out of Polyethylene to reduce bio-fouling which was one of the biggest concerns for the cold water pipe then. The heat exchangers were made out of Titanium.

The next experimental plant was an open-cycle land based facility, also located in Hawaii. This facility ran for 6 years, from the years 1993-1998, and till today, record the highest OTEC production outputs (255kWe gross power, 103kW net power, and 0.4L/s of desalinated water). (Vega, 2012)

In October 2008, Department of Energy (DOE) and the State of Hawaii declared the Hawaii Clean Energy Initiative (HCEI), to reduce the fossil-fuel dependency in Hawaii, and expressing a commitment of having at least 70% of Hawaii's power come from clean energy by 2030. Based on the Naval Energy Strategic Roadmap, by 2020, about 50% of the Department of Navy's (DON) energy consumption should come from alternative sources (Thomas & Robbins, 2010).

In effort to support this initiative, an energy partnership was announced in the same year, between the Taiwan Industrial Technology Research Institute (ITRI), the State of Hawaii, and Lockheed Martin to study the OTEC power potential for Taiwan. This partnership also explored the potential of an OTEC pilot plant, located, located off Kahe Point- at the island of Oahu, Hawaii (Johnson, 2009).

Hawaii has 92% reliance on fossil fuels, and targets to reduce its fossil fuel reliance as per its policy directives. Thus, Hawaii is relatively resistant to additional fossil fuel plants and instead needs to explore alternative renewable energy sources.

Hawaii's large Department of Defense (DoD) presence reflects the substantial energy needs of the island. OTEC may be suitable to meet these energy needs, and in addition, creates a new industry with new jobs largely benefiting the community. The strong collaboration with Hawaii Electric Company (HECO) and the Navy make Hawaii an ideal location for OTEC development. (Cooper, 2009) Therefore, major department of defence bases are targeted on Oahu. These are depicted in Figure 2.10.

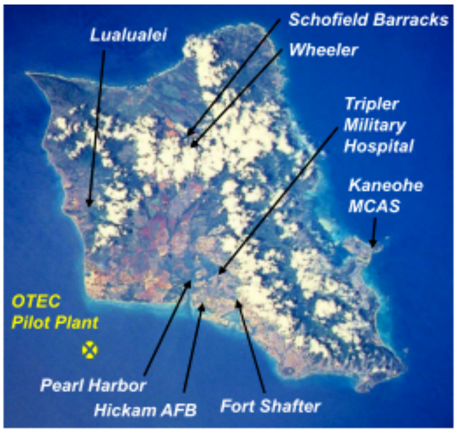

Figure 2.10 Major Department of Defence (DoD) Bases on Oahu (Johnson, 2009)

Major OTEC industry players in the United States are Lockheed Martin and also Makai Ocean Engineering. Lockheed Martin's OTEC vision is shown in Figure 2.11.

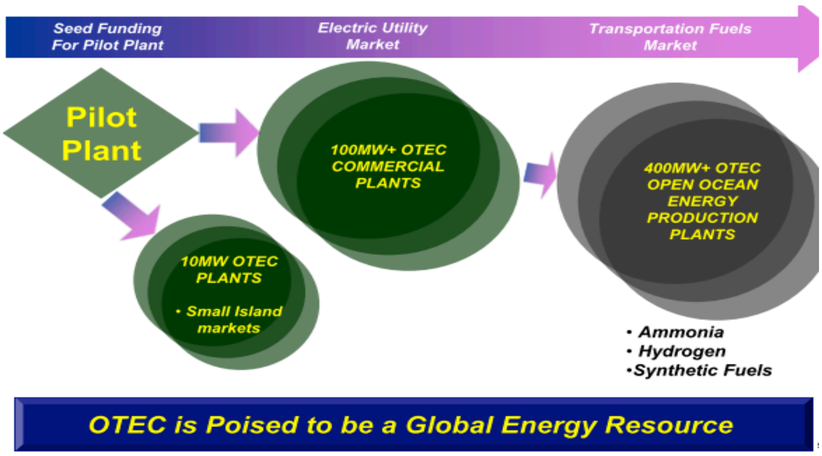

Figure 2.11 Lockheed Martin OTEC vision (Varley, Meyer & Cooper, 2011)

The Lockheed Martin has identified the target market, which is energy source for defence and commercial applications, depicted in Figure 2.12. The near term development (5-10 years) targets locations such as Hawaii, Okinawa, China, Puerto Rico, and Guam. Other potentials include West Africa, East Africa, India, Taiwan, Japan, Marshall Islands, Diego, Australia, American Samoa, Kwajalein, Central & South America, and Florida & Gulf.

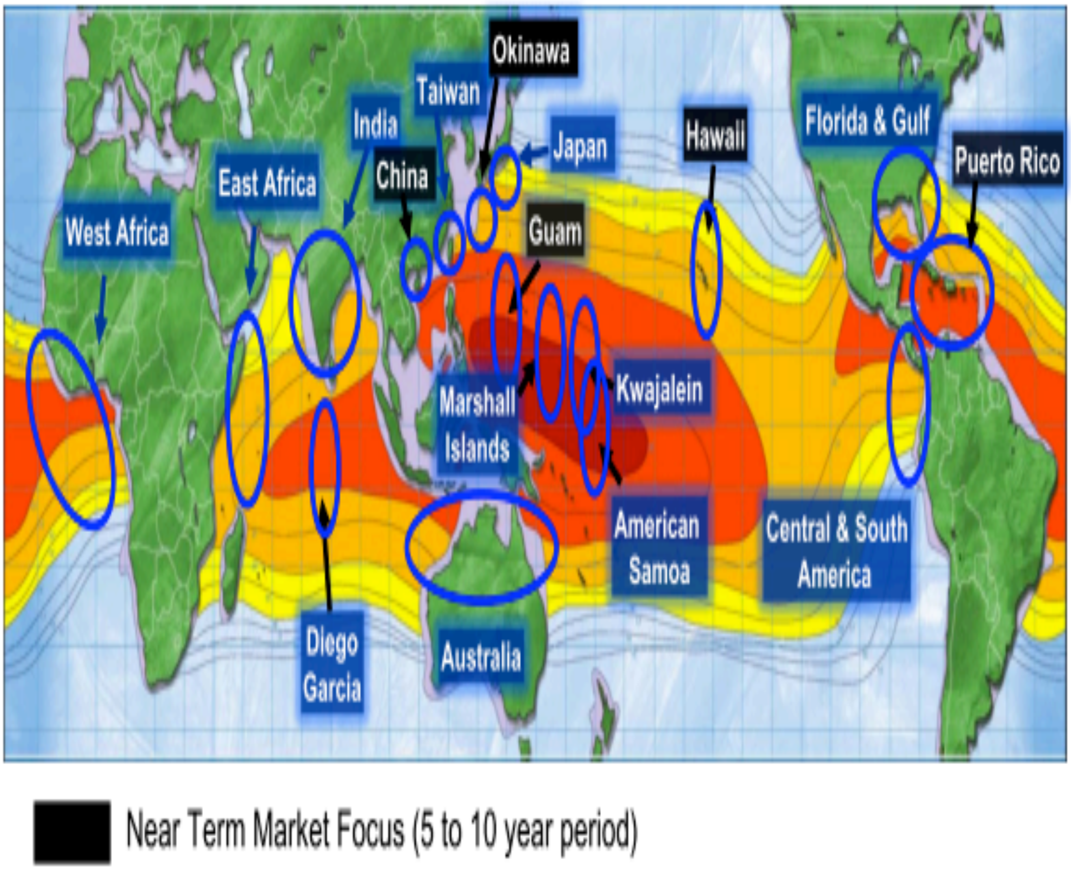

Figure 2.12 Lockheed Martin OTEC target market (Varley, Meyer & Cooper, 2011)

In greater detail, Lockheed Martin's OTEC market entry strategy is to focus on early commercial markets, and early department of defence (DoD) markets, as depicted in Figure 2.13. This includes 4-5 markets of 100MW opportunities, and smaller capacities of 10MW for 3 potential markets. The selection of markets, are dependent on the convergence of three factors. These are (i) OTEC resource availability (temperature gradient), (ii) the limited options of other (competing) renewable sources, and (iii) oil dependent markets, which include the price of crude oil, the availability or security factors, and the consumers' price tolerance for the near term.

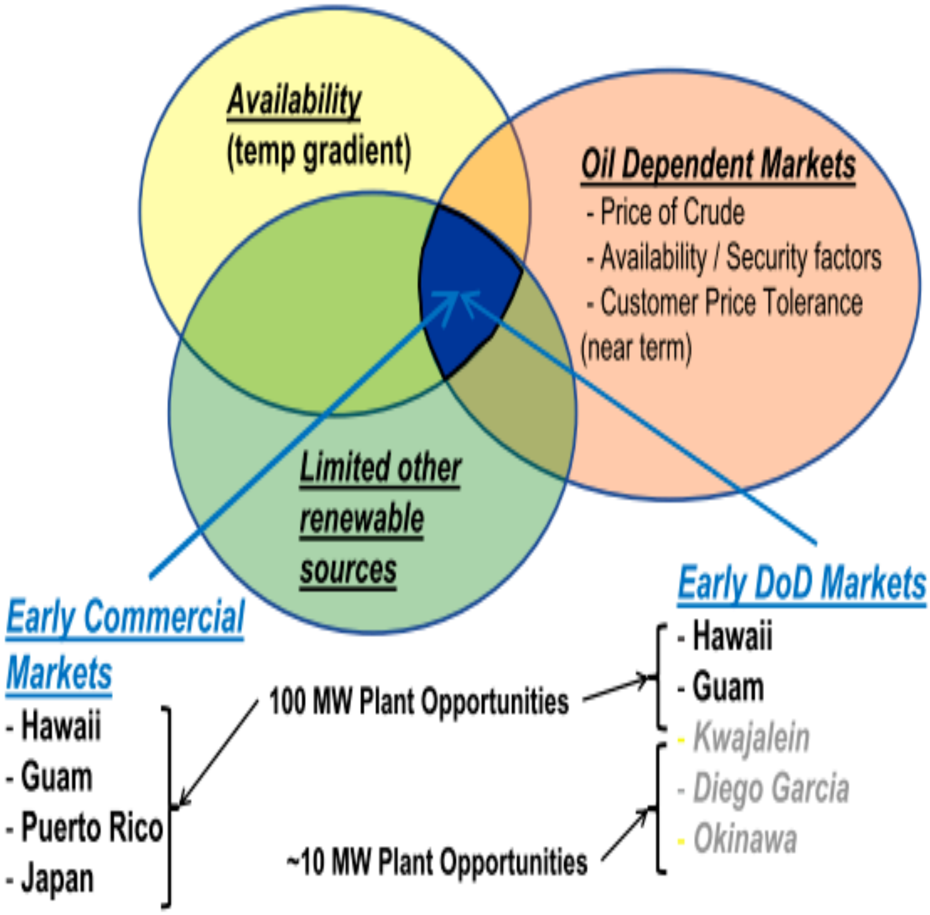

Figure 2.13 OTEC Market Entry Strategy (Varley, Meyer & Cooper, 2011)

Lockheed Martin has also developed a commercialization roadmap (see Figure 2.14), depicting 3 main phases of development from the years 2010-2020. The initial phase (from the years 2010-2012) was targeted at risk reduction, by enhancing key technologies. The years 2014-2015 was targeted at the construction of a pilot plant, which is needed for commercialization. From the years 2018-2020, utility scale commercial or Department of Defence (DoD) plants are targeted.

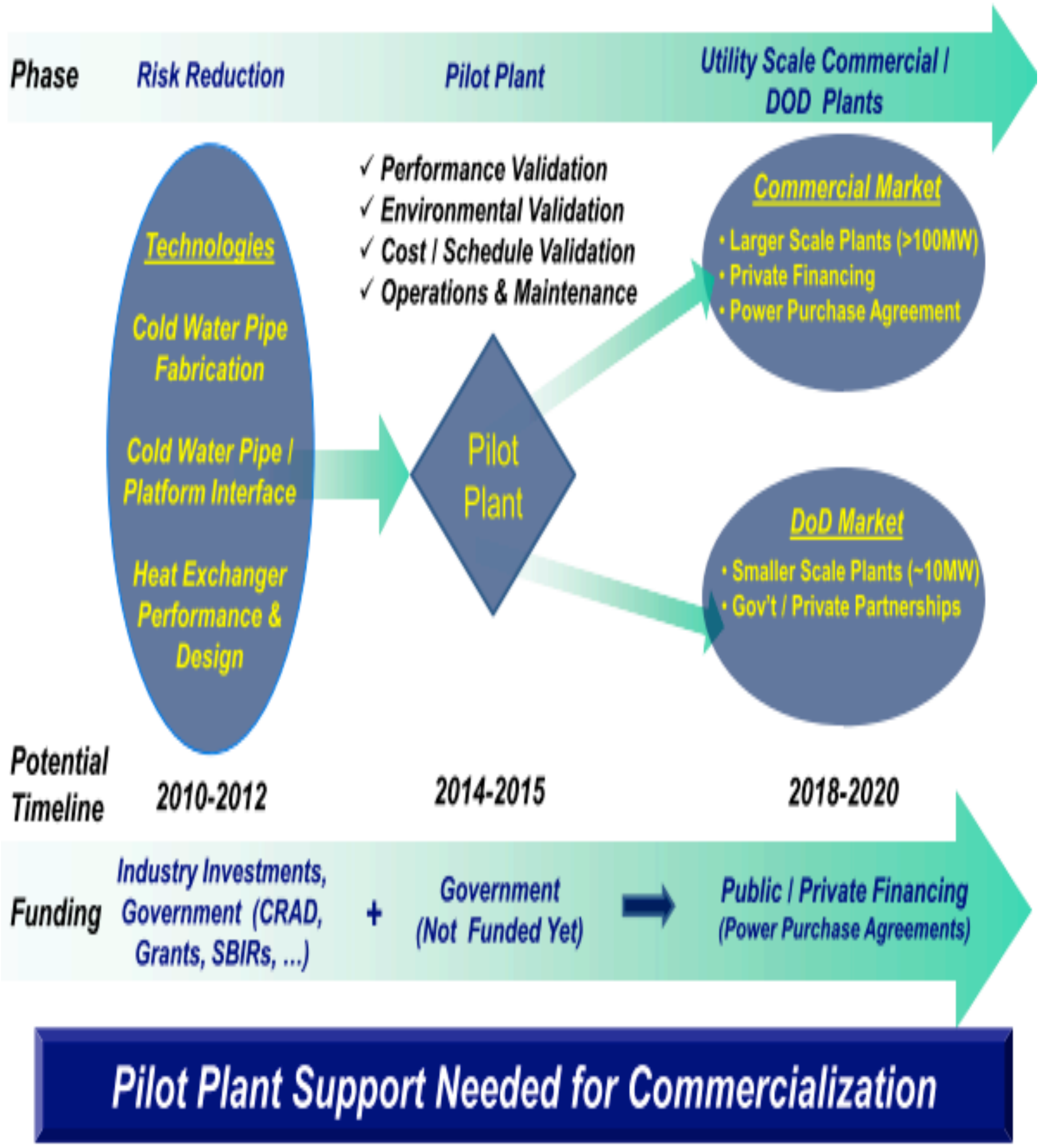

Figure 2.14 Commercialization Roadmap (Lockheed Martin, 2014)

It is also important to examine an OTEC commercialization strategy in hindsight (from the years 2007-2014), which may provide lessons learnt or best practices, shown in Figure 2.15. The outset of the commercialization began with building the core competencies, such as staffing or team and technology department, while concurrently pursuing industry or market contacts, and funding opportunities. Based on the opportunity qualifications, upscaling opportunities were possible, contributing to the development of a pilot plant, and after that, targeting a 100MW commercial plant.

Figure 2.15 OTEC Commercialization Strategy (Makai Ocean Engineering, n.d.)

As a long-term objective to commercialize OTEC technology, is to allow purchase of power and water at cost effective rates. However, in the near term, the objective is to support technical efforts that reduce overall deployment risks (Cable, Tayler & Tindal, 2010). A multi-phased project shall be structured to support commercialization and future acquisition of energy from OTEC systems at Diego Garcia and other Navy locations.

Efforts have also concentrated on understanding the transferable applications of existing offshore standards in the final OTEC system design. Other concerns include safety and operations, by the certification and classification experts. The National Oceanic and Atmospheric Administration (NOAA) and environmental experts on the other hand, focus on main ecological issues.(Meyer, Cooper & Varley, 2011)

The Lockheed Martin and Makai Ocean Engineering team have worked on enhancing OTEC capabilities through strategic partnerships, and leveraging companies with expertise in the offshore industry, naval architecture, ocean engineering, OTEC systems, composites, and the environment (Meyer, Cooper & Varley, 2011).

2.4.2.3 Indonesia

Indonesia is a vast archipelago country (> 17,000 islands), thus OTEC stands to serve as an important energy source in the future. The country is geographically suitable for OTEC (see Figure 2.16, page 46), with areas covering1.9 million km. An estimation of OTEC potential in Indonesia is 70% of a coastline length of 66,627km, with a distance of 30km between each 100MW OTEC plant. This translates to 222GW of electricity produced per OTEC plant, or 1,555TWh of electricity produced per year, with OTEC plants operating at about 80% capacity (Achiruddin, 2011). The upper surface sea water is at a temperature of 30°C all year round, which is ideal for OTEC resource. Besides that, there are no typhoons in Indonesia, hence little risk of the OTEC plant being destroyed by natural disasters.

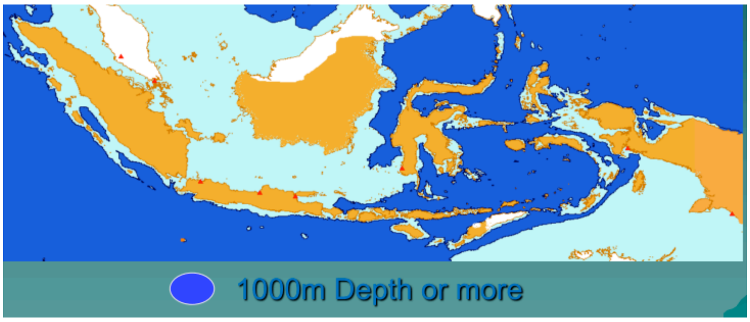

Figure 2.16 OTEC potential in Indonesia (Achiruddin, 2011)

Ideally developed are the 50-100MW sized OTEC electricity plants, with presumably significant economies of scale. Although smaller sized OTEC pants are needed to obtain initial operational data, these facilities face challenges in attracting financial support, due to its less desirable high capital costs. This OTEC paradox is as depicted in Figure 2.17.

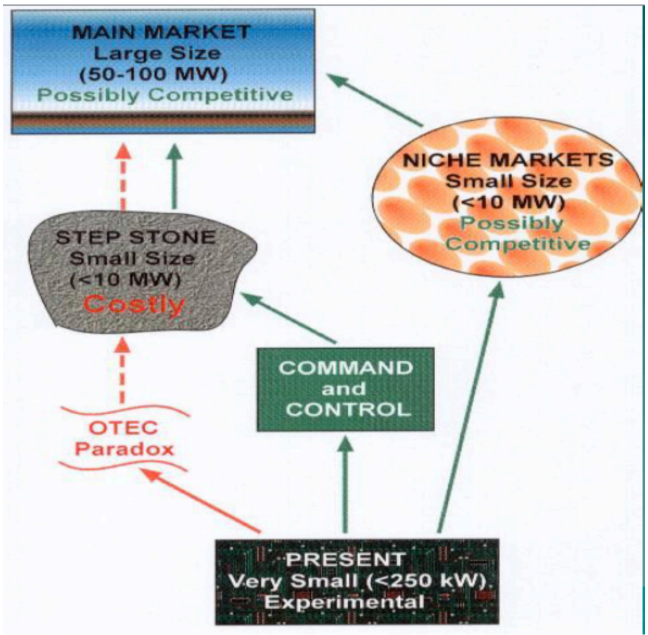

Figure 2.17 OTEC paradox (Achiruddin, 2011)

The commercial development of OTEC requires the targeting of niche markets where smaller OTEC plants are viable. For Indonesia, the remote islands and tourist resorts are deemed as niche markets.

Indonesia's strategy is to develop OTEC in small remote islands and touristic resorts. Small remote islands communities are favourable, compared to production cost of electricity by small diesel generators. Moreover, the main needs of small island communities are electricity and fresh water, which is the main product of OTEC.

The potential small remote islands are located within the province of Aceh, Sumatera Utara, Sumatera Barat, Bengkulu, Bali, Nusa Tenggara Barat, Central Nusa Tenggara, Nusa Tenggara Timur, Maluku Tengah, Maluku Utara, Sulawesi Utara, and Papua. The targeted islands have a distance from shore to depth of 1,000m ranging from 3-5 km or 5-15km, as listed in Table 2.6.

Table 2.6: OTEC Sites in Indonesia (Achiruddin, 2011)

	Name of island	**Province**	**Distance from shore to depth 1,000m (km)**
1	Sabang	Aceh	3-5
2	Simeulue	Sumatera Utara	5-15
3	Nias	Sumatera Utara	5-15
4	Siberut	Sumatera Barat	5-15
5	Pagai	Sumatera Barat	5-15
6	Enggano	Bengkulu	5-15
7	Bali	Bali	3-5
8	Lombok	Nusa Tenggara Barat	5-10
9	Sumbawa	Nusa Tenggara Barat	5-10
10	Flores	Central Nusa Tenggara	5-10
11	Sumba	Nusa Tenggara Timur	5-10
12	West Timor	Nusa Tenggara Timur	5-10
13	Ambon	Maluku Tengah	3-10
14	Seram	Maluku Tengah	5-10
15	Buru	Maluku Tengah	5-10
16	Morotai	Maluku Utara	3-10
17	Ternate	Maluku Utara	3-10
18	Miangas	Sulawesi Utara	1-5
19	Sangir	Sulawesi Utara	3-5
20	Sapiori	Papua	5-10

In tourist resorts, integrating OTEC with Deep Ocean Water Applications (DOWAs) will possibly boost the economic viability of OTEC. The most popular DOWAs are desalinated water, deep-seawater air-conditioning, and aquaculture. The use DOWA for an air-conditioning load of 1,000 tons, may cool about 1,000 hotel rooms, amounting significant energy savings of more than 800 kW.

Bali and Manado has suitable OTEC resources. Landmark hotels in Bali form about three clusters around Denpasar including Kuta (2,500 hotel rooms), Nusa Dua (1,200 hotel rooms) and Sanur (1,000 hotel rooms), while Manado has about 3,000 rooms. The OTEC and Deep Ocean Water Applications (DOWA) can be differentiated according to their targets location and developments, which are small remote islands, resorts, and commercial plants as shown in Figure 2.18.

OTEC & DOWA's	Small Remote Islands	Resorts	Commercial Plants
Electricity	V	V	V
Desalinated Water	V	V	V
Aquaculture	V	V	V
Cool Green House Plant	V	V	V
Local Area Chilling System		V	V
Lithium			V
Hydrogen			V

p = [CC(Z) f - S(1, 2, 3, …..)]/{70,080 RP(Z)[¢/kWh]

Figure 2.18 OTEC and Deep Ocean Water Applications (DOWA) (Achiruddin, 2011)

From the policy perspective, Indonesia has proposed strategic alliances with Japan, suggesting for Japan to undertake the development of Indonesia's OTEC resources. Such policy is a tie-in strategy, which would provide Indonesia with financial resources to introduce OTEC technology, while Japan may adopt implementing emissions reduction. In this case, the Kyoto protocol would be the key push for the call to reduce GHG emissions, via carbon trading shown in Figure 2.19 and Figure 2.20.

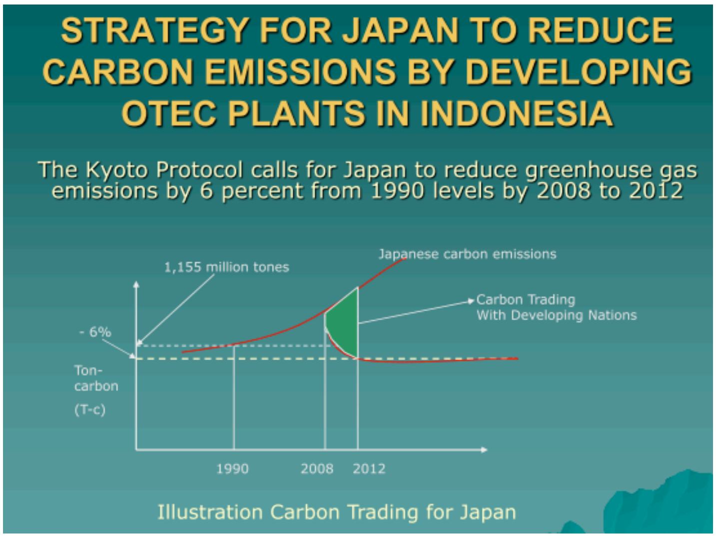

Figure 2.19 Proposed strategy for Japan to reduce carbon emissions by developing OTEC plants in Indonesia (Achiruddin, 2011)

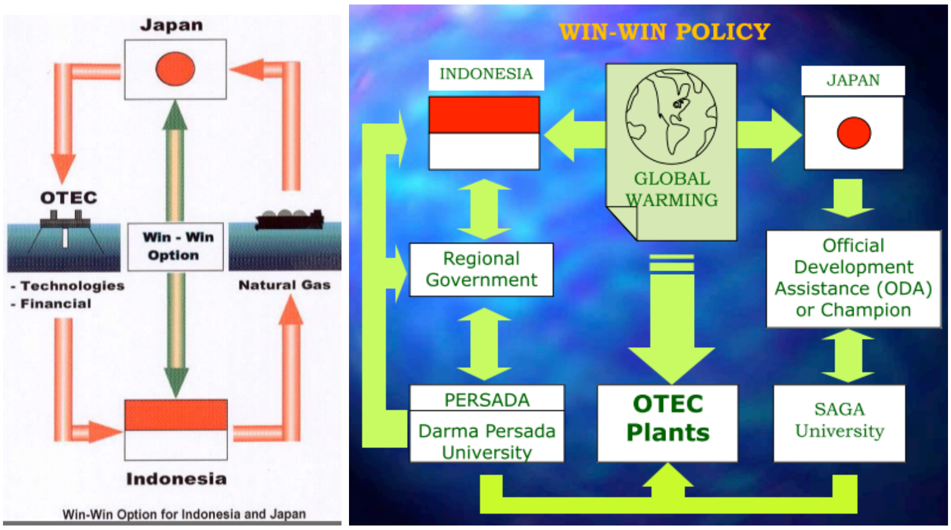

Figure 2.20 Indonesia- Japan proposed collaboration; a win-win policy (Achiruddin, 2011)

According to Achiruddin (2011), some key activities include; the socialitation about OTEC in ESDM, Padang, Denpasar, and Manado (in the year 2009), distributing the letters from Governor of West Sumatra & North Sulawesi to Japan Embassy in Jakarta (in the year 2010), and a joint research between Darma Persada University and Saga University on Study of OTEC Potential in Indonesia (in the year 2010).

The on-going activities include; mapping of Indonesia OTEC Resources for Pilot Project 5 MW, a feasibility Study and Estimation Unit Cost on Decided Specific Area in Indonesia, a proposal for Indonesian Government to Develop a small OTEC Plant, a Proposal for Japan to Develop Pilot project 5 MW OTEC Plants in Indonesia by Supporting Technology and Fund, and attendance in Ocean Energy Conference in May 2013 in Bali (Achiruddin, 2011).

As stepping stone, it is proposed to develop small 5 MW OTEC plants as a pilot project in Indonesia. This may catalyse more cost-effective OTEC plants at larger power outputs of 50 to 100 MW.

2.4.2.4 Philippines

Another potentially suitable site for ocean energy is the Philippines. Efforts to map energy potentials began from the early 1980's by Mindanao State University. In 1997 and in 2009, the Department of Science and Technology (DOST) in collaboration with the National Power Corporation (NPC) and University of San Carlos, respectively assessed the marine current potential sites.

The energy potential in the Philippines requires additional capacity requirements by the year 2030, in targeted locations of 11,900 MW in Luzon, 2,150MW in Visayas, 2,500MW in Mindanao. According to the Philippine Energy Plan (2012-2030), ocean power should account for about 140MW of the renewable energy mix, to ensure energy security (see Figure 2.21).

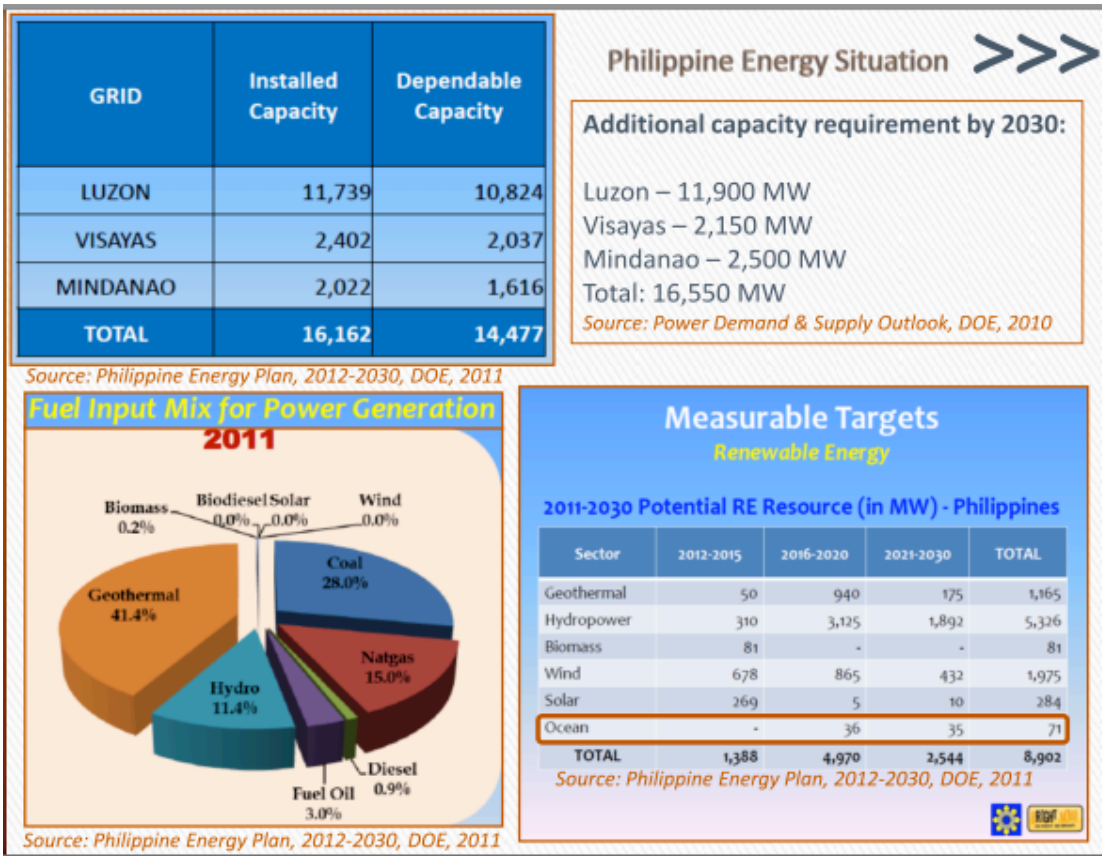

Figure 2.21 Philippine energy situation and future requirements (Marasigan, 2012)

However, as with other countries, Philippines faces challenges and barriers in OTEC development due to high upfront and technology costs, non-competitiveness, non-viable markets, inaccessible financial packages, and social acceptability. To address these barriers, the government proclaimed landmark laws (ie. R.A. No. 9513: The Renewable Energy Act of 2008) to accelerate the development of renewable energy resources (Marasigan, 2013). By this, fiscal and non-fiscal incentives are provided to private sector investors, and equipment manufacturers/ suppliers. Competitiveness is enhanced by mandatory utilization of RE resources, with renewable portfolio standards (RPS) and feed-in tariff (FIT). There is provision of interconnection/ ancillary services, and new market options, such as net metering concept, and the green energy option. This is depicted in Figure 2.22.

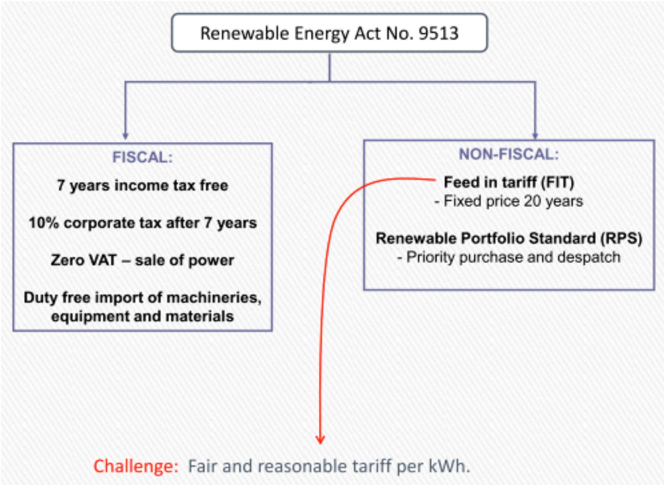

Figure 2.22 Government incentives and support for OTEC (Latimer, 2013)

To match the Philippine nations strategic plan, the Ocean Energy Sector roadmap (2011-2030) has been developed (see Figure 2.23), targeting a total capacity addition of 10MW by the year 2030 and 100% completion of contracted projects.

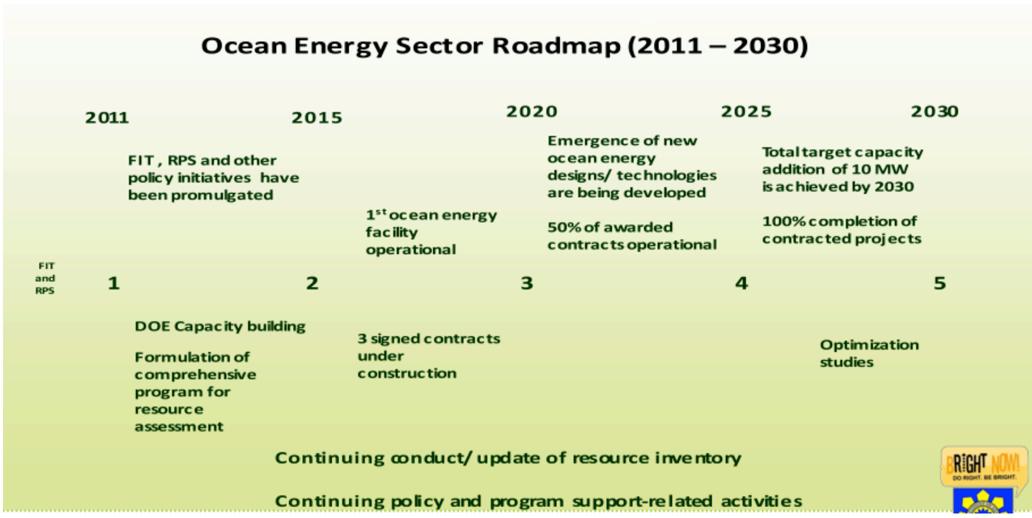

Figure 2.23 Philippines Ocean Energy Sector Roadmap (Marasigan, 2013)

The short term to long term renewable energy development roadmap consists of 5 layers; Renewable Energy (RE) Industry Services, Resource Development, Research, development and demonstration, RE Technology Support, and Policy and Program Support Activities (see Figure 2.24).

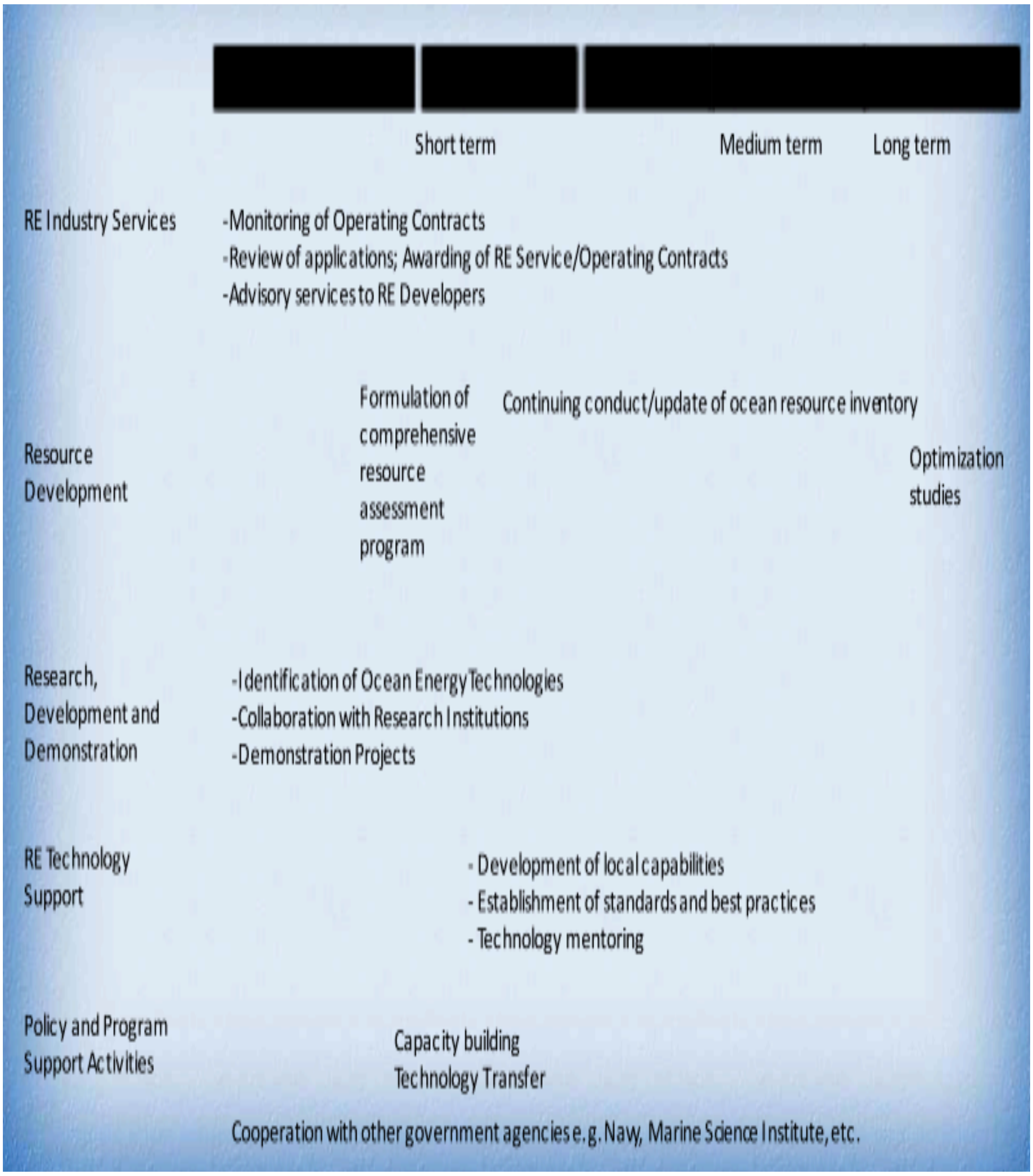

Figure 2.24 Philippines RE Development Roadmap (Marasigan, 2013)

From a developer's perspective, the role of an OTEC project owner or developer is to secure government service contract, register with securities and exchange commission, secure permits and licenses, secure power purchase agreement, and secure financial closing, as shown in Figure 2.25.

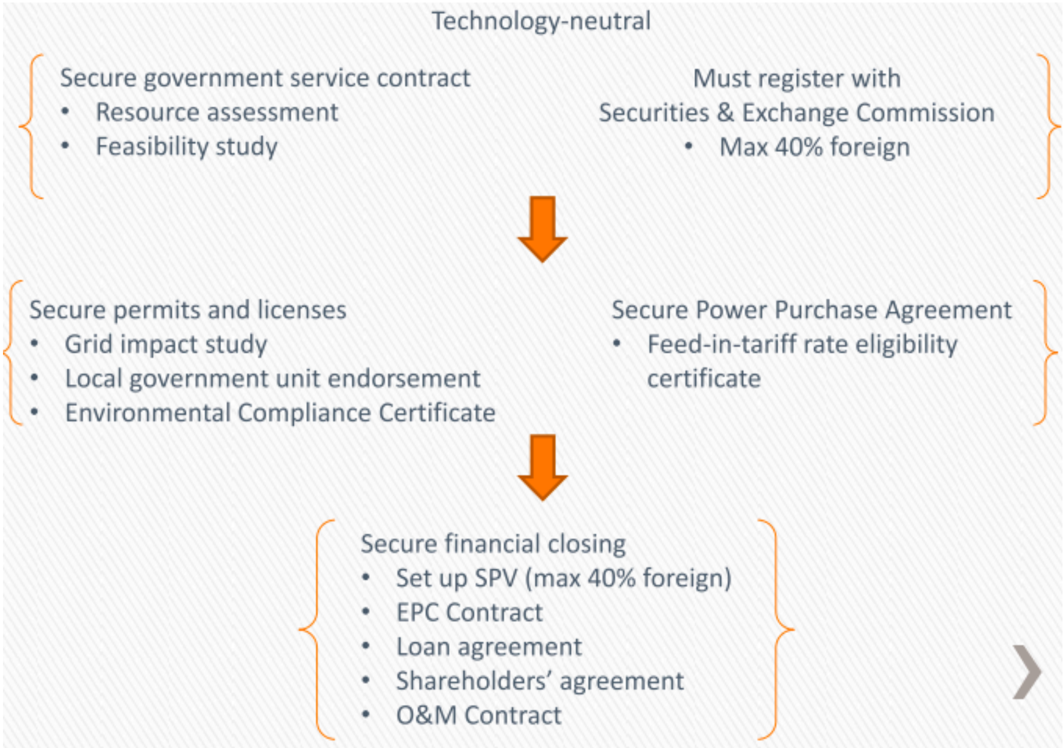

Figure 2.25 OTEC project developer/ owner role in the Philippines (Latimer, 2013)

OTEC makes business sense in the Philippines, due to its high dependence on fossil fuels (oil and coal). In this economic climate, a 10MW plant is competitive with diesel. Government support and incentives for OTEC enhance project feasibility, in addition to the buoyant debt and equity market. The Phillipines is targeting a first mover advantage, with existing expertise in geothermal.

A proposed investment model involves a technology provider, power producer, and off taker. The Renewable Energy Purchase Agreement (REPA) allows the off taker to purchase power from the power producer. The ideal technology providers are ones that can/ are; sign an engineering, procurement and construction

(EPC) contract, bankable with a strong balance sheet, become an special purpose vehicle (SPV) shareholder (maximum 40% foreign), provide availability and performance guarantee, willing to share key risks; technology and engineering, design and construction (EDC), and provide acceptable long term O&M service commitment. A proposed investment model in the Philippines is depicted in Figure 2.26.

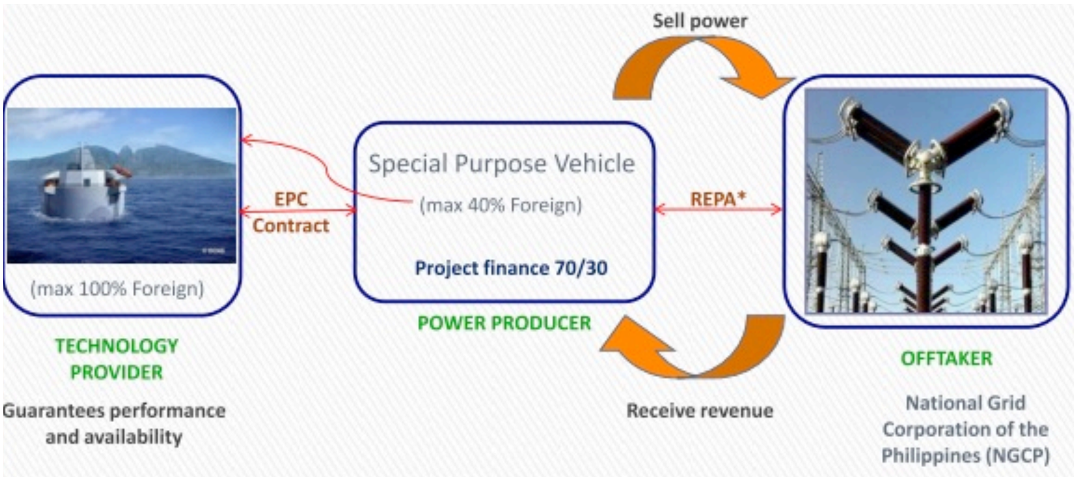

Figure 2.26 Philippines proposed investment model (Latimer, 2013)

2.4.2.5 South Korea

Various drivers spur South Korea into OTEC research, including population increase and industrialization based on fossil fuel, shortage of essential resources such as food, energy & water, CO_2 emission, global warming, climate change, and albinism.

In addition, OTEC serves to meet the global and domestic requirement needs. OTEC-Desalination-Aquaculture (ODA) activity as a donor shifted from receiver since 1996 based on experience and technical potential for low temperature gradients OTEC & Sea Water Air Conditioning (SWAC). Also, alternative energy utilization aims to increase by 11% in 2030 to reduce the dependency on imported fossil fuels for high temperature gradients OTEC & SWAC.

Estimating the ocean energy potential in Korea stands at 14,600MW, with some 600MW sized OTEC plants (see Figure 2.27). Different areas are targeted, with respect to the low or high temperature gradient. The low temperature gradient for OTEC application may be obtained from surface and deep layers in tropical seawaters. The higher temperature gradient may be obtained for OTEC utilization from solar/ geothermal heat or power plant discharge. Hence, OTEC is targeted to provide up to 11% of South Korea's energy requirements, and also that of the small tropical island nations (Kim & Yeo, 2013).

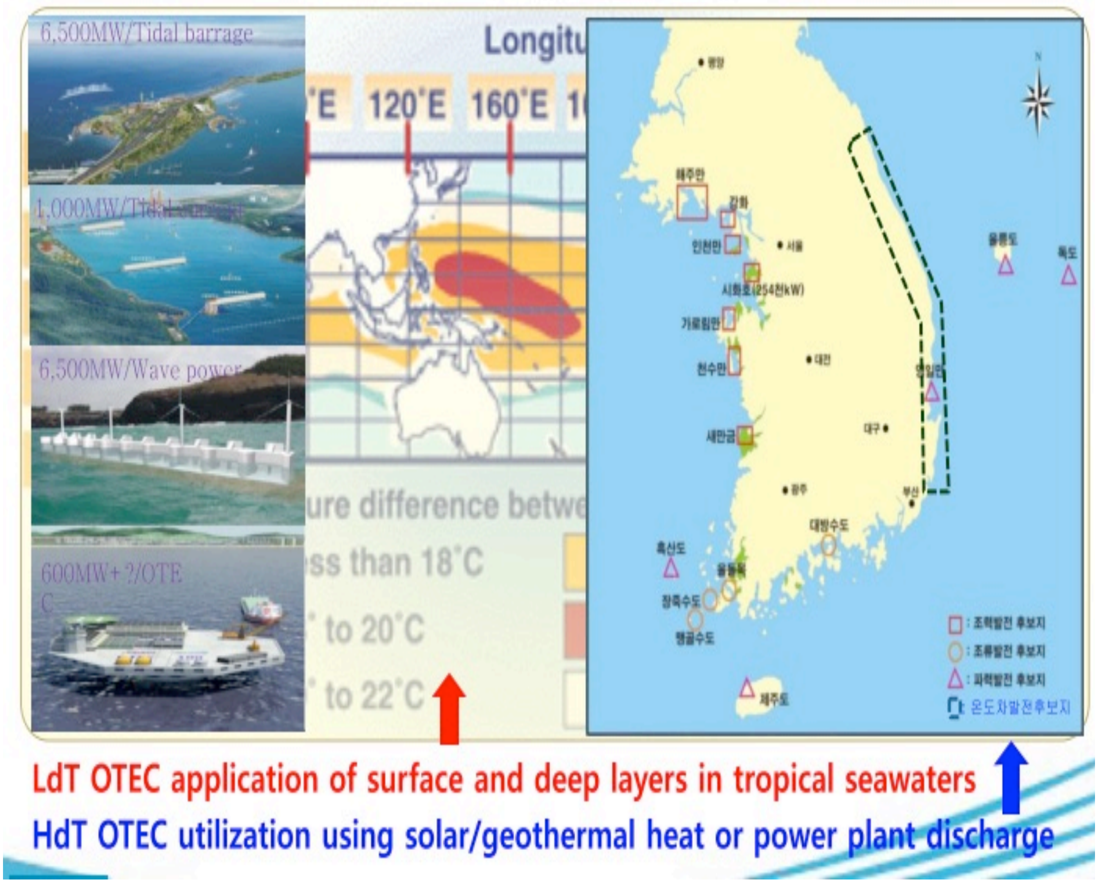

Figure 2.27 Ocean energy potentials in Korea (Kim & Yeo, 2013)

Referring to the National Master Plan 2030 of Renewable Energy Utilization, the national supply of new and renewable energy in 2030 should meet 11% of the national energy demand. Also, development of 80% of available ocean energy (tidal barrage, tidal current, wave, hybrid system, and OTEC) resources is targeted, until the year 2030. This may be achieved through a phased development strategy- phase 1 (2008-2012), phase 2 (2013-2020), and phase 3 (2021-2030), as shown in Figure 2.28.

Figure 2.28 Ocean Energy Phased Development Strategy (Kim & Yeo, 2013)

Specific to OTEC, a roadmap was established for Korea meet timely demands of R&D and industrialization needs. This leverages on Korea's technical strength, as a leading producer of ships, and steel. International cooperation is sought from organizations such as Asia Development Bank (ADB), and Green Climate Fund (GCF). Shown in Figure 2.29, from the years 2014-2030, various sizes of OTEC plants are proposed, that is from a 0.2MW OTEC plant, gradually increasing to a 100MW plant.

Figure 2.29 OTEC R&D and industrialization needs (Kim & Yeo, 2013)

In greater detail, the R&D development plans from the year 2010-2015 are depicted in Figure 2.30.

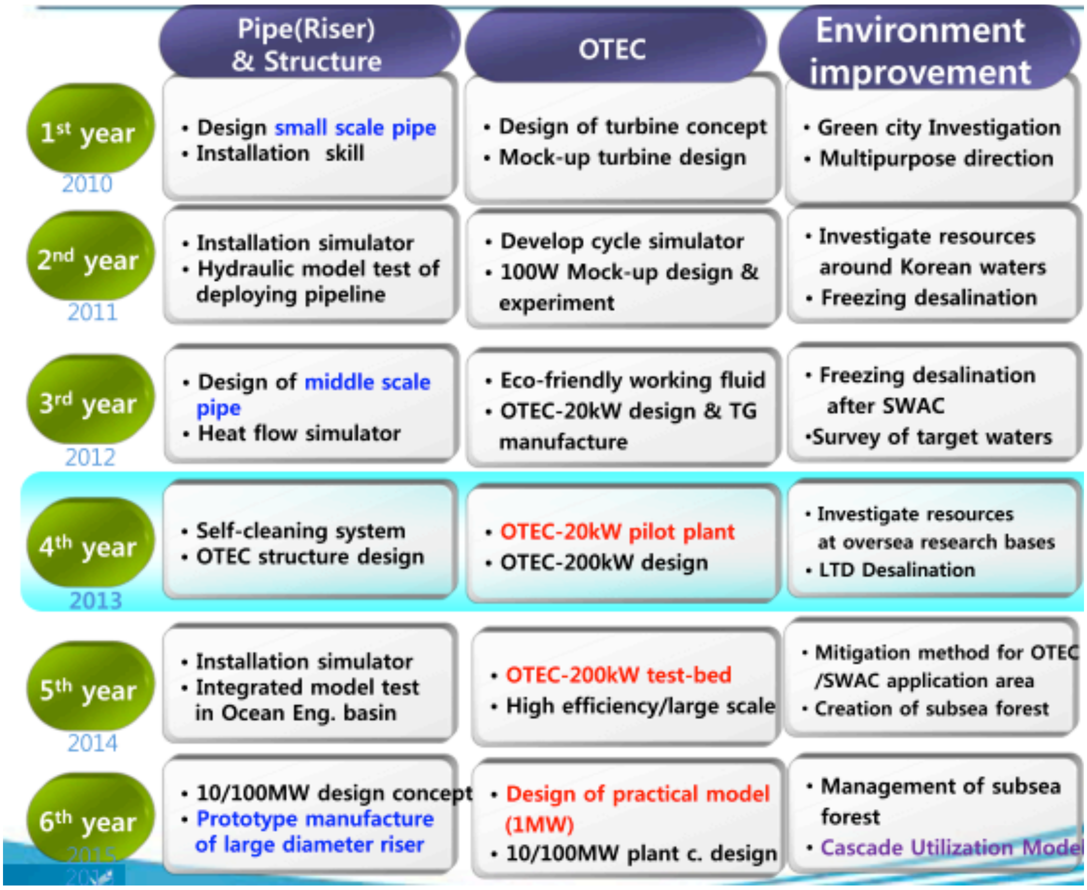

Figure 2.30 Annual OTEC R&D plan in Korea (Kim & Yeo, 2013)

As previously mentioned, the final roadmap goal of OTEC is to design, manufacture, install and operate 100MW commercial OTEC plants in tropical waters. A brief explanation of each approaching step is depicted in Figure 2.31.

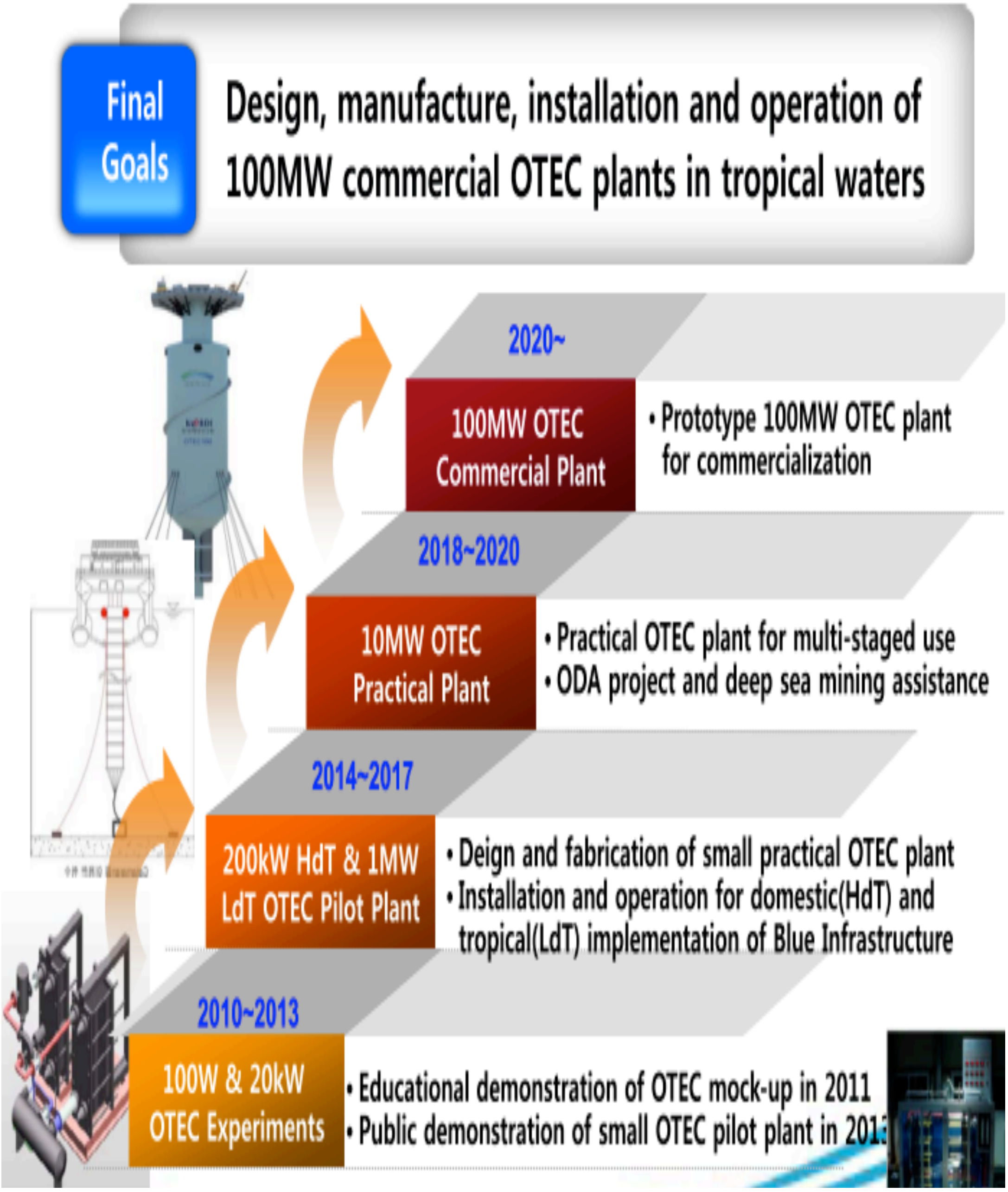

Figure 2.31 OTEC roadmap final goal and approaching steps (Kim & Yeo, 2013)

Some strategic plans for OTEC industrialization include the multipurpose utilization of OTEC (SWAC, desalting, extraction, aquaculture, and thalossotheraphy) for 'blue infrastructure'. As shown in Figure 2.32, it contains the blue island, blue port, blue campus, blue arena, blue city, and the blue village.

Figure 2.32 Blue Infrastructure (Kim & Yeo, 2013)

2.4.2.6 India

India, through the National Institute of Ocean Technology (NIOT) had a meandering experience deploying OTEC technology. A 1MW floating plant, (500kW net power) was built off the coast of Tamil Nadu, India (Mohammed Faizal & M. Rafiuddin Ahmed, 2011). The plant was designed to use an ammonia cycle, with a four-stage turbine, on a floating barge. However, issues in deploying the coldwater pipe to the platform caused the project to be discontinued. Instead, the OTEC project was repurposed to produce desalinated water. (Muralidharan, 2012)

2.4.2.7 Small Island Developing Nations

Less developed countries and Small Island Developing States (SIDS), have particular benefit from OTEC development, since these locations suffer a lack of electric power and fresh water for industrial and irrigation purposes (Magesh, 2010). Hence, the installation of an OTEC 5MW capacity plant may be able to mitigate these issues. Table 2.7 shows the less developed countries with access to ocean thermal resources at a distance of 25km or less from the shore.

Table 2.7: Potential Sites with OTEC Resources (Magesh, 2010)

Country/ Area	ΔT (°C)	D (Km)	Country/ Area	ΔT (°C)	D (Km)	Country/ Area	ΔT (°C)	D (Km)
Africa			**Latin America and Carribean**			**Indian and Pacific Oceans**		
Benin	22-24	25	Bahamas	20-22	15	Comoros	20-25	1 ~10
Gabon	20-22	15	Barbados	22	1 ~10	Cook Islands	21-22	1 ~10
Ghana	22-24	25	Cuba	22-24	1	Fiji	22-23	1 ~10
Kenya	20-21	25	Dominica	22	1 ~10	Guam	24	1
Mozambique	18-21	25	Dominican Republic	21-24	1	Kiribati	23-24	1 ~10
Sao Tome and Principe	22	1 ~10	Grenada	27	1 ~10	Maldives	22	1 ~10
Somalia	18-20	25	Haiti	21-24	1	Mauritius	20-21	1 ~10
Tanzania	20-22	25	Jamaica	22	1 ~10	Philippines	22-24	1
			Saint Lusia	22	1 ~10	Samoa	22-23	1 ~10
			Saint Vincent & Grenadines	22	1 ~10	Seychelles	21-22	1
			Trinidad and Tobago	22-24	10	Solomon Islands	23-24	1 ~10
			US Virgin Islands	21-24	1	Vanuatu	22-23	1 ~10

Notes: ΔT (°C) = Temperature difference of water between 0 m and 1000 m, D= Distance from OTEC resource to shore, ° C = degree centigrade, Km = Kilometer.

2.4.2.8 Malaysia

In Malaysia, OTEC is geographically suitable within the Sabah trough, covering an area of 134, 284 km^2 (Yaakob, 2012)' which translates to about 105,000MW of power (Bakar Jaafar, 2013). The potential sites for initial OTEC development include Lahat Datu, Pulau Layang-Layang, Sempurna Island, Kuala Baram, and Gemusut Kakap.

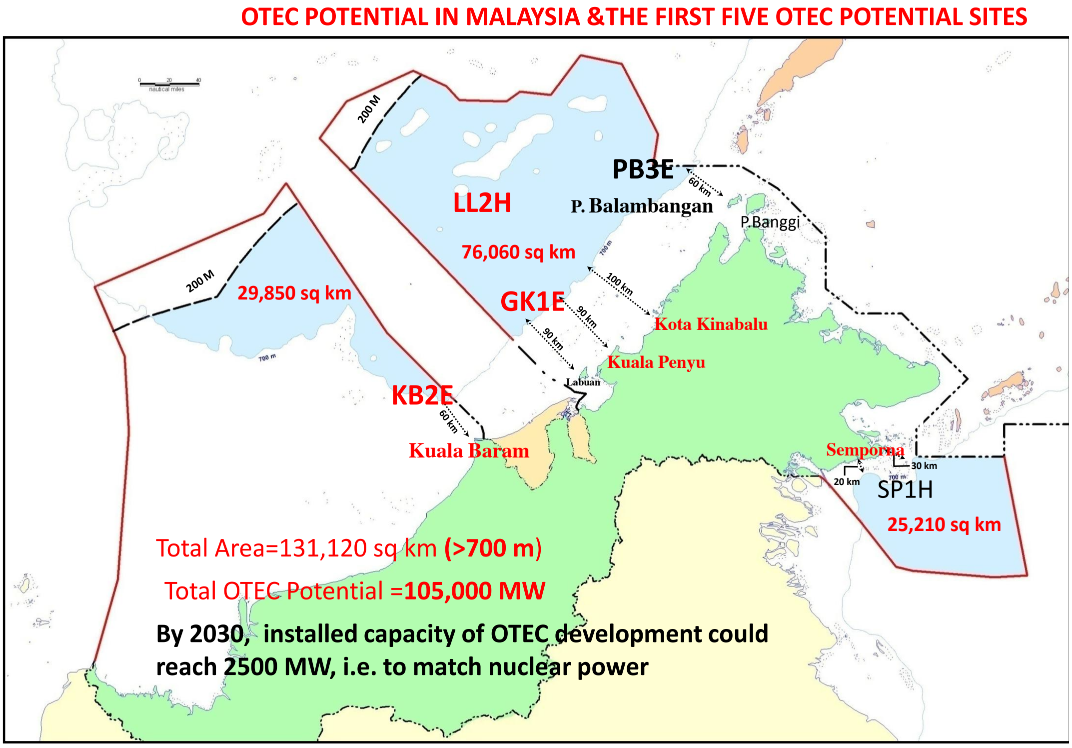

Figure 2.33 OTEC Potential in Malaysia (Bakar Jaafar, 2015)

Following the discovery of Malaysia’s OTEC resources, various development efforts have ensued. This includes firstly, the establishment of the University of Technology Malaysia Ocean Thermal Energy Centre (UTM-OTEC) in the year 2013, to champion the cause for OTEC in Malaysia. Subsequently, several SPVs and companies have been incorporated, including Deep Sea Thermal Solutions Sdn Bhd, UTM OTEC Sdn Bhd, UTM OTEC Solutions Sdn Bhd, Pro-Active MH Resources Sdn Bhd; and [Sustainable Ocean Thermal Energy Resources Sdn Bhd (SOUTHER)] (Bakar Jaafar, 2015).

A proposal was submitted for an OTEC project from the 11th Malaysia plan budget Figure 2.34 (Md Nor Musa, 2015). One of the target market for OTEC in Malaysia includes supplying energy to the oil and gas production plants, off the coast of Sabah, and for any surplus energy to be converted into hydrogen, which may be stored and transported as when needed. The long-term goal is for the establishment of floating cities, and an underwater tourist resort.

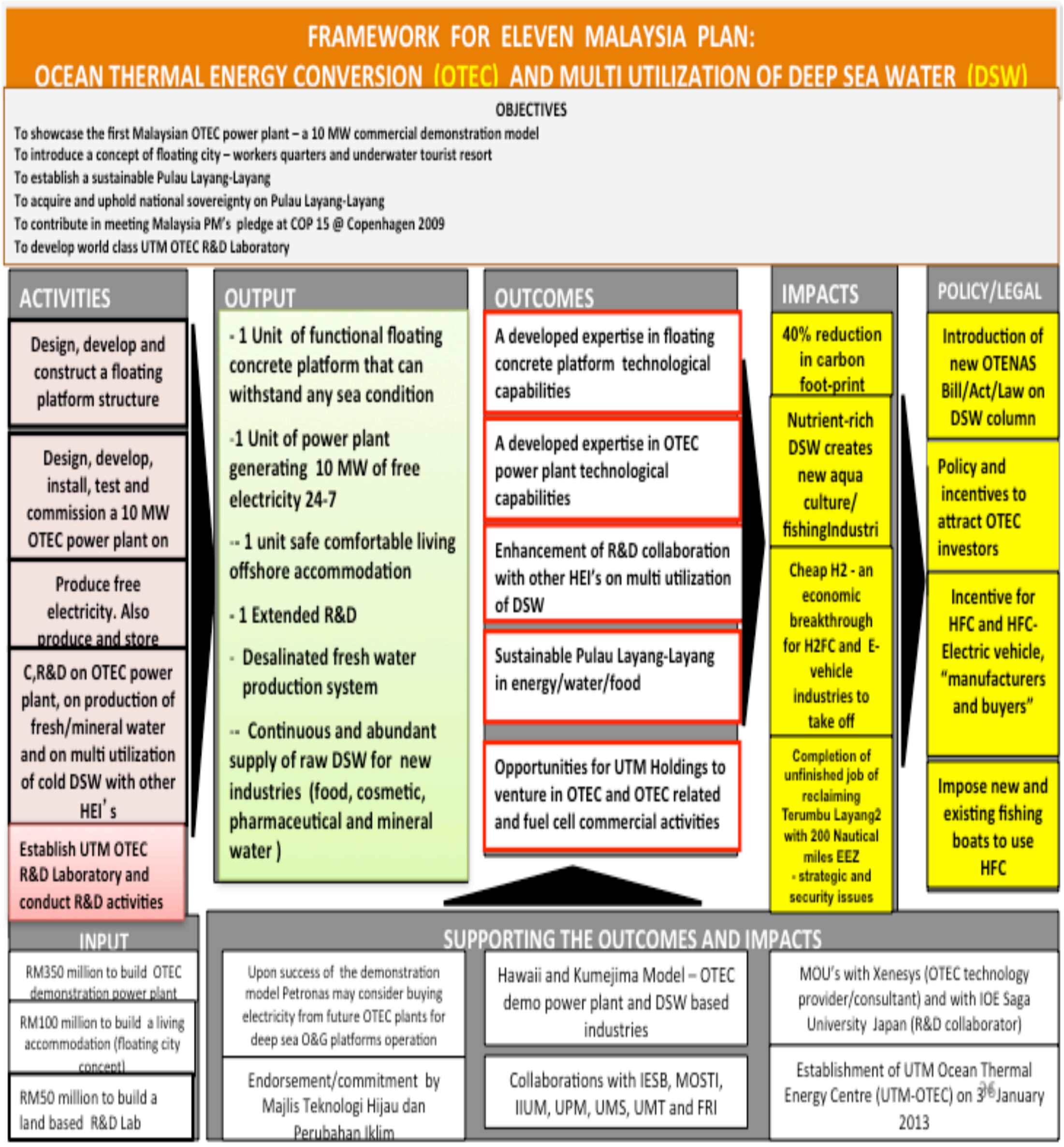

Figure 2.34 OTEC Development Framework in Malaysia (Md Nor Musa, 2015)

2.4.3 OTEC Value Proposition

There is great potential for OTEC to act as an enabling technology for a low carbon economy. Renewable energy integration, electrified transportation, and independent distributed power production are just some ways that the OTEC may fundamentally reshape the future energy landscape.

OTEC has some capability to displace the dependence on traditional non-renewable energy sources. It is estimated that each 100MW OTEC plant saves 1.3 million barrels of oil per year, and at USD100 per barrel of oil, that equates to USD130 million per year. In addition, 0.5 million tons of CO_2 is also saved per year, which at USD30 per ton of carbon credit will save USD15 million per year (Varley, Meyer & Cooper, 2011).

The production of freshwater may be obtained from the by-product of various OTEC cycles. OTEC may also be used to supply power to specific plants, such as the reverse osmosis desalination plant. Based on Magesh (2010) research, this translates to about 2.28 million litres of desalinated water from every 1MW of energy produced by the OTEC hybrid cycle plant. The OTEC solution also provides more cost effective freshwater at about USD 0.89/ kgallon, vs. USD 2.6-4.0/ kgallon from a desalination plant (Muralidharan, 2012).

Using the deep sea water, OTEC plants can provide for various infrastructure such as air-conditioning, seawater district cooling (SDC), or for aqua culture purposes. Other areas that may be supported include the hotel industry, by channelling the cool deep-sea water for district cooling, and supporting the water consumption for coastal region hotels.

OTEC also creates employment, with as much as 3,425 jobs per 100MW plant (Varley *et al*. 2011). It will not compete for water resources, and avoids visual impacts and does not crowd out valuable land uses, being at offshore locations. This non-polluting technology stands to solve many critical energy challenges, and even provides energy carriers (hydrogen) in addition to a multitude of products, which have been duly mentioned. Figure 2.35 shows the multifunction ability of an OTEC plant.

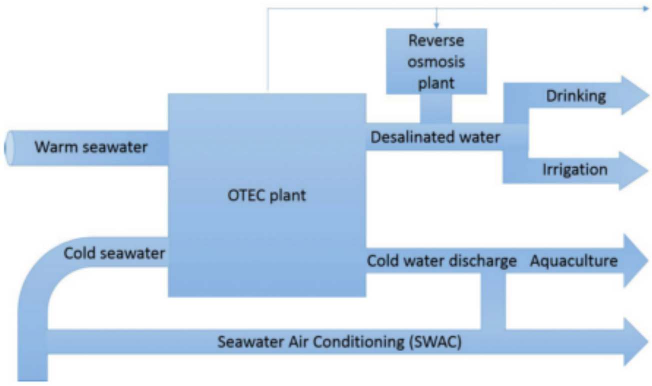

Figure 2.35 Multifunction ability of an OTEC plant (IRENA, 2014)

2.4.4 OTEC Costs

Some initial comparisons by a potential OTEC project developer in the Philippines have deemed a 10MW OTEC plant to be competitive with diesel. This is due to the price volatility of diesel, and from 10 out of the 12 months, the Wholesale Electricity Spot Market (WESM) had price spikes higher than OTEC's feed-in tariff (FIT) rate of P17.65 or USD 0.38. This is shown in Figure 2.36.

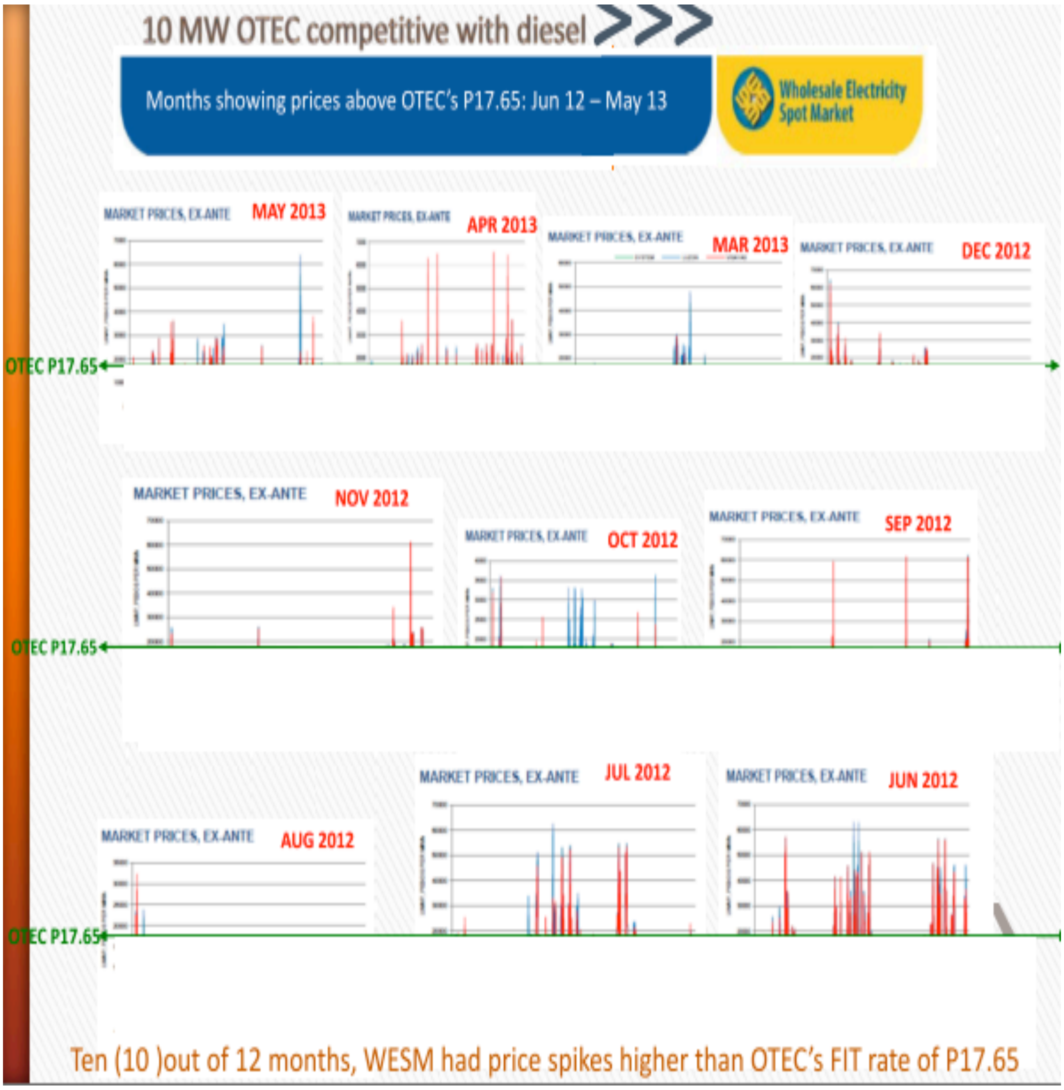

Figure 2.36 OTEC vs Diesel- Price comparison (Latimer, 2013)

Large Scale OTEC plants (greater than 100MW) are cost competitive in markets highly dependent on petroleum for electrical generation by 2020. It is anticipated that OTEC CAPEX costs will decrease over time and capacity will increase, thereby opening other markets. This logic is depicted Lockheed Martin's estimates of cost of electricity (¢/ kWh) vs CAPEX cost (USD million). See Figure 2.37.

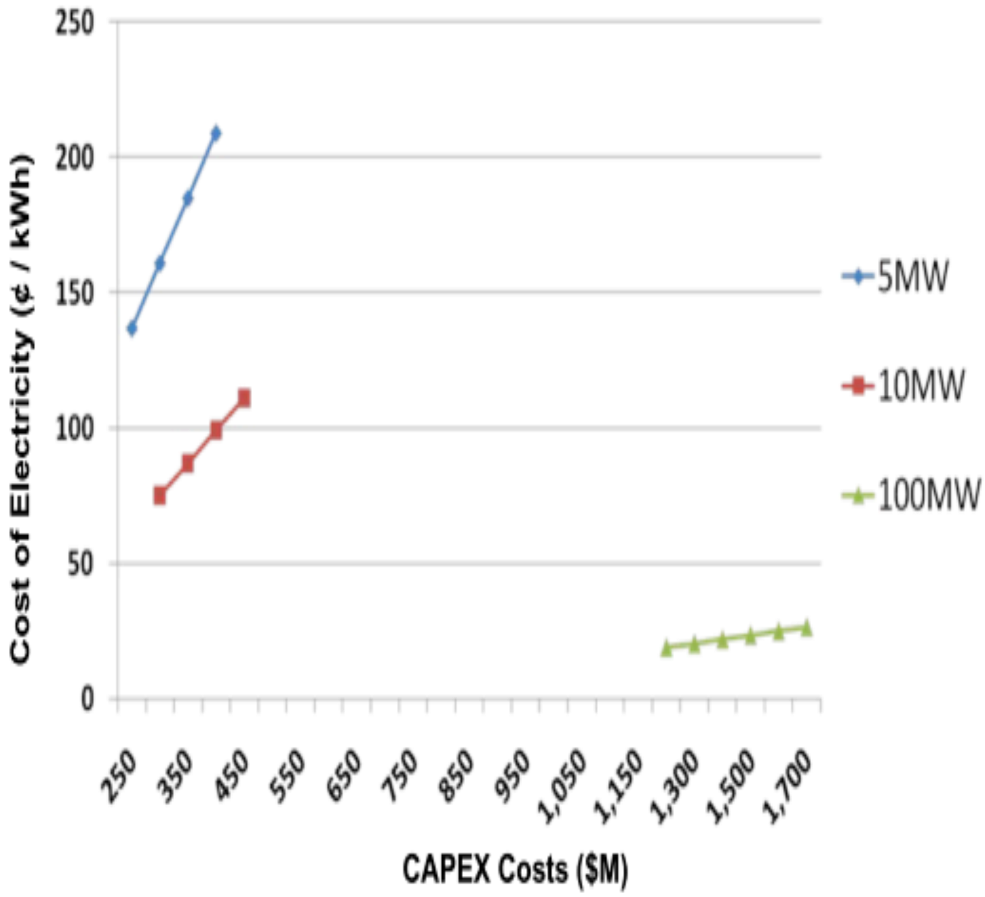

Figure 2.37 OTEC plant- economies of scale (Varley, Meyer & Cooper, 2011)

In greater detail, the first 100MW OTEC plant should have a CAPEX of about USD1.5 billion. USD800 million should come from the OTEC payload, whereas USD700 million is accounts for the OTEC platform and installation. The bulk of the cost comes from the heat exchangers, which costs about USD3.5 million per Watt. (Varley, Meyer & Cooper, 2011) See Figure 2.38.

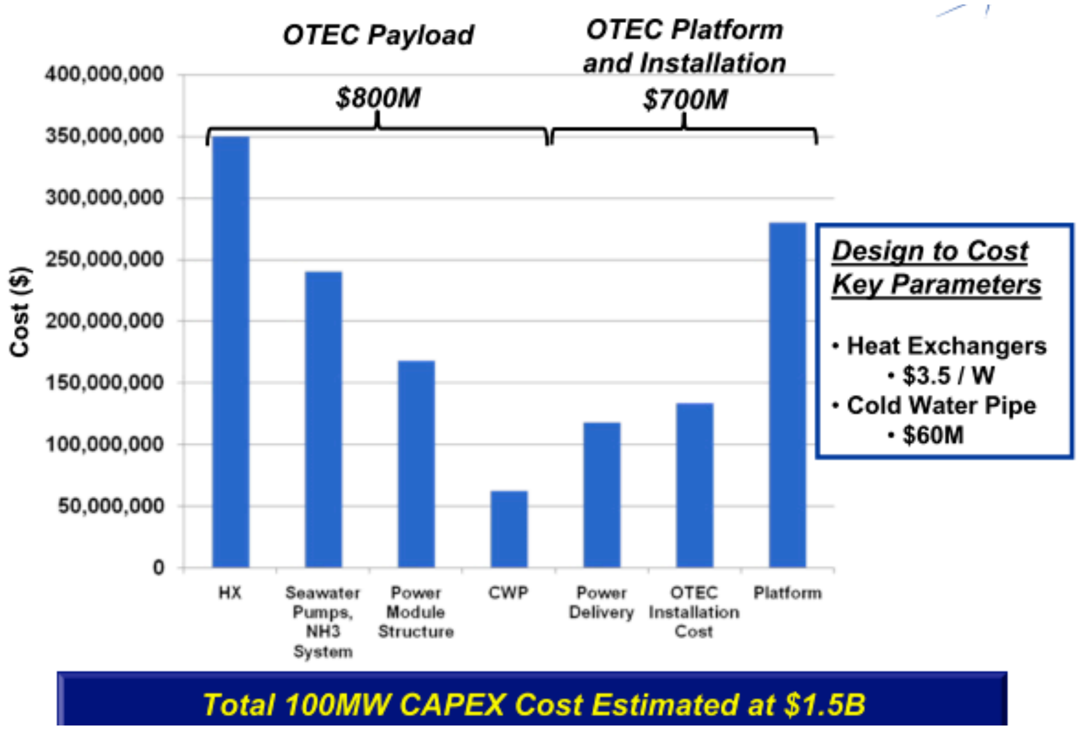

Figure 2.38 CAPEX breakdown of a 100MW OTEC plant (Varley, Meyer & Cooper, 2011)

OTEC is a large long-term opportunity. Other factors that might increase OTEC competitiveness are; Green House Gas (GHG) penalties, premiums for clean, renewable, baseload stable power, and investment and production credits. The comparison of externalities that result from energy technologies may prove OTEC favourable, however operational records (of about 5MW sized plants) are urgently needed to convince OTEC financers to proceed for commercialization (Vega, 1992).

2.5 Summary

OTEC has the highest potential (about 300 exajoules (EJ) per year or, 90% of the global ocean energy potential) when comparing all ocean energy technologies. A total of 98 nations and territories are deemed geographically suitable for OTEC development (Lewis, *et al*., 2011). Recent studies by Rajagopalan and Nihous, (2013) explain that even if global power generation capacity were supplied by OTEC, it would hardly affect the ocean's temperature stability.

Numerous island states in the Caribbean and Pacific Ocean have OTEC resources within 10 km from coast. These remote island states stand to benefit greatly from OTEC since energy production may be integrated with such as district cooling and fresh water production (IRENA, 2014).

Reviewing the recent developments of OTEC around the world, a number of nations have showcased OTEC momentum. For instance, stakeholders in France, Japan, the Philippines and South Korea have presented Ocean energy, or OTEC roadmaps, including developmental targets and commercialization goals (DCNS, 2013; Ikegami, 2015; Marasigan, 2012; Kim & Yeo, 2013). Indonesia has mapped its OTEC resource and niche markets (Achiruddin, 2011), and the Philippines has been considering feed-in tariffs for OTEC (NREB, 2012).

For the case of Malaysia, according to Bakar Jaafar, (2013), a new law on OTEC development is being proposed. The press release by MIMA, (2013) indicated itself as a strong proponent for the OTEC as an alternative energy source for the future, with technical inputs and policy recommendations needed. In addition approval was granted by the Malaysian government for the Ocean Thermal Energy Corporation to conduct a study to generate electricity from the deep sea in Sabah, Malaysia (Khairdzir Md Yunus, 2012).

From the outset of any emerging technology study, as in the case of this research, Technology Roadmapping is beneficial in providing strategic direction and to facilitate development prioritizations. This is urged by Kehoe, (2013) who reiterates a:

> "—multi-national vision, strategy and collaboration is needed to; conduct fundamental and applied OTEC research, develop a stable market structure for OTEC, identify areas suitable for development, perform in situ environmental studies, build a trained OTEC workforce, contracting services and infrastructure, improve performance and reduce costs, and resolve grid integration issues."

In addition, it was agreed that an international joint research project on OTEC was necessary, to explore various inter-related in the promotion of OTEC, including current landscape, evaluation methodologies, environmental assessment, cost of energy, operation and safety and OTEC Roadmap (Ocean Energy Systems, 2014). According to Cable *et al*. (2010) a structured OTEC roadmap may guide government and industry to expedite OTEC commercialization.

However, the OTEC industry technology roadmap has not yet been developed for the context of Malaysia, and this research may fill this gap in knowledge, drawing lessons from past roadmaps proposed by France, Japan, Philippines, and South Korea. As per this study, a Roadmap may provide both public and private institutes a knowledge base for development, while also exploring various aspects of the OTEC ecosystem, including the infrastructural, market, policy, educational and regulatory developments as well as technological issues (McDowall, 2012).

CHAPTER 3

RESEARCH METHODOLOGY

3.1 Introduction

This chapter presents the research methodology used in this study to support the following research objective:

> To develop and propose an Industry Technology Roadmap on hydrogen production for the OTEC industry in Malaysia.

The research questions determine the methodological point of departure for scholarly research, and allow the researcher to clarify purpose, make connections with a field of study, reflect on and interrogate the impact of the research trajectory.

Two main research questions will be addressed;

i. What are the critical elements in the OTEC ecosystem that need to be considered in the development of the OTEC Industry Technology Roadmap?
   a. What are the key elements that play major role in ensuring the success planning, implementation, execution and monitoring in the OTEC ecosystem?
   b. How did the Malaysian energy and research community perceive OTEC future potential, particularly on hydrogen production?
   c. To what extent are OTEC-related technologies readily available?

d. How may the development of OTEC industry be hindered, in the context of Malaysia?

ii. What would be a feasible Industry Technology Roadmap to be adopted for the development of OTEC industry in Malaysia?

3.2 Purpose of Research

The purpose of this research is to propose an Industry Technology Roadmap for the OTEC industry. Through this process, this research will identify future market goals for the OTEC industry and provide various technological and other supportive industry-level solutions to achieve their goals. Ultimately, this will help OTEC companies and the whole OTEC industry to prepare for development and future growth.

3.3 Research Design

A good research design is crucial to obtain accurate answers to the research problem. Yin (2014) explained that the research design in its most elementary sense is the logical sequence that deals with a logical problem and guides what evidence is needed for data collection through linking of the research questions and ultimately to its conclusion. The research design is also summarized by Nachmias & Nachmias (1992) as a plan that guides the investigator in the process of collecting, analysing, and interpreting observations. This logical model of proof allows the researcher to draw inferences concerning causal relations among the variables under investigation.

This research design began with the OTEC Roadmap conceptualization and development for Malaysia, in order to construct the theoretical prepositions as a basis for this study. Theory development is essential prior to the conduct of any data collection, expressly when following the case study method (Yin, 2014). Through the review of the theory of complexity, a theoretical basis was formed, suggesting that successful development plans such as that of technology foresight needs to take into account various actors and levels of management. Next, the concept of OTEC and its evolutional development were reviewed, providing a context for the study. This brought into focus the rationale for the research and identified the research needs and direction.

This research explores the technology readiness of developing the OTEC industry in Malaysia and proposes an OTEC Industry Technology Roadmap. The data collection process involved three main phases and a variety of sources, which was necessary for data triangulation and validation (Yin, 2014). This research adopted methodological triangulation to substantiate the validity of the research.

The richness of inputs allowed the researcher to effectively explore the research from various angles. Firstly, the critical technology elements for OTEC development were identified. The views and perceptions of the energy and research community regarding the OTEC future product potential, particularly on hydrogen production, and the major challenges that would have been faced in the process of developing OTEC industry in Malaysia were also investigated.

The analytic strategy for this research relied on the theoretical proposition that technology foresight is a useful tool to facilitate planning a company or industry's future direction. Constant comparison analysis was used to analyse the data. Through this process, any newly collected data is compared with previous data that was collected in one or more earlier studies. This is similar to the congruence method in political science research (George & Bennett, 2004). The observed similarity of the predicted patterns can help strengthen the research's internal validity (Yin, 2014). In this case, data collected from the various phases and sources were compared for pattern matching.

Similar emergent themes facilitated the construction of a feasible Industry Technology Roadmap to be adopted for the development of OTEC industry in Malaysia. Finally, these findings were distilled and captured in the form of a dissertation. The research design is depicted in Figure 3.1 (page75).

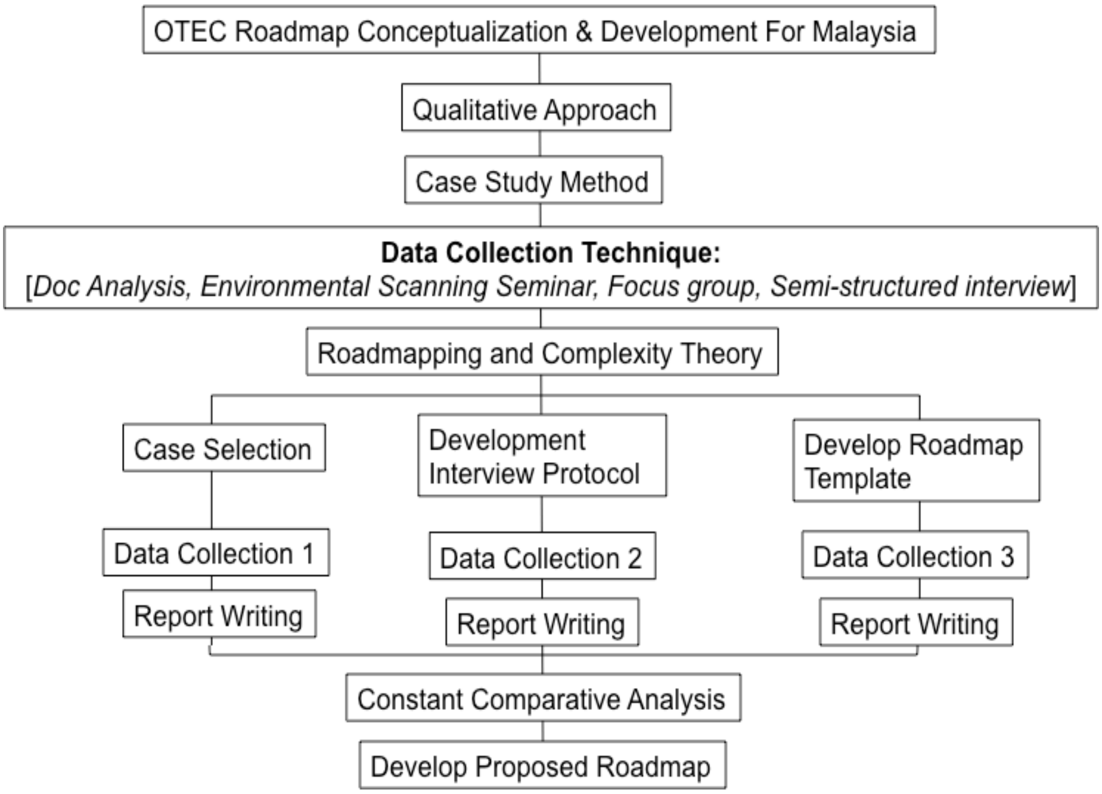

Figure 3.1 Research Design (Akbariah Mohd Mahdzir, 2008)

3.3.1 Qualitative Approach

Qualitative research is defined by Creswell (2014) as:

> "an inquiry process of understanding based on distinct methodological traditions of inquiry that explore a social or human problem. The researcher builds a complex, holistic picture, analyzes words, reports detailed views of informants, and conducts the study in a natural setting".

This research adopted the qualitative method, which is done by analysing reports, synthesis and evaluation of ideas or documents, and brainstorming. For this, the level and type of participation are of importance. This includes the people (actors, sponsors, managers, and users). This research used both primary data and secondary data.

According to Kostoff and Schaller (2001), two major sources for the Technology Roadmapping are experts and large textual databases. Published papers, reports, memoranda, letters, patents could be included in the textual databases. The textual database approach is more objective than the expert-based approach, because the textual data lacks the preconceived limitations, constraints, biases, and personal and organizational agendas of the experts. Kostoff and Schaller (2001) argued that a balanced combination of the expert and textual database analysis might prove to be the most effective and efficient approach to Roadmap construction. This research leveraged both sources, capitalizing on qualitative data from semi-structured interviews consisting of industry experts, and those from in the energy and research community, as well as textual database, which include documents, reports, and a patent analysis.

Since Industry Technology Roadmaps considers both market pull and technology push approaches, understanding consumers' need and their opinions are meaningful. This is especially significant to understand future market potential, in order to effectively cross-validate the findings from consumers (market pull) and industry experts (technology push). Therefore, meaningful dialog need to be created by both potential consumers and industry experts, that is potential customers representing the market pull, whereas industry experts representing the technology push aspects respectively. This was achieved through a focus group session and a document analysis of textual database and patent analysis.

The findings of Rohrbeck *et al*., (2009) support the intentional cross-cutting involvement of stakeholders, showing that top performance companies invest significantly more resources in gathering data from restricted sources, utilize more qualitative methods, and more often select methods deliberately. These companies engage in more bottom-up triggered foresight activities, which should raise the overall level of alertness as well as their scanning reach and scope.

The theoretical framework perspective for this study is explicitly formed from the theory of complexity which largely influenced the researchers approach towards Industry Technology Roadmapping for OTEC, as have been explained in Chapter 2.

There are two primary approaches to using theory: deductive and inductive. A deductive approach, which is emphasized in post-positivism, tests theory or a hypothesis against data. An inductive approach, which is usually emphasized in interpretive and critical belief systems, generates theory directly out of the data. This research adopts the inductive approach in research design, as depicted in Figure 3.2.

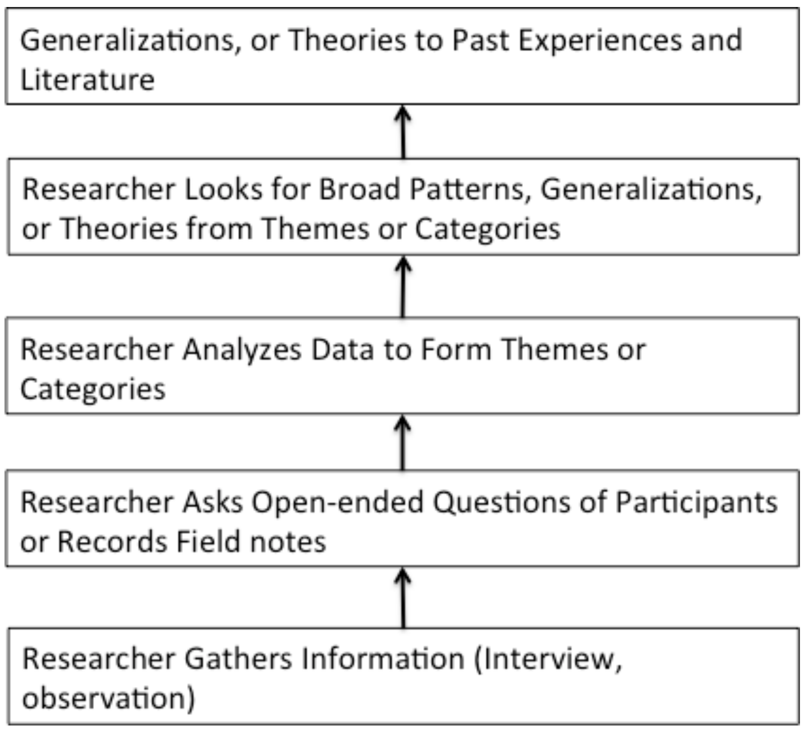

Figure 3.2 Inductive approach (Creswell, 2003)

Related to the inductive approach, this research was conducted based on three assumptions:

i. Technology is one of the most important factors to improve a company's or industry's competitiveness
ii. Industry Technology Roadmap is an effective long-term planning method, and

iii. The input from the energy and research community is critical towards developing the OTEC future direction

An amount of research have proven that the first assumption may be regarded true (Porter, 1980, 1985; Betz, 1993; Martino, 1993; Harmel & Praharad, 1994; Chesbrough 2003; Probet *et al*., 2004). The second assumption is supported by the extensive usage of Technology Roadmaps, which includes the development of 250 U.S. Industry Technology Roadmaps (Probert & Randor, 2003) and also that of various countries (De Laat & McKibbin, 2001). The third assumption may be supported by the theory of complexity, in the observation of social change through 'bottom up' processes (Holland & Miller, 1991; Gell-Mann, 1994b; Miller & Page, 2007).

The fit for using Technology Roadmapping in the context of this research has also been illustrated in Chapter 2.

3.3.2 Philosophical Underpinning and Foresight Research

Creswell (2014) explains that there are five traditional designs of qualitative inquiry: Biography, Phenomenology, Grounded Theory, Ethnography, and Case Study.

The methodological approach or theoretical perspective is an account of social reality or some component of it that extends further than what has been empirically investigated. There are three major methodological approaches in qualitative research, with different functions: post-positivist (predicts), interpretive/ constructivist (understands), and critical (emancipates).

The case study method is in agreement with the interpretive and post-positivism paradigm. Determining the paradigm in which the researcher operates will greatly influence the approach of study. For instance, the post-positivist researcher takes a more distant observation approach towards implementing a case study, whereas the interpretivist researcher would approach it with an ‘insider’ view (Torrance & Stark, 2005).

For evaluation of foresight research, the common application of case study methodology uses the interpretive lens. This was the research paradigm held by Vecchiato and Roveda (2010), Battistella (2013), Vecchiato, (2012), and Khairuddin *et al.*, (2013). This theoretical prespective and the case study method in particular, is suitable for evaluating impacts of an existing or innovative programmes which may enchance decision-making, policy or practice (Elliott & Lukes, 2008; Kervin, Vialle, Herrington, *et al.*, 2006; Torrance & Stark, 2005). The interpretive case studies views the case members as active participants in the construction of the case narrative, providing opportunities for mutual refletion and verify interpretation of the phenomenon; thereby adopting the interpretive lens. The interpretive position assumes the social world is constantly being constructed through group interactions, and thus, social reality can be understood via the perspectives of social actors enmeshed in meaning-making activities. This interpretive research paradigm is less suitable for the context of this research, since the research is not an evaluative study, designed to describe, understand, and interpret, but rather one that seeks to predict, control and generalize, as per the post-positivist perspective.

Yin's (2009) approach to case study adopts the post-positivism lens, which posits that the social world is patterned and that causal relationships can be discovered and tested via reliable strategies. This lens is also adopted by Rohrbeck & Gemünden's, (2011), who used the deductive approach to explain the theoretical proposition that corporate foresight can enhance innovation capacity.

Similarly, this research adopted the post-positivism lens. The post-positivism lens is especially suitable for this research, since it aims to create an Industry Technology Roadmap on Hydrogen Production from OTEC, as well as to generalize the perceptions within the energy and research community, which will in turn shape the outcome of the roadmap and industry development. In this sense, the reality of the research is objective, external, and ‘out there’ (Merriam, 2009).

3.3.3 Foresight Model Selection

Although quantitative OTEC development targets (energy projections) have been proposed in the Academy Science Malaysia special task force workshops (Bakar Jaafar, 2015), no OTEC Industry Roadmap has been developed for the context of Malaysia, as of yet. A review of OTEC development, including foresight activities around the world was presented in Chapter 2. Although several OTEC roadmaps have been developed, such as that of France (DCNS, 2013) and South Korea (Kim & Yeo, 2013), its development targets was limited to the company/ organization level. For the case of Japan, the roadmap development was targeted at national, industry level, within the environment of Japan. In this resultant (Japanese) OTEC technology roadmap, the targeted goals, assignment and correspondence, and target of R&D was taken into consideration (Ikegami, 2015). However, all past roadmaps listed have not taken into account the applications of potential spin-off industries, but rather focused on the development of OTEC and its electricity production as an end product. This study on the other hand, envisions Hydrogen as a product of OTEC, and attempts to extend previously developed OTEC models to incorporate more comprehensive developmental goals such as proposed technology, applications, programs, and resources.

This study contextualizes OTEC as an industry in Malaysia. The researcher adopted Phaal, Farrukh & Probert's, (2001) approach for technology roadmapping, which is not a one size fits all approach. For this purpose, the selection of suitable foresight model(s) to be incorporated for industry level planning/ mapping was necessary, and the various foresight models discussed in Chapter 2 formed the basis for selection.

As depicted by Popper's (2008) foresight diamond model in Figure 3.3 (page 81), the different foresight methods can be classified according to its research approaches, be it qualitative, semi-quantitative, or quantitative.

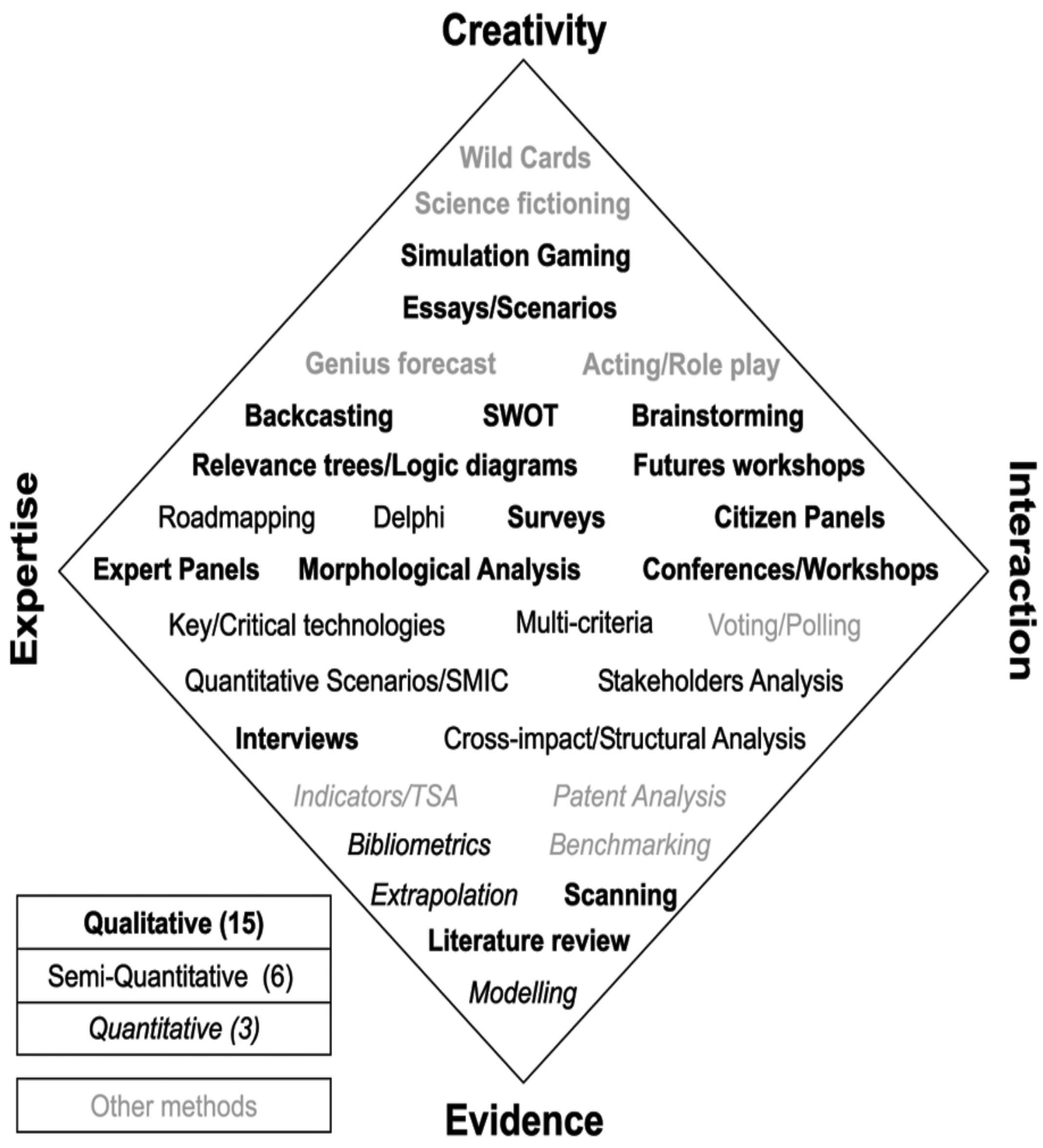

Figure 3.3 Foresight diamond (Popper, 2008b)

For this study, the qualitative approach models were shortlisted, due to the suitability of a qualitative approach in constructing a complex, holistic picture, through word analysis, and detailed respondent perspectives (Creswell, 2014). Next, the models were examined based on their inclination level towards creativity, interaction, evidence, and or expertise. This formed the basis for deciding which models best fit the researcher's agenda.

In concurrence with Yin's (2009) post-positivist research paradigm that was adopted by this researcher, the foresight models considered needed to reflect a high degree of interaction, evidence, and expertise requirement. Therefore, the models which reflect these elements was selected by the researcher, including literature review, scanning, conferences, futures workshops, patent analysis, expert panels, and surveys (for roadmap validation). However, lacking in this models selection is the element of creativity, which is not necessary when adopting the post-positivist paradigm.

The triangulation of these models was necessary to form a holistic view of the industry and develop the elements in the OTEC Industry Technology Roadmap. This also reflected the data triangulation in this research, which incorporated various sources of informants. Foresight models may also adopt specific research methods, including particular data collection and analysis technics. Although the approaches are similar, the terms of reference differ due to academic field jargon. Therefore as shown in Table 3.1, each model used was matched based on its similarity or appropriateness to the phase of research in this study.

Table 3.1: Research phase and connection to foresight model

Phase of Research	Foresight Model
Phase 1: Document analysis	Literature review
Phase 1: Environmental Scan of the OTEC Industry	Scanning, Conferences
Phase 2: Focus group	Futures workshops
Phase 3: Semi structured interviews	Expert panels
Roadmap validation	Expert panels, Surveys

Each phase of research is greater detailed, with regard to the case study method and data collection approaches, in the following subsections. The incorporation of all the models listed in Table 3.1 (as a data collection approach, including sampling) resulted in the formation and informed development of layers for the OTEC industry roadmap.

3.3.4 Case Study Method

Case study methodology is represented by several principal authors (Creswell, 2013; Merriam, 2009; Yin, 2014). Case study methodology maintains deep connections to core values and intentions and is "particularistic, descriptive and heuristic" (Merriam, 2009). As a qualitative case study design, This qualitative approach "explores a real-life, contemporary bounded system (a case) or multiple bounded systems (cases) over time, through detailed, in-depth data collection involving multiple sources of information, and reports a case description and case themes" (Creswell, 2013). Case study research has been defined by the unit of analysis, the process of study, and the outcome or end product, all essentially the case (Merriam, 2009).

This research adopted the case study method, which is defined by Yin (2014) as,

> "an empirical enquiry that: (i) investigates a contemporary phenomenon (the "case") in depth and within its real-world context, especially when (ii) the boundaries between phenomenon and context may not be clearly evident."

Based on this definition, the first part of the explains the scope of the study, that is to understand real-world case, assuming that an understanding is likely to involve important contextual contradictions pertinent to the research (Yin & Davis, 2007). Secondly, case studies arise since the phenomenon and context are not always sharply distinguishable in real-world situations.

Several foresight studies appropriately adopt the case study method, which involves developing in-depth descriptions and analysis of a case or multiple cases. This is immensely useful to study an event or activity, such as foresight.

According to Yin (2009), a case study approach should be considered when: (i) the focus of the study is to answer 'how' and 'why' questions; (ii) you cannot manipulate the behaviour of those involved in the study; (iii) you want to cover contextual conditions because you believe they are relevant to the phenomenon under study; or (iv) the boundaries are not clear between the phenomenon and context. For this research, a case study was chosen because the case was the development of an OTEC Industry roadmap, and more specifically in the context of the hyrdogen product future potential. It was in this context that the technical readiness of OTEC related technology need to be ascertained. It would be impossible for the researcher to have a true image of of the hydrogen potential without also considering the context within which it may be sourced.

The case study process includes data collection, analysis, and documentation. Data may be collected from multiple sources such as interviews, observations, documents, and artifacts. Next, data should be analyzed through description of the case and themes of the case. Finally, a detailed analysis of the said case should be developed, and documented in the written report. (Stake, 1995).

Phase 1. Environmental scan of the OTEC industry

In Phase 1, overall outlook of OTEC industry was reviewed and analysed using document analysis of secondary data sources. The results of the environmental scan became the basis for identifying the target product of hydrogen. The results also formed a foundation for identifying the current environment of the OTEC industry. The scope of the Roadmap has been decided based on the previous research, which is 15 years into the future (until time horizon of the year 2030) (Garcia & Bray, 1997). In addition, target speakers were identified for an OTEC Environmental Scanning Seminar to furnish the existing knowledge gaps. The activities of Phase 1 and their contribution to the research questions are depicted in Table 3.2 (page 85).

Table 3.2: Summary of phase 1 data sources and contribution to research questions (Nelson, 2008)

Provide broad understanding of	**Secondary source**	**Primary source**	**Contribution to research questions**
OTEC industry overview	Internet search, presentation materials, conference proceedings	Focus group session, Semi-structured interviews	RQ1a
OTEC technology specifications	Workshop outputs	Semi-structured interview	RQ1c
OTEC value proposition	Internet search, presentation materials, conference proceedings	Focus group session	RQ1a

Phase 2. Focus Group

The focus group method has been long neglected in sociological research methods. However, since the 1990s the method has been steadily of use in the field of marketing studies, where it maintained popularity (Jowett & O'Toole, 2006; Peek & Fothergill, 2009).

A focus group is 'a small group discussion focused on a particular topic and facilitated by a researcher' (Tonkiss, 2004 pp. 194). The proposition of focus groups as a social scientific research method is advantageous in its ability 'for exploring the attitudes, opinions, meanings and definitions on the participants own terms' (Tonkiss, 2004). Asserted by Cronin, (2008) , 'the main goal of a focus group is to gain insight and understanding by hearing from representatives from the target population', by which in the case of this study, refers to the energy and research community.

On focus groups size, Cronin, (2008), states that 'ideally, focus groups should consist of between six to ten people'. Peek and Fothergill (2009), agreed with this proposition, further explaining that 'groups that included between 3-5 participants ran more smoothly than the larger group interviews we conducted,' and that 'managing the larger focus groups, from anywhere from 6- 15 participants, was difficult'. Cronin (2008) concurred that managing groups of more than ten is difficult and, in addition, that such focus groups 'result in data lacking both depth and substance'. Also, in larger groups participants might rely on others to do the talking, also termed 'social floating' (Cronin, 2008).

The aim of this study is to form an understanding of how the energy and scientific research community perceives the OTEC potential based on one focus area. Therefore, both depth and substance are important. Moreover, since the focus is on the participants' opinions, the researcher wanted to use a 'low' moderator style (Morgan, 1997), meaning a modest role for the moderator in the discussion. Such a style is manageable only if the groups are relatively small. Combining this need for both depth and manageability of the groups, it was decided to limit the size of the groups to six participants. The summary of Phase 2 activities and their contribution to the research questions are depicted in Table 3.3.

Table 3.3: Summary of Phase 2 data sources and contribution to research questions (Nelson, 2008)

Provide broad understanding of	**Secondary source**	**Primary source**	**Contribution to research questions**
Energy and research community's perception of OTEC and its future potential		Focus group	RQ1b, RQ1c

Phase 3. Semi Structured Interview

An expert panel was used for this semi structured interview phase phase. This normally consists of individuals who are mandated to use their collective expertise in addressing a particular problem or set of issues. For the case of this research, the expert panel was used to provide additional inputs and validate the proposed Industry Technology Roadmap. The benefits of using expert panels in Technology Foresight (TF) are widely acknowledged (United Nations, 2005), such as:

i. Availability of expert judgment "on tap": at the centre of an exercise, which can be particularly important when dealing with the uncertainties associated with the future
ii. In-depth and meaningful interaction and networking between different scientific disciplines and areas of expertise that may otherwise be difficult to organize
iii. Generation of inputs, interpretation of outputs, and/ or the overall conduct of the method
iv. Credibility and authority lent to the TF exercise through the profile of panel members and the visibility of expert/ stakeholder panels

Eliciting expert and stakeholder views may include the use of interviews and questionnaire surveys. However, this research selected the semi-structured interview approach, allowing greater ability to gain additional inputs that may have otherwise been missed. Table 3.4 summarizes the phase 3 activities and their contribution to research questions.

Table 3.4: Summary of phase 3 data sources and contribution to research questions (Nelson, 2008)

Provide broad understanding of	**Secondary source**	**Primary source**	**Contribution to research questions**
Developing the OTEC Ecosystem in Malaysia		Semi-structured interview	RQ1a, RQ1b, RQ1c, RQ1d,
Developing the OTEC Roadmap in Malaysia		Semi-structured interview	RQ2

3.4 Population and sample selection

The population for this research refers to the energy and research community. Purposive sampling is used to select the respondents, with the organizations being the unit of analysis. In the context of a technology foresight exercise, these respondents can be recruited by 3 ways; personal contacts, stakeholders, and formal process. This research adopted the stakeholders approach, as well as formal process to select respondents.

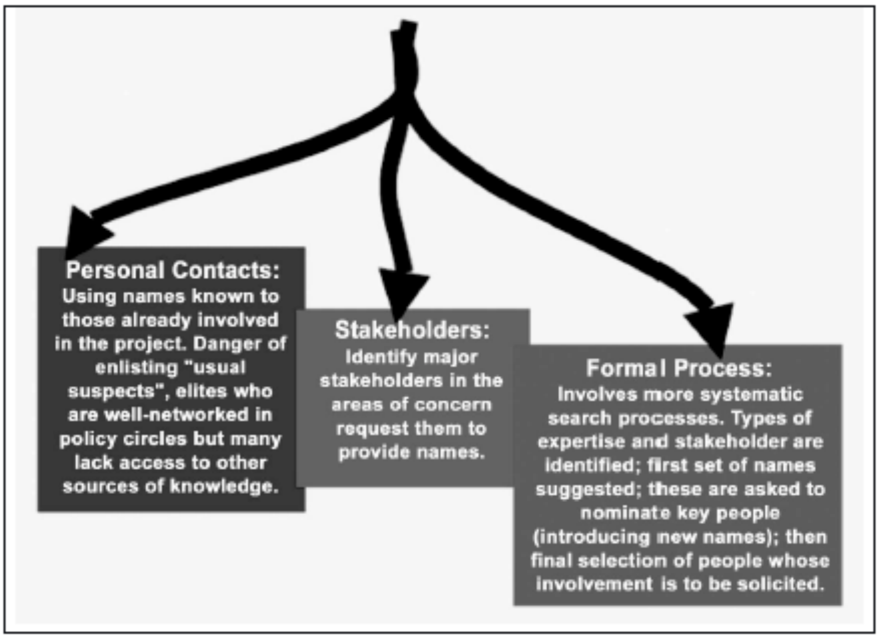

Figure 3.3 Three ways of recruiting members and participants (Miles & Keenan, 2002)

The focus group respondents were identified based on the following criteria;

- Composition; what mix of knowledge is required to address the focus group's remit?
- Balance; what mix of views/ positions/ value judgements/ scientific disciplines should be represented in the focus group to ensure even-handed analysis and conclusions?

The selection of appropriate panels or respondents should be technically qualified and even-handed to achieve authority, credibility and legitimacy. In this research, the criteria for selection were at least 10 years in the energy, finance, or business development industry. For hydrogen industry, which is relatively new, a criterion of at least 3 years as a service provider in the industry was set. This includes academic experience, civil service experience, or private sector. Thus, the list of selected expert panels for the semi-structured interview respondents (Phase 3) is shown in Table 3.5

Table 3.5: Shortlisted Expert panel

Criteria	Organization	Designation	Specialization	Name
>10 years in energy research, academia	OTEC Department, Company X	Director	OTEC technical viabilities	Expert 1
>10 years in energy research, civil service	OTEC Department, Company X	Co-chair	OTEC strategic development	Expert 2
>10 years in finance, civil service and private sector	Engineering Modeling Consultancy Services KL Malaysia	Prof.	Energy economics	Expert 3
>10 years in business development	Company Y	Director	Business viability	Expert 4
>3 years in hydrogen industry	Company Z	Co-Founder	Business viability	Expert 5

3.5 Data collection

According to Kostoff and Shaller (2001) a balanced combination of the expert input and the large textual data, including published papers, reports, memoranda, and letters, may offer the most effective and efficient approach to Roadmap construction. Both expert-based data and large textual data possess different values. For optimal results, the best combination of expert-based approaches and textural approaches should be identified, extracted, and employed.

For gathering ideas, sorting opinions, and building consensus of stakeholders, various methods have been introduced. These include workshops or conferences (Phaal, Farrukh, Michell, *et al.*, 2003), electronic communications including e-mail or conference calls (MacKenzie, Donald, Harrington, *et al.*, 2002), literature-based discovery of critical technology components (Kostoff, R. & Simons, 2004), data-mining (Probert, Farrukh & Phaal, 2003), and using software (Duckles & Coyle, 2002; Grossman, 2004; Probert & Randor, 2003). In addition, market research, interviews, surveys and analysis can also be good tools for gathering information (Phaal, Farrukh, Mills, *et al.*, 2003).

As stated in the previous section, data collection in this research was carried out via 3 phases; environmental scanning seminar, focus group, and semi-structured interview. The specific activities are detailed in the following subsections.

3.5.1 Environmental Scanning Seminar

The environmental scanning seminar required a diverse mix of inputs from various experts. The topic identification was done based on knowledge gaps, and the relevant experts contacted to participate as speakers for the seminar. Speakers were identified through workshop, conference, internet search, and the recommendation of other industry experts. E-mail invitations and follow up calls were made, to request for the speaker's participation. The speakers and their respective topics are shown in Table 3.6 (page 91).

Table 3.6: Short Course on OTEC, List of Speakers and Topics

Speaker	**Topic**
Prof. Dato' Ir. Dr. Abu Bakar Jaafar, *Co-Chair, UTM Ocean Thermal Energy Center (OTEC)*	Energy overview in temperate and tropical regions
Prof. Dr. Md Nor Musa, *Director, UTM Ocean Thermal Energy Center (OTEC)*	Ocean Thermal Energy Conversion Technology
Prof. Dr. Mohamed Mahmoud El-Sayed Nasef, *Deputy Director, Institute of Hydrogen Economy, UTM*	The Age of Hydrogen is Here, Not in the Future
Assoc. Prof. Dr. Fauziah Sh. Ahmad, *International Business School, UTM*	Techno-Economics of OTEC
Mr. Mizuan Abdul Manaf, *CEO, UTM Holdings Sdn. Bhd.*	Investments of the Future: OTEC Business Plan
Mr. Amir Clyde, *Projects and Business Development, UTM Holdings*	OTEC Kick-Start in Malaysia
Dr. Akbariah Mohd Mahdzir *Malaysia Japan International Institute of Technology, UTM* **Dr. Aini Suzana Datuk Haji Ariffin** *Perdana School of Science, Technology and Innovation Policy, UTM*	OTEC Spin-off Industries and Social Economic Transformation
Mr. Haris Abd Rani, *PhD Candidate, Malaysia Japan International Institute of Technology*	Legal and policy framework
Ms. Anne-Sophie Colleaux, *Business Development Manager, DCNS*	OTEC Advancing Beyond French Territories: Perspectives from the Technology Providers
Assoc. Prof. Dr. Jennifer Chan, *Tourism Management Program, UMS*	Social Transformation of Underdeveloped Coastal & Island Communities with OTEC Solutions

3.5.2 Focus Group

The goal of the focus group session is to gather a multitude of participants within the energy and research community to contribute their opinion regarding the OTEC potential. The composition of focus group participants were recruited based on the attendees of the Environmental Scanning Seminar, with invitations sent to about 800 prospects. It was observed that the prospects had viewed the invitation, through an e-mail tracking tool, 'Mail Chimp'. Thus wide and diverse compositions of prospects were given the opportunity to voluntarily participate in this research.

The focus group discussion was held for a full day on 11th December 2014 at an activity room in the Universiti Teknologi Malaysia, Kuala Lumpur Campus. The objective of the focus group discussion was explained, which is to discuss perspectives regarding the future hydrogen energy landscape. In this regard, the respondents were encouraged to speak freely, with no prejudices or limitations. The researcher also assured the individual anonymity of the respondents. Each layer of the roadmap was discussed consecutively, moderated by the researcher. The topics of discussion were categorized as trends and drivers (Social, Technology, Economic, Environment, Politic), Applications, Technology, Programs, and Resources.

3.5.3 Semi-structured interview with expert panel

In-depth interviews of a representative sample of key companies, institutions, or organizations from the OTEC industry were conducted to identify the future directions for more focused research. A semi-structured questionnaire was designed for this purpose. In-depth interviews were performed at face-to-face meetings with managers or directors responsible for R&D strategy of the company or organization.

Respondents were identified through workshop, conference, internet search, and the recommendation of other industry experts, were directly contacted and asked for their participation in an interview through a personal visit.

Then, interview was scheduled and interview method was decided based on the convenience for each interviewee with on-site contacts. Industry expert interviews were conducted for a 2-month period. The interviews were conducted until the data collected reached saturation point, that is achieving data that is both ‘rich’ and ‘thick’, meaning layered, intricate, and nuanced, with no new themes (Mason, 2010; Fusch & Ness, 2015).

3.6 Data analysis

According to Yin (2014), for most case studies, including in-depth interviews, the lack of a formal database is a weakness. However, putting information into different arrays, making a matrix of categories, creating flow charts or other graphics, and putting information in chronological order can be a starting point for qualitative data analysis (Yin, 2009, p.129-130).

The data analysis followed a rigorous and iterative process of transcribing, validating transcripts, data reduction, derived meaning, and presentation of output for validation.

After the interview process, the researcher prepared the interview transcripts, which served as qualitative data material for analysis. The transcribing of the recorded interviews is a tedious process, which took at least two months. By transcribing the interviews personally, the researcher was able to grasp and identify subtle nuances of the respondents, bringing richer meaning into the study.

Due care was given to validate the interview transcripts, through peer review. This supported the credibility, dependability and conformability of the research. Any errors in transcription were promptly edited, and reread to comprehend the complete meaning and context.

The data analysis followed Silverman's, (2010) recommendation for qualitative data analysis, which is a three step process of data reduction, data display, and conclusion drawing.

For data reduction, the consolidated data was analysed according to themes. ‘A theme,’ according to Boyatzis (1998), ‘is a pattern found in the information that at minimum describes and organizes the possible observations and at maximum interprets aspects of the phenomenon. A theme may be identified at the manifest level (directly observable information) or at the latent level (underlying the phenomenon)’. A thematic analysis of the focus group data thus involves reading and rereading the transcripts, coding the distinctive themes in each discussion, comparing the themes with those found in the transcript of the other discussion, and finally coming to a (limited) amount of analytically distinctive themes with which the diverse opinions can be compared.

Through the various phases of research, the current state of OTEC, critical requirements, technology gaps, and possible paths to fill these gaps were identified by synthesizing all collected qualitative data, primary data, and secondary data. In addition, with the same methods, other supportable solutions to meet critical requirements were also analysed, including spin-off industry (hydrogen) potential, physical infrastructure, strategies for making and reacting to regulations, and the type of collaboration needed among industry, academia, government, and other stakeholders. The reduction of the data was categorized based on the framework for technology roadmap development as put forward by Phaal, Farrukh & Probert, (2001).

All resulting solutions were synthesised and displayed in the form of an Industry Technology Roadmap. With this display, meaningful relationships or networks we able to be identified through a layered map which included trends and drivers, applications, technology, programs, and resources.

Meaning was derived from the information displayed in the Industry Technology Roadmap, and macro-level conclusions were drawn, forming a comprehensive overview of the OTEC industry in the Malaysian contextual landscape. The derived meanings were presented and validated among a panel of 30 international experts. Discrepancies were captured in the form of a 'degree of agreement' survey. The expert opinions were analysed, cross-checked and synthesised with the previously transcribed interviews for context and cohesiveness. Final conclusions were drawn for the overall study, with ascertained validations. The entire data analysis process is depicted in Figure 3.4.

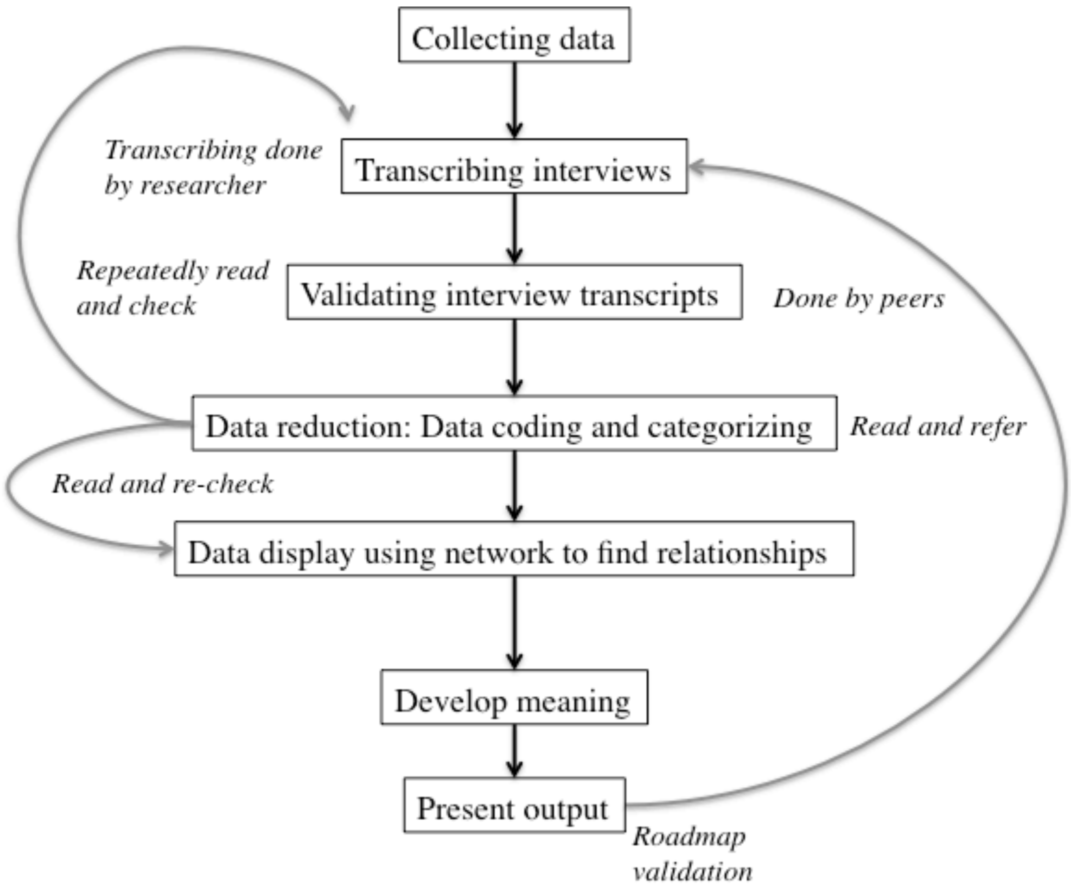

Figure 3.4 Qualitative Data Analysis Process

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CHAPTER 4

RESULTS AND INTERPRETATION

4.1 Introduction

The result of this research is an Industry Technology Roadmap for the OTEC industry, which provides future markets, current environments, critical requirements and alternative solutions to achieve future goals, and collaborative possibilities among various stakeholders. The resulting Industry Technology Roadmap was created by gathering and analysing a variety of information obtained from focus groups, expert interviews, and document analysis, including a patent search, through the process of Phase 1 to Phase 3 of the research process as described in Chapter 3. Experts from the energy and research community including academia, industry associations, and research institutes provided their opinions for this study. They represent not only the technology field but also the marketing field, and the experts were in various positions with diverse experience, contributing to a broad view. This supported the value and validity of this research. This chapter presents and deliberates on the findings of this research.

4.2 Industry Technology Roadmap on Hydrogen Production from OTEC in Malaysia

The Malaysian Energy and Research Community have identified hydrogen as an important energy carrier in the near future. The most crucial issue in the establishment of the hydrogen economy is the identification of a sustainable and economically viable source for hydrogen. According to the responses gathered from the Malaysian Energy and Research community, OTEC may be one of the feasible sources of hydrogen, thereby being a solution to help realize the future of a low or zero carbon economy.

Several key factors propel the OTEC industry forward, such as the decreasing supply and increasing costs of fossil fuels, advancements in OTEC and hydrogen conversion technologies, renewable energy mandates, and energy security concerns. This resulted in resurgent interest in OTEC, especially for the geographically suitable tropical locations. The potential of OTEC to help fulfill the hydrogen economy is discussed in the following.

The industry technology roadmap for OTEC was constructed based on 3 main time periods; Short term (2014-2015), Medium term (2016-2030), and Long term (2031-2050). These time frames are consistently referenced, henceforth in this research.

Addressing some of the timelines perspectives, some respondents were apprehensive about the ambitious timelines to onset the OTEC and hydrogen industry. As one respondent remarked,

> "Slow slow pun tak per.. I rasa diorang cakap takkan dapat dalam 3 tahun.. I ingat 50 tahun pun tak tentu... la."
>
> (Respondent 2/ academia/ male)

However, it should be noted that the development targets were adapted from the National Hydrogen Roadmap, and revised based on a validation with international stakeholders, therefore reflects an ideal development timeline or scenario. Actual project development timeliness may vary, since the onset of the OTEC industry is largely dependent on the amount of financing available. Figure 4.1 depicts the Industry technology roadmap on hydrogen production from OTEC in Malaysia.

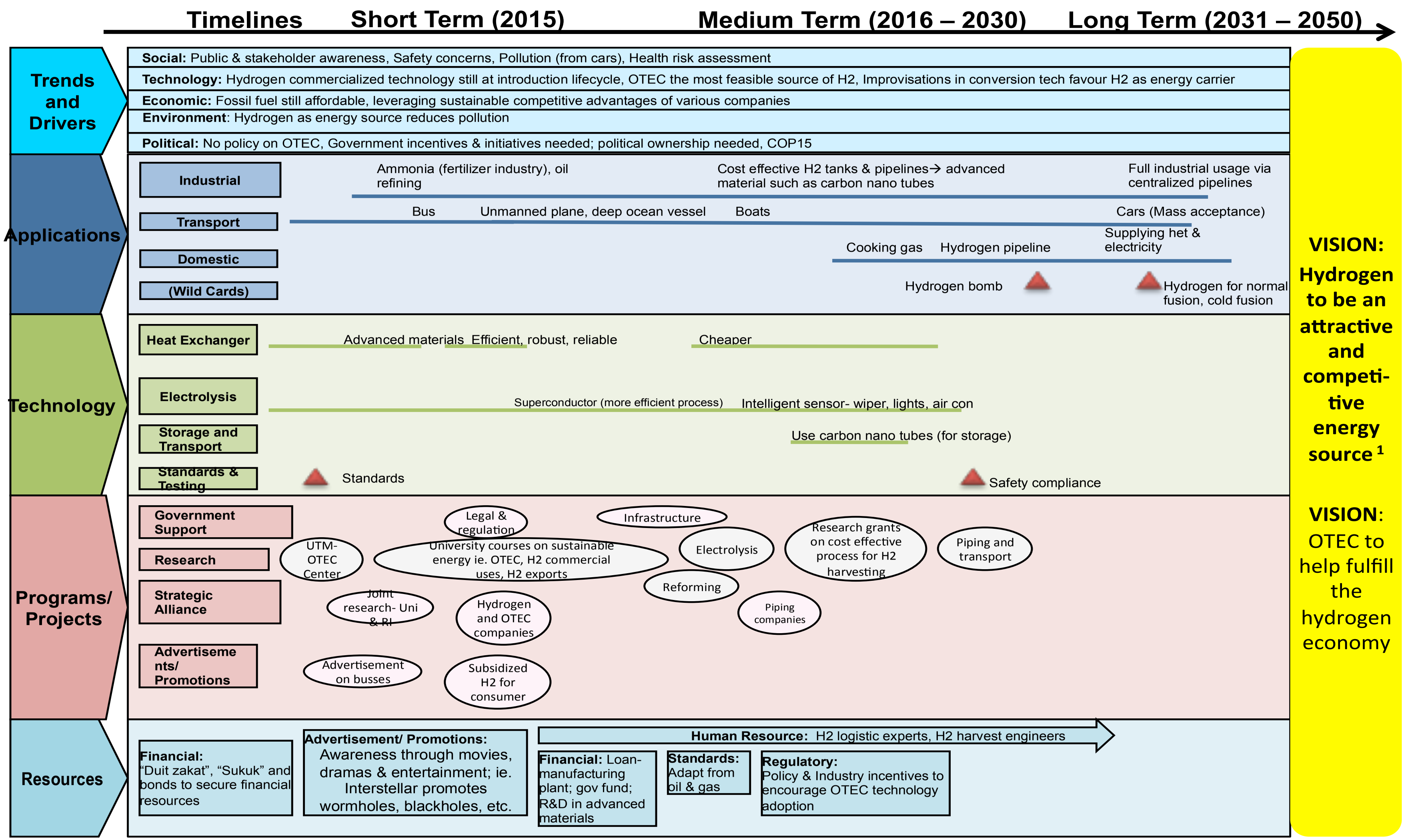


Figure 4.1 Industry Technology Roadmap on Hydrogen Production from OTEC

4.2.1 OTEC-Hydrogen Integration Rationale and Future Direction

Energy is a prime contributor for economic growth. Its contribution is two-fold. Firstly, energy is a large sector of the economy that creates jobs and value by extracting, transforming, and distributing energy goods and services throughout the economy. Secondly, energy is the backbone of the rest of the economy, being an input for nearly all goods and services. Therefore a reliable and sustainable source of energy is necessary, since price shocks and supply interruptions can shake whole economies. (World Economic Forum, 2012)

The future of hydrogen as a dominant energy carrier is projected through the evolution of global market shares for different final-energy carriers in the years 1990-2100. This reflected in Figure 4.2 (Barreto, Makihira & Riahi, 2002) which portrays that hydrogen will be the most dominant energy carrier by the end of the 21st century, accounting for almost 50% of the global final energy share in the year 2100. However, on a side note, this figure fails to account for the district cooling, suggesting that this study is skewed towards the temperate region perspective.

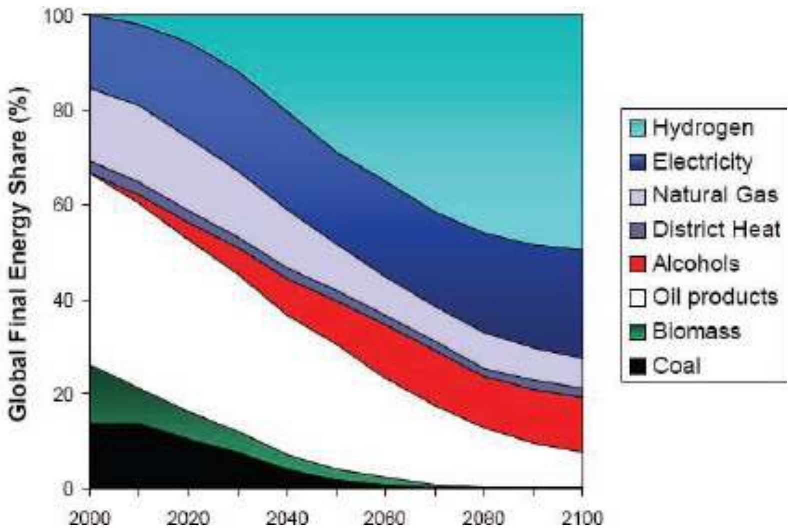
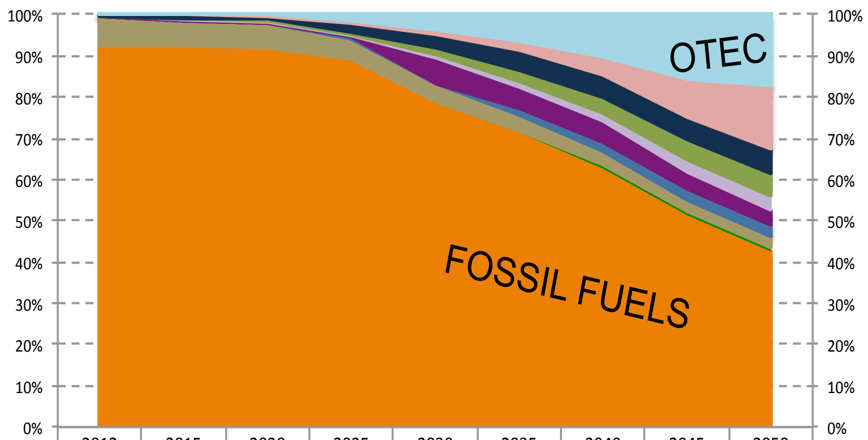


Figure 4.2 Hydrogen as the most dominant energy carrier in the future (Barreto, Makihira & Riahi, 2002)

For the case of Malaysia, a Special Task force was set up by the *Akademi Sains Malaysia (ASM)* to brainstorm routes towards a Carbon Free Economy in Malaysia. Considering the projected energy generation by source in the year 2050, fossil fuels are projected to account for 42% of the energy mix, and renewables accounting for the more dominant 58% share. OTEC and the fuel cell combined will account for slightly over 30% of the energy mix in the year 2015. The fuel cell technology is forecasted to a 15% share of the total energy mix in the year 2050. Since hydrogen is the energy source that powers the fuel cell, and considering this sizable energy share, it requires special regard to identify viable sources of hydrogen production. The initial outputs of the group are depicted in Figure 4.3.



	2012	2015	2020	2025	2030	2035	2040	2045	2050
OTEC	0.0	0.0	0.1	1.5	3.7	6.6	10.2	15.5	17.1
Fuel Cell	0.0	0.0	0.0	0.2	0.8	1.7	4.3	9.1	15.4
Bioenergy	0.6	1.0	1.0	2.2	3.6	5.3	5.5	5.8	6.1
Wind Energy	0.0	0.0	0.3	0.6	1.2	2.5	3.7	4.8	5.5
Solar PV	0.0	0.3	0.5	0.8	1.2	1.7	2.3	3.1	3.4
Nuclear	0.0	0.0	0.0	0.0	5.8	5.1	4.5	4.0	3.4
Wave/ Tidal/ Current	0.0	0.0	0.1	0.3	0.4	1.5	2.2	2.5	2.8
Hydropower	6.7	6.2	5.8	5.1	4.5	4.0	3.5	3.1	2.8
Geothermal	0.0	0.0	0.1	0.2	0.3	0.5	0.8	1.0	1.3
Fossil Fuel	92.7	92.5	92.1	89.0	78.5	71.1	62.9	51.0	42.3
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

Source: ASM TF CFE (2015)

Figure 4.3 Shares of Energy Sources in Electricity Generation, % (Bakar Jaafar, 2015)

Based on literature, it was surmised that identification of a viable source of hydrogen remains the prime challenge in moving towards the hydrogen economy. For instance, if the scenario where hydrogen is the core energy for transportation, Peninsular Malaysia requires at least 18 hydrogen production plants to cater for the vehicle hydrogen fuel demand (Kamarudin, *et al.*, 2009). In the effort to advance the hydrogen economy for instance, careful preparation is needed particularly on the planning and execution of the installation of both the source of hydrogen and its applications. For OTEC to be seriously considered as a legitimate source of hydrogen, the hydrogen production pathway from OTEC should be integrated into the national development agenda.

Anticipating energy demand growth, the OTEC strategic roadmap vision is for, "OTEC to help fulfil the hydrogen economy." To meet this vision, a strategic plan for OTEC-Hydrogen integration measures was developed. The development of hydrogen OTEC-Hydrogen integration measures was based on an adaptation of the timelines and development targets proposed in the Malaysian national hydrogen roadmap (Wan Ramli Wan Daud, 2006).

In this adaptation, the OTEC-Hydrogen Integration follows 3 main developmental phases. The current situation, moving towards the year 2020, embraces the intensive expansion of hydrogen awareness and use. This also includes the introduction of fuel cells into society. From the year 2021 moving towards the year 2030, in anticipating energy demand growth, hydrogen is expected to gain increasing prominence and use as an energy carrier. Therefore, the initiation of hydrogen power generation and the establishment of integrated systems for supplying hydrogen are critical in the years 2020-2030. From the years 2031 to 2050, activities should focus on initiations of the hydrogen supply system and its establishment throughout the manufacturing process. These phases of development are outlined in Figure 4.4.

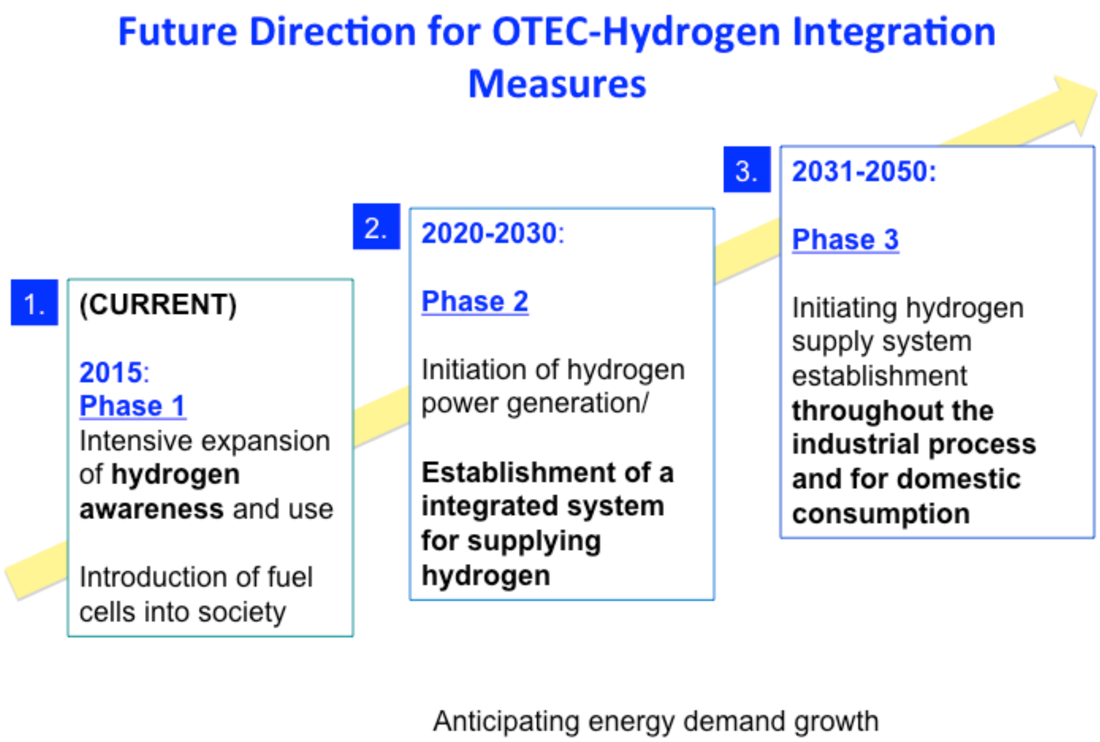


Figure 4.4 Future Direction for OTEC- Hydrogen Integration Measures

OTEC is identified as viable source of hydrogen production, due to its economic advantage and constant generation capability. Since OTEC is a renewable technology, its energy generation potential is boundless and sustainable. Compared to the cost of producing hydrogen from non-renewables, OTEC is far more cost effective, because it does not include the cost of fossil fuels, which amounts to about 80% of the cost of producing hydrogen from non-renewables. This is clearly explained by one of the respondents,

> "the source of energy for that electricity in electrolysis does matter…. But if the source of energy is renewable, including OTEC, then hydrogen production by electrolysis would be competitive, since 80% of the cost of H_2 production from non-renewables is the cost of fuels itself. In short, the economics of hydrogen from renewables, including OTEC, would be much more competitive than that of fossil-fuels, including oil & gas."
>
> (Expert 2/ academia/ male)

An economics expert further explained that the assessment of 'critical components' were crucial in identifying and streamlining the economic viability of OTEC. From the analysis of 'critical components', it was revealed that the cost of the OTEC plant may be significantly marginalized by the removal of marine power cables, and instead producing hydrogen from OTEC. As the respondent explained:

> "The critical component here is the marine power cable… You see.. it goes deep down as far as 2,500m.. if we can cut the depth, and reduce the [parasitic] loads, then the project will be more viable"
>
> (Expert 3/ industry/ male)

Another key advantage of producing hydrogen from OTEC is that the hydrogen can be shipped to anywhere in the world. This is because the energy market reach is not stifled by the submarine power cables distance limitations. According to Krock, (2015), island nations will be the 'Saudi Arabia of hydrogen'. This is an ambitious target and implies that hydrogen production may replace the oil and gas production in the near future. Therefore, large distribution channels are needed, perhaps modelled after the oil and gas shipping routes.

The proposition is further supported by (Ryzin, Grandelli, Lipp, *et al.*, 2005) who explains:

> "OTEC is both a technically and economically viable hydrogen production pathway for delivery of massive quantities of energy; it is cost competitive with other renewable technologies and it is environmentally sustainable."

The strategic planning of OTEC is framed with the progressive development of the hydrogen economy. As shown in Figure 4.5, the OTEC plant deployment increases in capacity to meet the rising energy demand and diversification of the hydrogen economy. According to this landscape, the first OTEC plant is targeted to be deployed in the year 2020, since at this point, it is critical to establish a large scale system for supplying hydrogen. In order to test the viability of OTEC to fulfil this need, the development of the OTEC plant needs to begin by the year 2016. This is because it takes about 4 years to commission an OTEC plant.

Two factors that may hinder OTEC development are (i) technology and (ii) legal or policy frameworks. However, this research identified these factors to be of non-issue. According to Coastal Response Research Center, (2010) OTEC is technologically feasible for a 10MW plant. In fact, a French company will be commissioning the first 10MW commercial size OTEC plant in the year 2020. As for the legal or policy perspective, according to legal authority in maritime industry in Malaysia,

> "the existing law and regulations is sufficient to govern any application for OTEC to be develop either in the territorial sea or Exclusive Economic Zone of Malaysia".

It should be noted that the subject of 'Ocean energy' (encompassing OTEC) is incorporated in the 11th Malaysian plan. This allows opportunities for project proposals to be submitted and supported at national level development.

Figure 4.5 provides an integrated timeline highlighting expected developments from the hydrogen economy and the OTEC developments, which are needed to support the hydrogen demand.

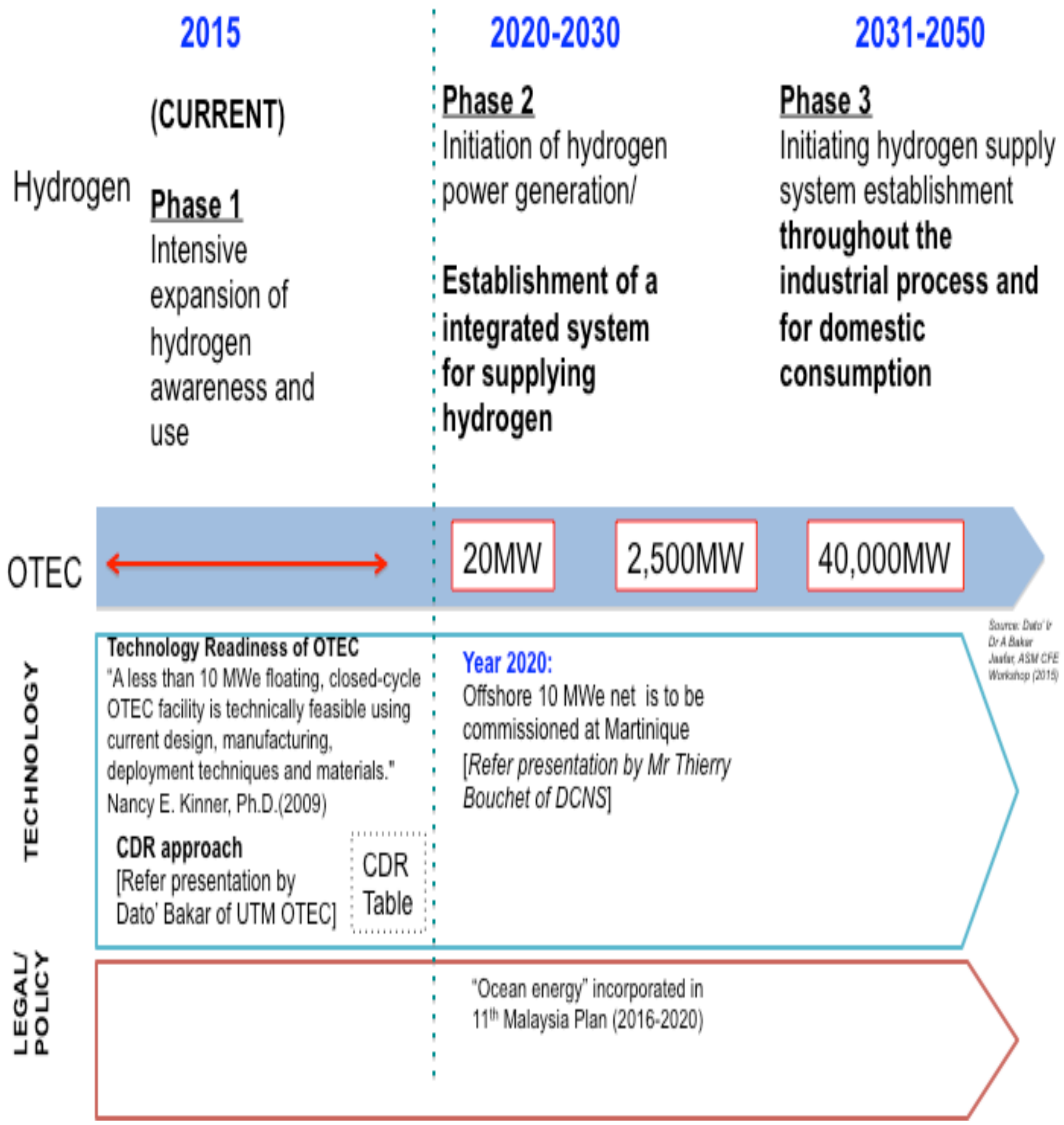


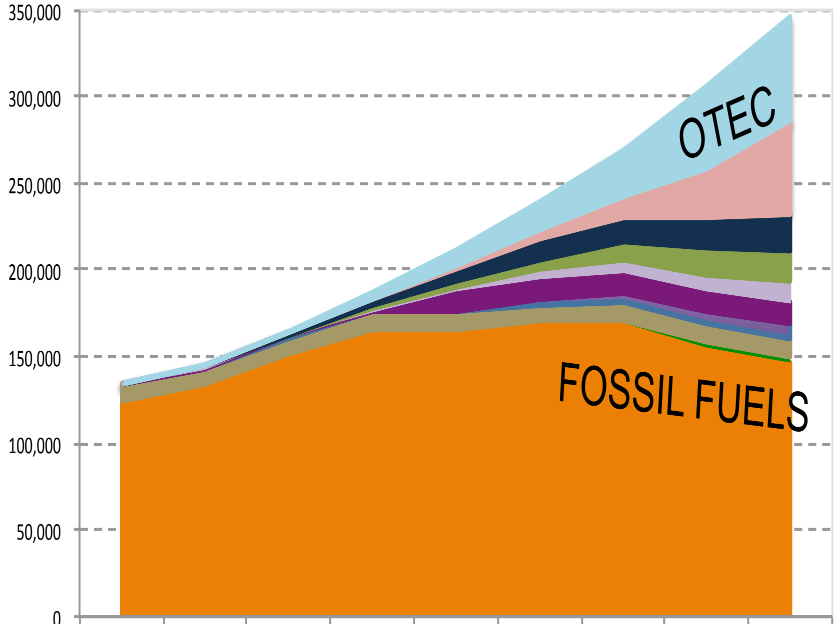
Figure 4.5 OTEC-Hydrogen Integration Highlights

Quantitatively, the OTEC development seeks to meet the future energy demands through increasing the number of OTEC plant deployments or installations and capacities. The first OTEC plant may be deployed in the year 2020, with a growth rate of 14 percent annually from the year 2025 onwards. The OTEC capacity is projected to reach 2,500MW in the year 2030 to match the nuclear power, and 40,000MW capacity in the year 2050 to meet the hydrogen demand. The proposed OTEC capacities are depicted in Table 4.1.

Table 4.1: OTEC Proposed Capacities in Malaysia (Bakar Jaafar, 2015)

Year	**Capacity (MW)**	**Growth Rate (%)**	**Remark**
2020	20	-	2x10 MW public-private RMK-11
2025	850	-	For 7% reduction in carbon intensity
2030	2,500	14	To match nuclear power
2035	5,000	14	To match nuclear power
2040	10,000	14	To meet hydrogen demand
2045	20,000	14	To meet hydrogen demand
2050	40,000	14	To meet hydrogen demand

With the increasing OTEC capacities, the OTEC energy generation in contribution to the national energy landscape is shown in Figure 4.6 (page 108). This depicts a forecast of electricity generated by source of technology over the years 2012-2050.



	2012	2015	2020	2025	2030	2035	2040	2045	2050
OTEC	0	0	134	2,848	7,884	15,768	27,594	47,304	59,129
Fuel Cell	0	0	16	354	1,665	4,054	11,603	27,782	53,194
Bioenergy	809	1,455	1,567	4,088	7,553	12,535	14,832	17,823	21,049
Wind Energy	0	0	547	1,095	2,601	5,913	10,052	14,520	18,922
Solar PV	7	437	790	1,579	2,631	3,999	6,314	9,502	11,913
Nuclear	0	0	0	0	12,264	12,264	12,264	12,264	11,650
Wave/ Tidal/ Current	0	0	219	548	751	3,548	5,868	7,603	9,662
Hydropower	9,056	9,084	9,531	9,531	9,531	9,531	9,531	9,531	9,531
Geothermal	0	0	216	382	531	1,264	2,122	3,174	4,318
Fossil Fuel	124,596	134,571	151,656	165,891	165,388	169,623	169,661	155,798	146,047
Total	134,468	145,547	164,675	186,316	210,800	238,500	269,841	305,300	345,417

Figure 4.6 Electricity generation by Energy Source, GWh (Bakar Jaafar, 2015)

4.2.2 Trends and Drivers

The industry landscape discusses the drivers of change, reflecting key factors that will spur the hydrogen economy forward. The key market trends and drivers may be categorized as Social, Economic, Environmental, and Political drivers. Each theme is discussed in the following, according to the proposed action plans and milestones.

4.2.2.1 Social

Analysis of the social trends reveal that awareness and perception are the most important criteria in shaping consumer behaviour and technology adoption decisions. Some respondents believe that society even has the power to influence political will, and this is especially important in the short term, in attempting to establish and drive an emerging industry. Therefore creating a safe, reliable, and accurate perception of hydrogen products and its applications for society is especially important, since there are various misconceptions and doubts regarding the reliability of the present day hydrogen technologies. Towards the medium term and long term, respondents suggest various activities to increase the market exposure and gain user acceptance with better technology evaluation and health risk assessments being communicated.

In the short term, it was agreed by the respondents that there is a lack of stakeholder's awareness on OTEC. This includes the OTEC technology concept and also its great benefits, including the potential contribution towards the hydrogen economy. These OTEC industry stakeholders include politicians, local council, non-governmental organizations, private sectors, and education institutions. Awareness of stakeholders is the first step towards concerted development. Some focus group respondents believe in the societal power to influence political will. As shared by a focus group respondent, "I am thinking that sociology is very important. When society will accept, then politicians will accept too… This is also very important because this is related to business model and network, where you have strong networks"

(Respondent 5/ academia/ male)

To date, there lacks mass-market exposure for hydrogen as an energy carrier. Hydrogen related technologies are perceived to be at the early stages of development. Hence, there exists some consumer safety concerns, as it is perceived to be a 'not-yet-proven' technology. Said some respondents:

"People still don't know about hydrogen"

(Respondent 13/ academia/ male)

"Hydrogen is still new… People don't know about hydrogen and its application. Is it safe? Kita assume takkan meletup ya? "

(Respondent 7/ industry/ male)

However, the concern regarding hydrogen safety is unwarranted, or rather, just a misconception. In actual fact, according to some technology experts, hydrogen is a relatively safe energy carrier, and it is 'safer' than other (even conventional) energy carrier options. Respondents said:

"Hydrogen has been around and is transported readily and easily. You see the red trucks on the highway? Those are hydrogen trucks."

(Expert 2/ academia/ male)

"No problem.. Hydrogen is safer than other gasses such as methane, and even fossil fuels. For example, if there is a leak, the hydrogen gas which is light will just float up to the atmosphere, whereas petrol will be there, and take time to evaporate. The fumes are really much more harmful."

(Expert 5/ industry/ male)

Another current trend is that, consumers are not particularly concerned about green energy, and are especially resistant to being 'early technology adopters'. This is due to various factors, such as a high initial cost, uncertain infrastructure or value chain, and technology risk aversion attitudes.

> "I'm thinking about Japan, we have green cars.. but it is expensive.. Maybe we can wait for it to be cheaper.."
>
> (Respondent 8/ academia/ male)

> "Kita tak pasti, macam mana nak buat refueling, infrastructure kena betul-betul in place"
>
> (Respondent 2/ academia/ male)

> "Kita di Malaysia, selalu technology follower. Sebab tak nak take the risk. Kita tunggu dulu tengok negara maju, kalau teknologi dah okay…"
>
> (Respondent 12/ academia/ male)

Towards the medium term, better advertisement campaigns should be in place to increase market exposure and user acceptance. The availability of small start facilities will enable better evaluation of the hydrogen product, and give users more confidence. Said the respondents:

> "How to increase market exposure? We need to have more promo and ad [advertisement] campaigns."
>
> (Respondent 1/ academia/ male)

> "Macam tu[start facilities].. user boleh lagi confident"
>
> (Respondent 2/ academia/ male)

In the long term, respondents asserted that pollution might become a great social concern. The pollution from petrol-powered cars will strongly propel the need for greener vehicles, such as the hydrogen fuel cell vehicle. Therefore the shift to renewables may not be a mere choice, but rather a necessity. The increased health concerns and health risk assessments will also make the hydrogen fuel cell vehicles more favourable to society.

Finally, based on the analysis of the social trends, it can be concluded that awareness, perception as well as societal influence on political decision are the critical criteria in shaping consumer behaviour and technology adoption decisions. It was highlighted that with more intensive and consistent hydrogen awareness initiatives, the society at large would become increasingly aware and concerned about renewable energy. This will significantly shape the future hydrogen economy landscape, since society is the pillar of a nation's development.

4.2.2.2 Economic viability

Analysis of economic trends indicates that the economy will go through some volatility. Notwithstanding, OTEC development may progress effectively. It was concluded that the utilization of hydrogen was imminent, following the exhaustion of fossil fuels. This contributes to the lowering of the hydrogen price point, according to demand and supply logic. This scenario is highly attractive for consumers and supports the economic viability of hydrogen from OTEC.

At present, fossil fuel is still affordable for domestic consumers and industries, at USD67 per barrel (as of Dec 2014). Respondents state that the lack of price issue allows consumers to be contented with the current norms of using petro-vehicles. However, the eminent increase in fossil fuels prices following the declining petroleum resource availability may compel consumers to explore alternative fuel preferences in the future.

In the medium term, respondents foresee an economic downturn, which may stall the much-needed investments into high technology development. This technology development will be crucial to support the continued growth of the hydrogen or low carbon economy. Said the respondent:

"I think at this time… the economy will be slow.. all over the world.. ahh.. economic downturn. But we need funds right? To invest in R&D..? Maybe a bit slow at this time.."

(Respondent 7/ industry/ male)

Despite the economic downturn, respondents assert that the gross domestic product (GDP) of Malaysia is expected to increase from the years 2015-2020. According to Trading Economics (2015), the Malaysian GDP is projected to increase from 356 in the year 2015, to 427 in the year 2020. The increasing health and size of the Malaysian economy indicates that various industries will continue to thrive with the progressive development of the nation. This suggests some potential for OTEC development, with adequate funds available for initial investments. The extra research and OTEC development may also contribute to generating economic growth. The economic development for the long term was unforeseen, however Expert 3 shared that the utilization of clean fuel, i.e. hydrogen will be dependent on 2 main factors; availability of fossil fuels, and subsequently its price point, as shown in Figure 4.7 (page 114).

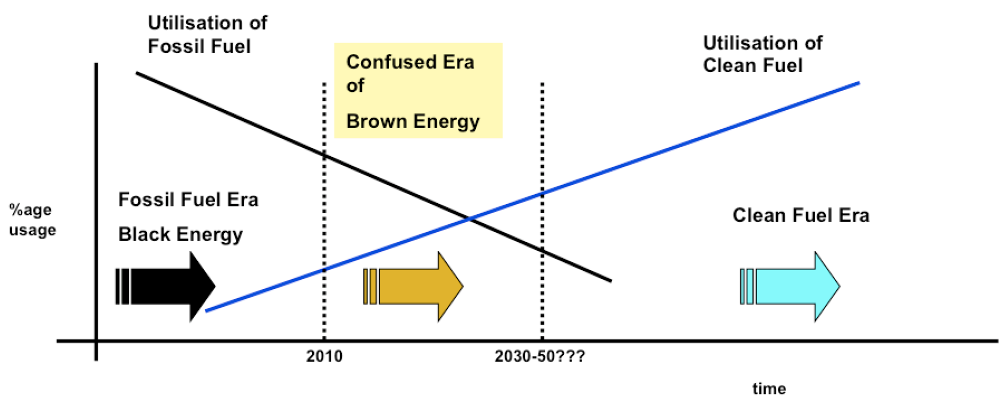


Figure 4.7 Projected usage of fossil fuels vs clean fuel

According to one respondent,

"the increased utilization of fossil fuels inevitably will result in a constant decline of these non-renewable resources. To supplement the constantly rising energy needs, increasing clean fuel utilization is necessary. The point at this intersection, where the utilization of fossil fuel and clean fuel equal, is termed as the 'grid parity point', and the era (slightly before and after this point), a 'confused era of brown energy'".

(Expert 3/ industry/ male)

This scenario of supply and demand, a fundamental concept of economics and the backbone of market economy can be used to relate the prices of fuel. According to the law of supply, a lower supply coupled with a constant or increasing demand will lead to increased prices. Hence, the scarcity of fossil fuels and the rising energy needs will lead to the increasing price of fossil fuel generation. This concept is illustrated in Figure 4.8.

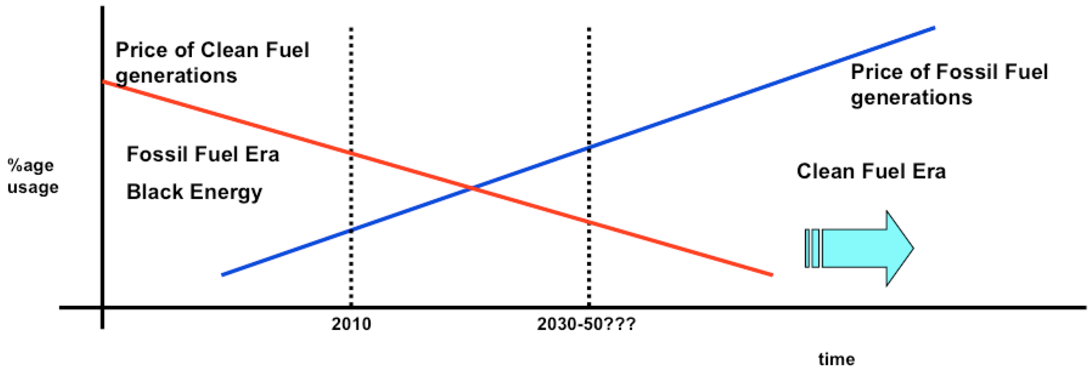


Figure 4.8 Price of clean fuel vs. fossil fuel generation

The prices of clean fuel generation on the other hand, may be lowered over time, considering the constant availability of the renewable resources. Technological advances may also lower the prices of clean fuel generations.

Moving towards the future of ‘clean fuel era’, the expert envisaged that

> “the price of clean fuel generation will be low, and the utilization of clean fuel will be high, whereas fossil fuel prices will be high, and its utilization low.”
>
> (Expert 3/ industry/ male)

As hydrogen may be used to replace the current gasoline, one expert calculated a price comparison, indicating the hydrogen fuel cell vehicle to be more economically efficient to the consumer.

> “Comparing that 1 kg of H_2 is equivalent to 1 gallon of gasoline, the hydrogen fuel cell vehicle is able to travel 60 miles, whereas the petrol powered vehicle only 25 miles. This is a greater mileage of 140%. The conventional cost of H2 to gasoline is at a ratio of 100:70, that is 30% more expensive. However, to the consumer the hydrogen fuel cell vehicle is more effective since the greater mileage more than makes up for it.”
>
> (Expert 3/ industry/ male)

Various respondents exclaim the importance of hydrogen being economically viable solution for consumers. Respondents explain that this is the main factor, if not the only factor being considered by consumers. Showcasing this agreement between the respondents :

> “Everybody will be longing for hydrogen, because it's cheaper than the conventional” and “OTEC has bright future, because uhh...since there is no cheaper alternative fuel, so we think that the best option is hydrogen”
>
> (Respondent 2/ academia/ male)

"On hydrogen, I think the main driver is, this is my comment lah, is.. what hits your pocket"

(Expert 2/ academia/ male)

Cost. For a technology to be widely accepted, cost has to be it".

(Respondent 3/ industry/ male)

Cost should be the FIRST!

(Respondent 5/ academia/ male)

The focus group respondents shared their views that consumers are especially concerned about the prices they are paying for energy. Consistent with the experts' views, hydrogen or renewable energy becomes the best choice when 'cheaper alternatives' and fossil fuels are exhausted.

To surmise, the economic viability of hydrogen production from OTEC was discussed in respect to the prices of fossil fuels, national economic scenario, and projected energy carrier usage. It was asserted that hydrogen would be a viable energy carrier due to its economic advantage, from the perspective of fuel efficiency.

4.2.2.3 Environmental

In essence, hydrogen produced from OTEC brings profound environmental benefits. It has lasting effects in mitigating pollution, especially if used in place of fossil fuels, will aid in the reduction of greenhouse gasses emissions, and the release of harmful particulates. Hydrogen fuel is also more environmentally friendly than most alternative fuels, which have toxic elements. Hydrogen, if produced from OTEC is extremely environmentally friendly, since the entire generation process is clean and renewable.

Spanning from the short term to the long term, it was commonly agreed by the respondents that hydrogen as an energy carrier, when produced from OTEC, has obvious benefits in reducing pollution. This is because hydrogen energy when burned leaves behind little or no harmful byproducts. In fact, produces no harmful greenhouse gasses or harmful particulates when burned, and it only releases water vapour. Therefore, if hydrogen energy is used to phase out the use of fossil fuels, it may improve air quality, mitigate global warming, and help to alleviate pollution from fossil fuels. This includes the mitigation of CO_2 emissions from the combustion of fossil fuels, and the risk of oil-spills in the ocean.

Hydrogen is also environmentally friendly, since it is non-toxic. This is a positive contrast from the alternative fuel sources of nuclear energy, coal and gasoline. These alternatives are all either toxic or found in hazardous environments. Although some respondents were concerned about the pollution resulting from OTEC, one respondent highlighted that it is a misconception, that OTEC causes pollution. He says:

> "But, I must correct you, that there will be no pollution coming out of OTEC. Just a perception."
>
> (Expert 2/ academia/ male)

> "But, we know for the fact that if we go below 650 metres, there is no virus or bacteria at all."
>
> (Respondent 2/ academia/ male)

Since hydrogen may be produced from OTEC, which is a renewable resource, it protects the environment from the further exploitation of natural resources. Conventional non-renewable energy resources are rapidly depleting, and the shift to renewables will help to preserve the natural resources and environmental balance.

Moving towards the long term, respondents expect a heavier consideration for ozone safety. The dire need to address ozone layer depletion may be caused by society's constant indiscriminate usage of chlorofluorocarbon (CFC) products and ozone-depleting substances (ODS). Some consequences of ozone layer depletion include increased UV exposure, carcinogenic effects on humans, cortical cataracts, and an affected crop growth. The phenomena can be mitigated through the use of hydrogen as a clean and renewable energy carrier. 'Ozone safety needs' strongly support the benefits of hydrogen usage and may drive the supporting technologies to realize this environmental saving potential. Said one respondent:

> "What about the ozone? I think in the future, the Ozone will be a problem… Maybe hydrogen can help.. since it is a renewable.."
>
> (Respondent 5/ academia/ male)

Although hydrogen from OTEC brings about various environmental benefits, marine pollution that is potentially caused by the OTEC plant is a particular concern for one respondent. Therefore, adequate environmental impact studies need to be conducted, prior to OTEC development. He stated cynically:

> "there may be adverse effects of the OTEC plant toward environmental chemistry, environmental exposure, and thermal pollution of the deep seas. This may in turn, cause disharmony for the marine ecosystem. Thorough geographical mapping and environmental assessments must be conducted, prior to development. Marine parks must be protected."
>
> (Respondent 9/ NGO/ male)

In summary, OTEC development, which produces hydrogen as an energy carrier may greatly reduce pollution. The current carbon emission trajectory is unsustainable, and new alternatives are needed to preserve the declining natural resources, and limit carbon emissions. Hydrogen generated from OTEC is a renewable, sustainable source of energy, with minimal environmental risks. The shift to hydrogen is recommended, since rising pollution has become a fast growing issue, especially in developing countries such as Malaysia. However, establishing the OTEC industry requires due diligence, such as conducting the initial Environmental Impact Assessment (EIA) studies, ensuring conscientious development.

4.2.2.4 Political

The political drivers in Malaysia are unique, and may significantly propel the OTEC industry forward if set appropriately. As Malaysia may be a 'technology follower country', increasing political ownership is expected moving forward, as the nation looks into building OTEC opportunities. In OTEC policy setting, this political ownership may be used to effectively plan and execute integrated development. Adequate planning should consider the timelines needed to set up a commercial plant and its supporting infrastructure.

In establishing an emerging industry such as OTEC, respondents agree that Malaysia is a 'technology-follower' country. This means that Malaysia lags behind the world's technology frontier and might only adopt (instead of develop) new technology, with or without adaptation to local climate. Therefore, there is an urgent need for Malaysia to encourage not only technology adaptation but inspire breakthrough innovation to be a 'fast follower' in the future. Technology adaptation would require local R&D activities to be strengthened, and will affect its long-run level of technology advancements and output. For the context of OTEC, the respondents agree:

> "Malaysia is usually a technology follower. If we want to be at the lead, now is the chance, with OTEC. What are the other countries developments…? Oh, just starting..? Ok.. but usually Malaysia likes to wait for other countries to take the lead first la…"
>
> (Respondent 3/ industry/ male)

> "You mean in Malaysian scenario..? Malaysia is always a follower la…"
>
> (Expert 5/ industry/ male)

Based on the focus group discussion, it was agreed that policy is pivotal in setting direction and providing guidelines. The total involvement of stakeholders is extremely important since linkages between various stakeholders are essential for concerted development. Besides that, respondents discussed the supreme control of politicians, and designated units (such as the Economic Planning Unit) for direction setting and pushing agendas forward. The respondents emphasize,

> "All Malaysia national R&D activities are driven by political directives."
>
> (Respondent 4/ industry/ male)

> "Betul.. stakeholder tu.. kena masukkan.. dia link link link je.. Kan roadmap dah ada."
>
> (Respondent 1/ academia/ male)

> "For EPU [Economic Planning Unit], money.. provide. Bayar"
>
> (Respondent 5/ academia/ male)

> "Political will.. By the politicians. Dia ada roadmap. Semua dah masuk. Link macam jig-saw puzzle la.. Sambung sambung la.."
>
> (Respondent 10/ government/ male)

This assertion is supported by the World Economic Forum (2012), which reports that successful policies work in several ways: they encourage private investment; tackle objectives in a cost-effective way; promote continuous innovation; and are designed through processes that are transparent, accountable and participatory. Policy interventions are generally needed for workforce development, university-based R&D, public capital formation and specialized physical infrastructure.

Although there are no policies for OTEC per se, the subject of 'ocean energy' has been incorporated in the 11th Malaysian plan (2016-2020). The subject ocean energy includes Ocean thermal energy, Offshore wind energy; Tidal movement; Oceanic current; Wave energy; and Salinity gradient. From the 11th Malaysia Plan:

> "New Renewable Energy (RE) sources such as wind, geothermal and Ocean Energy will be explored. RE capacity is expected to reach 2,080 MW by 2020, contributing to 7.8% of total installed capacity in Peninsular Malaysia and Sabah."
>
> (Economic Planning Unit, Malaysia, 2015)

Energy security is essential for the functioning of modern economies. A stronger political agenda would result in more rapid deployment of renewable energy and energy efficiency, and the technological diversification of energy sources, such as OTEC.

Moving towards the end of the medium term, which is by the year 2020, Malaysia is expected to fulfil the COP15 pledge. As one respondent remarked:

> "By 2020, the COP15 pledge would need to be fulfilled, that is to reduce Malaysia's CO_2 emissions to 40 per cent compared with its 2005 levels."
>
> (Respondent 2/ academia/ male)

Such drastic reductions in CO_2 emissions can only be achieved through strategic exploration and implementation of renewables in tandem with gradual decrease in fossil fuel usage. Thus, respondents have identified OTEC to be one of the renewable energy contributors, making its first energy consumption mark in the 2020 energy mix.

> "If *nak* develop OTEC, we have to start now.. How long does it take to build a plant? 4 years? Yes… So if we do it now.. then by 2020 we would have the first OTEC plant in Malaysia"
>
> (Respondent 6/ academia/ male)

Based on the analysis and in relation to one of the main product of OTEC-hydrogen, a policy gap was identified, whereby Energy Efficient Vehicles (EEV) policy incentives for vehicle manufacturers in Malaysia focus mostly on fuel consumption and CO_2 emission. More consideration may be put for tax incentives, to make it more attractive for customers. A respondent remarked:

> "I think the policy incentives are only mainly on the fuel consumption… and CO2 emission.. What about the customers?"
>
> (Respondent 4/ industry/ male)

Although current policies provide some guidelines, experts anticipated in the medium term, respondents explained the role of more robust policy drafts to direct technology investments and development. Said a respondent:

> "In order to control the technology, politic should play a very big role."
>
> (Respondent 5/ academia/ male)

Therefore, the political remedies would need to be stronger to ensure energy security. According to a respondent, some energy security threats may include:

> "political instability, manipulation of energy supplies, competition over energy sources, and reliance on foreign countries for coal".
>
> (Respondent 4/ industry/ male)

In the long term, more "political ownership" was discussed by experts. It takes a broad view of policy-making to look at the role of knowledge and consideration from planning to implementation. This safeguards against institutional misalignment, and missed opportunities for linking research and policy to support the development of hydrogen. With hydrogen identified as the way forward, more political savvy programming will enable government ownership of OTEC, facilitating the target contribution; 40% of the energy mix in the year 2050 (ASM TaskForce, 2015).

> "Who is the owner for OTEC? If it is to develop, the government has to push… There must be one body that own and champion it"
>
> (Respondent 3/ industry/ male)

In summary, respondents highlighted the immense role of political drivers to propel the OTEC industry forward. Political drivers are important to direct research priorities and determine appropriate actions in ensuring energy security. In policy setting, a long term outlook is needed to plan for integrated development, considering the amount of time it takes to set up a commercial plant, and its supporting infrastructure. Moving into the future, increasing political ownership is expected in Malaysia as the nation looks into building OTEC opportunities.

4.2.3 Hydrogen Applications

The hydrogen applications are varied, with added types of applications moving from the short term to the long-term future. In the short term, experts observed hydrogen used sparingly in industrial and transport applications. The industrial applications of hydrogen include the use of ammonia for fertilizer industry. Hydrogen is also used to process crude oil into refined fuels, like gasoline and diesel. In transport, hydrogen is used to power fuel cell cars, like the Toyota Mirai, that is available in the market from 2015. Compressed hydrogen is suitable for long range and haul use, such as unmanned planes and deep ocean vessels, due to its high energy density.

The current, or immediate focus is on the transportation sector, which is for public transportation being a government initiative.

> "So i think sekarang.. kita focus on transportation dulu kan.. kita boleh manage.."
>
> (Respondent 1/ academia/ male)

"Government tu.. Kalau personal susah... Kalau public transport tu senang.. macam bas."

(Respondent 6/ academia/ male)

"I think only transport lah, like the hydrogen fuel cell car hybrid with EV."

(Expert 5/ industry/ male)

In the medium term, industrial applications of hydrogen are diversified with Liquefied petroleum gas or liquid petroleum gas (LPG) hydrogen tanks. More cost effective hydrogen tanks and pipelines are expected to be in place, with the usage of advanced materials such as carbon nano tubes. Also, hydrogen boilers may be applicable for industry uses.

"Dia punya infrastructure tu.. ke boleh masuk dalam tank tu.. LPG tank"

(Respondent 7/ industry/ male)

In the transport sector, hydrogen is expected to be produced locally from various sources, supporting the expanded applications into hydrogen powered boats.

Nanti lepas tu teksi.. Gradually change. Lepas tu household. Kemungkinan besar tu slow slow slow. Dia masuk sikit sikit sikit"

(Respondent 6/ academia/ male)

Respondents indicated a very gradual expansion in hydrogen applications. Household applications of hydrogen may be facilitated with hydrogen pipelines, and used as cooking gas. One of the experts thought of a 'wild card' application of a hydrogen bomb.

"Hydrogen bomb.. Degree in hydrogen bomb making.. Kita tak tahu pun kan.."

(Respondent 12/ academia/ male)

In the long term, the experts envisioned a full industrial usage of hydrogen via centralized pipelines. Besides that, the hydrogen fuel cell vehicles may be widely adopted. In households, hydrogen usage may be extended to supply heat and electricity. For a ‘wild card’, hydrogen may be used for cold fusion, which produces huge energy.

> “Public transport.. Lepas tu domestic..”
>
> (Respondent 2/ academia/ male)

4.2.4 Technology

Technology trends provide a non-exhaustive list of key technology improvements will support the production of hydrogen from OTEC. The development of technology is greatly emphasized, being the prime mover of establishing an emerging industry. Then, gradual improvements to the technologies are needed to advance industry performances. The various aspects of technology improvement include enhancements to the heat exchangers, electrolysis, hydrogen storage and transport, and conversion technology. These are deemed critical, to support the immediate to long-term hydrogen production from OTEC.

In developing an emerging industry, respondents highlighted the importance of solid and reliable technology performance capabilities. This was discussed in relation to the education of society, and building a trained workforce. According to respondents, Malaysia’s technology development strategy involves firstly, procurement of technology and talent. Then, the next step would be to educate the local task force. Therefore, for the development of OTEC, it is vital that the technology components are commercially available, anywhere globally. Reiterated a respondent:

> “In Malaysia focus, they are more to technology and they need the [power] plant to go, regardless of education come after.”
>
> (Respondent 10/ government/ male)

Bringing into context hydrogen technology, some respondents explain that currently, it is still at the 'introduction phase' of the technology lifecycle. Based on the 'technology adoption lifecycle', this implies that the 'innovators' and 'early adopters', who represent the more educated and risk-oriented individuals of the demographic, will be the first to adopt the hydrogen technologies, and set the tone influencing the 'early majority' and 'late majority' technology adopters (Lee, Trimi & Kim, 2013). An expert recalled the hydrogen fuel cell vehicle (FCV), the "Toyota Mirai" ('Toyota Future' in Japanese) that will be available commercially in 2015. Being a FCV, it emits only water vapour, uses no gasoline, re-fuels in roughly five minutes, and possesses an active range of up to 483 kilometres. This provides substantial technological and economic competitive advantages compared to the current petro powered vehicles. Therefore major efforts should be targeted at reaching the 'innovators' and 'early adopters' of the technology adoption lifecycle.

In the medium term, supporting technology should focus on enhancing the heat exchanger design. A powerful heat exchange is the most essential component of a hydrogen storage system, in particular for using a high-pressure metal hydride (HPMH) to store hydrogen at high pressures (about 310 bar) and temperatures below 60°C. This pressure and temperature conditions are suitable for the FCV, however the reaction of the HPMH with hydrogen will release large amounts of energy that must be regulated using an efficient heat exchanger.

Advanced materials for the heat exchanger may conduct heat more efficiently. The improved heat exchanger should be efficient, robust, and reliable. Respondents have also stressed the importance for this component to be able to be manufactured at an affordable price.

Next, the electrolysis process (to convert electricity to hydrogen) may be made more efficient by using a superconductor. The superconductor allows electricity to be conducted with little or no resistance at cooler temperatures. This is especially useful, and increases the efficiency of electrolysis at lower temperatures, since the electrolysis process is typically more efficient at higher temperatures.

The storage and transportation of hydrogen is another important factor to consider. The material for hydrogen storage and transport can make a substantial difference. In this regard, a high strength to weight ratio is preferred. He says:

> "carbon nano tubes may be used for storage and transport, since it has a higher strength to weight ratio, compared to 115 times that of steel".
>
> (Respondent 3/ industry/ male)

For the long term, the further improvisations in hydrogen conversion technology will favour hydrogen as an energy carrier. This is especially necessary since hydrogen is not produced directly from an OTEC plant, but rather converted from the surplus electricity generated by the OTEC plant.

In summary, the technology trends reveal that OTEC and hydrogen development is at the introduction phase of the technology lifecycle. With that, Malaysia may develop this industry with initial procurement of technology and gradually guild a trained workforce. Several technology components may be researched for future development such as enhanced heat exchanger design and materials, more efficient electrolysis process and hydrogen conversion technology. The next subsections discuss the OTEC technology development in more detail, including a patent analysis.

4.2.5 OTEC Technology Development

OTEC technology has made significant progress in the past 2 decades by leveraging on cross-cutting industry technologies. It was advocated that no technical breakthroughs are required for OTEC deployment (Vega 2013). As of the year 2009, according to Coastal Response Research Center (2010), "A less than 10 MWe floating, closed-cycle OTEC facility is technically feasible using current design, manufacturing, deployment techniques and materials." In more recent years, OTEC research was targeted at upscaling the OTEC plant capacity, lowering costs, and increasing energy efficiency. OTEC is generally more feasible now, through the use of advanced materials and or innovative cross-cutting industry processes.

Innovative technology solutions from cross-cutting industries include oil and gas (offshore technology), aerospace, and automobile. For instance, offshore technology is presently more mature at the OTEC requisite scales in deep water. OTEC operating depths are well within the capabilities and experience of present day offshore industry, as shown in Figure 4.9. Due to the offshore platform advancements, there are proven platforms and installation methods, such as anchors, moorings and risers. In addition, there are proven dynamic and static power cables at OTEC compatible ratings (depths and voltages).

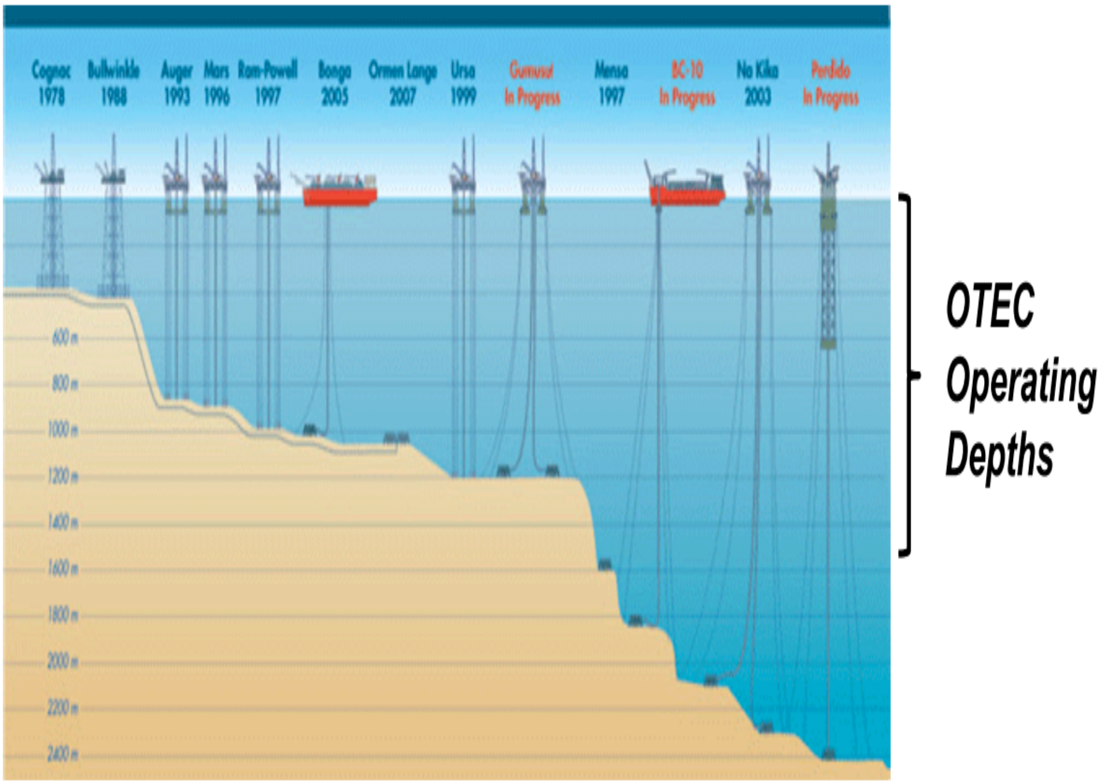


Figure 4.9 OTEC operating depths compared to various offshore platforms (Varley, Meyer & Cooper, 2011)

In the aerospace and automotive industries, materials such as Titanium and Aluminium have proved favourable. These materials may also be utilized in OTEC, particularly to address high cost components such as the cold water pipe (CWP) and heat exchanger (HX).

Several industry processes and practices have significantly improved over the past 20 years, such as performance prediction, fabrication, and manufacturing. Performance prediction practices are useful for early concept validation. This includes the high speed and low cost capability of computing, and improved analytical and design modelling techniques, which allow for validated complex modelling, prediction of coupled dynamic responses, and advanced model basin capability.

Various aspects of fabrication have improved. This includes extrusions, which is essentially shaping (an object) through a fixed cross-sectional profile. Aluminium brazing technology for leak free joints has also been enhanced, using cryogenics (study of the production and behaviour of materials at very low temperatures) and leveraging comparable advancements for liquefied natural gas (LNG). Welding techniques have also improved for sea water applications, such as petroleum industry, LNG, oil, ships, and power plant condensers. Besides that, the instrumentation or quality control and coating processes have also been enhanced.

In manufacturing, there has been a marked improvement in the capabilities and tooling of the petro industry and LNG. There are larger capacities available for heat exchangers, and greater automation in manufacturing.

It is interesting to highlight that one of the experts proposed an idea of

> "modifying the existing oil and gas technology cycle to integrate geothermal and ocean thermal technologies; increasing the differential temperature of OTEC"
>
> (Expert 1/ academia/ male)

In other words, conceptually this modification of the gas and condensate production process (CPOC) from existing oil and gas technology (Figure 4.10, page

129) with the added combination of geothermal technology may allow OTEC to be even suitable for shallow seas, in the future. This significantly broadens the geographical suitability of OTEC, making it a viable energy generation option for numerous nations.

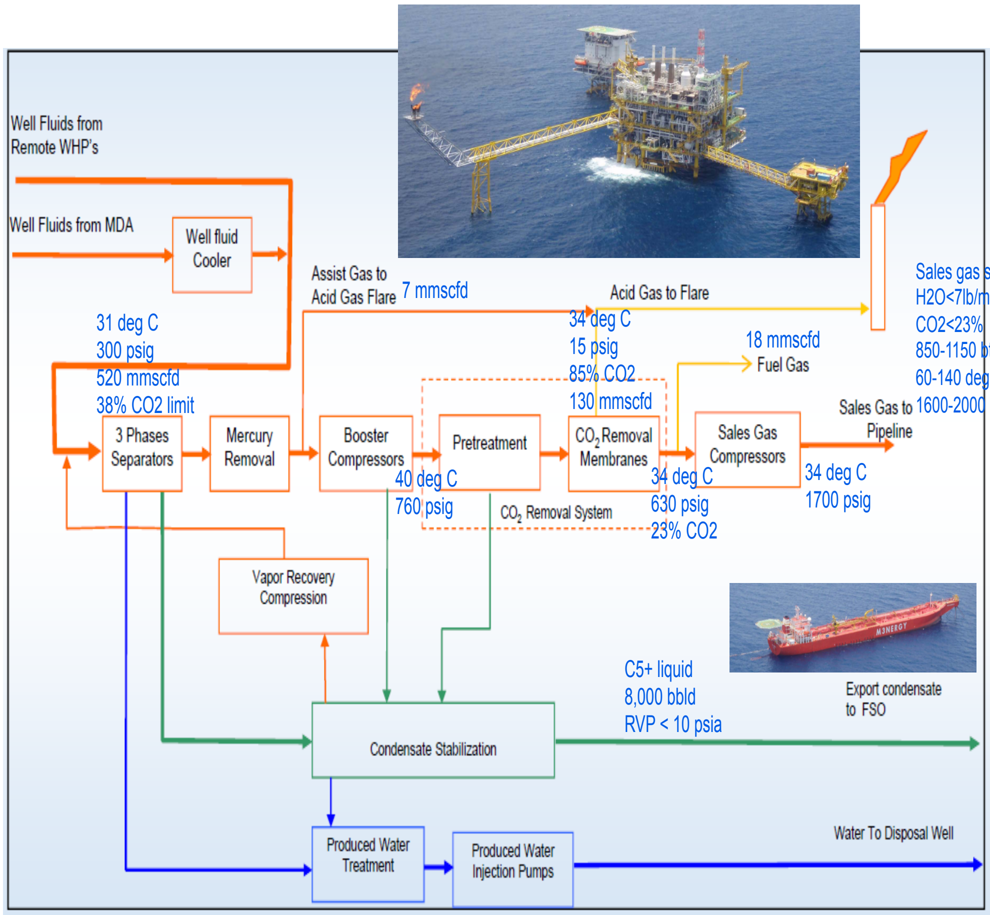


Figure 4.10 Gas and condensate production process (CPOC) (Malaysia-Thailand Joint Authority, 2015)

According to another expert, another innovative technology solution is the Solar Assisted OTEC, or SOTEC. Using solar power to raise the differential temperature of the working fluids, this can not only improve the existing OTEC technologies, but also significantly lower the cost of development. The respondent explains:

"OTEC critical components are depth, technology, and parasitic load.. If we can cut the length of the marine power cable, then we can reduce the depth, change to integrate solar technology, and reduce the parasitic load.. This improves the economic efficiency, because it reduces the CAPEX and OPEX."

(Expert 3/ industry/ male)

This is in agreement with Maulud, (2015) who explains that the critical components to OTEC financial viability include the OTEC depth, technology, and parasitic load. By reducing the depth, selecting the appropriate technology/ process, and reducing the parasitic load, the CAPEX and OPEX of the OTEC plant may be decreased, as shown in Figure 4.11.

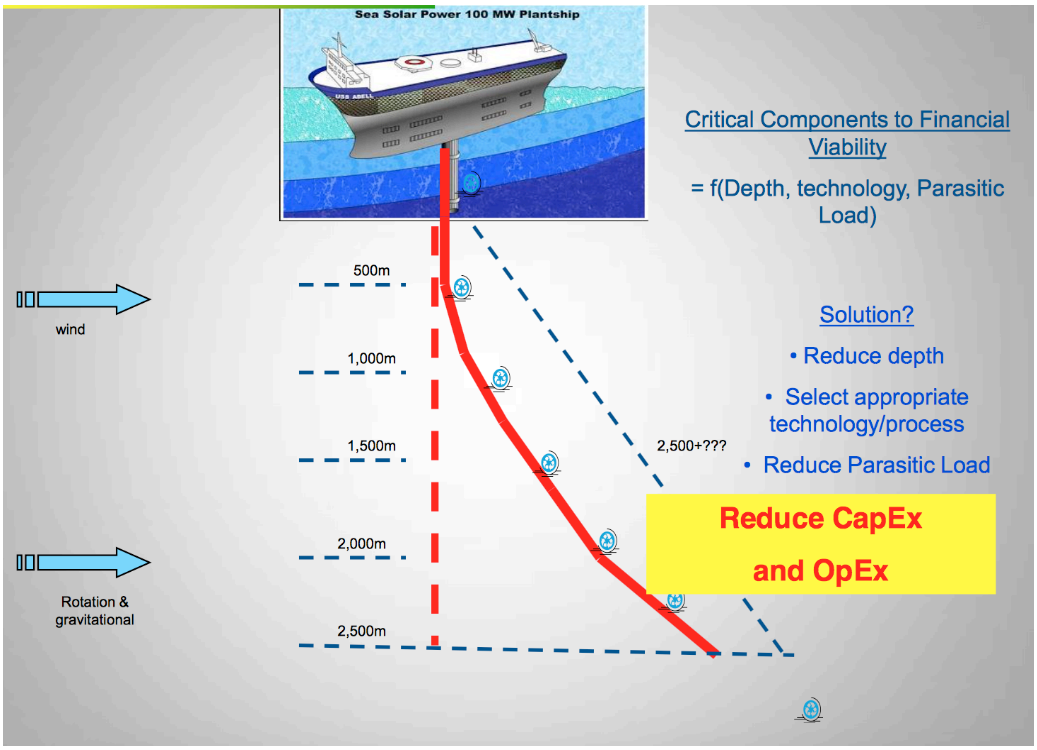


Figure 4.11 Critical Components of an OTEC Plant (Maulud, 2015)

4.2.5.1 OTEC C-D-R Technology Readiness Mapping

Considering a commercial scale 100MW OTEC plant, there are seven critical components of any OTEC system as well as the limiting ones for advancement of this technology. They are: platform, platform mooring systems, platform/ pipe interface, heat exchangers (HX), power cable, pumps and turbines, and cold water pipe.

The level of technical readiness for each critical component was mapped according to 3 main stages; commercial, development, and research. Commercial phase indicates technology that is currently commercially available (able to be manufactured on a large scale). Development phase indicates technology that is not yet available commercially, but soon to be, with further enhancement. Research phase indicates technology that is still at its initial phase.

Based on the findings from the document analysis and semi-structured interview with experts, the OTEC Commercialize→ Develop→ Research (OTEC-CDR) Technology Readiness Mapping table was developed (see Table 4.2, page 132-136). It is important to note that the specifications represented on this table is limited to the OTEC floating, closed-cycle, moored OTEC facility producing electricity transmitted to shore via an undersea cable, unless stated otherwise.

Table 4.2: OTEC C-D-R Technology Readiness Mapping (continued)

	Commercial Stage	**Development Stage**	**Research Stage**
Platforms	Semi- submersible, ship-shape, SPAR	Low cost manufacturing techniques, materials	
Platform Mooring System	• Synthetic Mooring lines have increased mooring depths to greater than 10k feet today • High strength to weight ratio, neutrally buoyant materials such as polyester, kevlar, spectra, etc • High strength steel for use in mooring wire and chain	• Investigate effective mooring systems on high slope bottoms	• Investigate and be flexible to new paradigms and designs relevant to OTEC needs • Investigate effective anchoring systems in volcanic rock • Investigate techniques that require minimal equipment for mooring & power cable installation • Increase the fidelity of tools to improve capability to allow overall system optimization

Table 4.2: OTEC C-D-R Technology Readiness Mapping (continued)

	Commercial Stage	**Development Stage**	**Research Stage**
Heat Exchanger	Material: • Titanium cost effectiveness (aerospace and automobile industries) • Titanium: developing improved processes (power plant condenser)	Material: • Graphite • Thermally enhanced plastics • Aluminium: alloying improved (aerospace industry) Design: • Potential new HX design • Plastic or foam HX new emerging techniques (improving efficiency in processing industry) • Surface enhancements • Improved heat transfer coefficient. Without incurring pressure drop penalty	Material: • Nano (solid)

Table 4.2: OTEC C-D-R Technology Readiness Mapping (continued)

	Commercial Stage	Development Stage	Research Stage
Pumps and Turbines	• Turbines shaft/rotor- carbon steel or low alloy steel • Turbine blades- 12% chromium stainless steel or higher alloy steel • Turbine casing- carbon steel • Misc. parts- bearings (babbit) – can be re-melted, valves and seals – stainless steel • Casings – carbon steel (may have epoxy coating or other corrosion protection) Impeller- stainless steel • Motor- combination of copper, solder, insulation material; non-metallic material, • Shaft casing- carbon steel • Conclusion: > 85-90% recyclable materials • Radial Flow for 10MW • 2 per plant, 7-8 MW gross each turbine; Commercially Available, multiple vendors • Axial Flow for 100MW; Trade study recommended to optimize size for NH3	• All components are technologically mature. All pumps and turbines 80-90% efficient.	• Trade-study recommended: axial, radial, modules, cost • Vacuum pump • Trade off studies need to be performed relative to the location of water production (onshore vs. offshore)

Table 4.2: OTEC C-D-R Technology Readiness Mapping (continued)

	Commercial Stage	Development Stage	Research Stage
Cold Water Pipe	• Best pipe - 2m HDPE, but not being constructed by industry • Engineering knowledge is available to create a CWP for a 30 year design life. • Design available for a 5-10 MW CWP, but not for 400 km off shore	• Nano-tube/ Carbon fiber for future • Design for a 5-10MW (400km offshore)	• Sandwich pipe, possibility of fiberglass • Fiberglass, carbon fiber composite (possible price update), steel, HDPE • Steel: AH36 shipbuilding steel • Possibility of new steel, but fatigue problems • Ability to detach pipe in extreme weather
Power Cable (continued)	• 5-10 MW to commercial scale (100 MW) • Three phase AC cable, up to 10 MW • Three single phase AC cables, 100 MW • Cable includes power and communication controls • Cable includes own diagnostic system, fiber optic for temperature sensing • Splicing technology known • Armoring: Steel • AC cable within 20 miles – copper conductor, polyethylene insulation	• High power dynamic cable greater than 30 MW • Requirement for disconnect in case of extreme storm/typhoon and hardware • Involvement, consideration needs to be made for the power cable	• Investigate techniques that require minimal equipment for mooring & power cable installation • Reducing weight with use of different materials – Flexible connection and termination to platform – Fatigue testing • Cable connection at platform

Table 4.2: OTEC C-D-R Technology Readiness Mapping (continued)

	Commercial Stage	**Development Stage**	**Research Stage**
Power Cable (continued)	• In water cable transition (platform to ocean bottom) • Computer modelled software available • Cables commercially available (10 kV to 500 kV)		• TRL and MRL-5; Depending on requirements (mooring, platform dynamics, quick disconnect) • Custom solution • Site specific
Cycle	• Open cycle performance validation • Hybrid cycle design • Direct contact condensers operational (geothermal application) • Flash evaporators demonstrated • Mixed working fluid cycle developed (demonstrated in geothermal)		• Develop new Musa cycle
Others			• Optimization of OTEC plant for electricity & freshwater production • Hybrid solar pond- OTEC for power generation

In conclusion, to address scalability, the existing platform, platform mooring, pumps and turbines, and heat exchanger technologies are generally scalable using modular designs (several smaller units to achieve the total capacity needed). Some areas that need further research, modelling and testing include the marine power cable, cold water pipe and the platform/pipe interface. These components present fabrication, and deployment challenges for ≥ 100 MWe facilities. For instance, a 100 MW OTEC plant requires cold water pipes of 10 metres in diameter or more and a length of 1,000 meters, which need to be securely connected to the platforms.

4.2.5.2 Review on Patent Analytics

To understand current and future technologies for OTEC, an analysis of patent applications for the OTEC related field was reviewed, limited to the US patent applications from the years 2009- 2014. This research included patents and applications retrieved on 5th December 2014. The document analysis in the form of a patent analysis revealed that currently, OTEC is a niche industry with few players, and the patent distribution largely dominated by only one company that is Lockheed Martin. The OTEC players are; Lockheed Martin Corporation US, The Abell Foundation Inc. US, OTEC Development US, Prueitt Melvin US, and the United States Department of Energy US. Lockheed Martin held 169 patents, which accounted for about 70% of all OTEC patents, followed by Abell Foundation at 16%. The other 3 players; OTEC Development US, Prueitt Melvin US, and the United States Department of Energy US held almost equal distribution of patents, at 12 patents, and 10 patents, which is about a 4-5% of total patents respectively. The patent distribution by companies is shown in Figure 4.12.

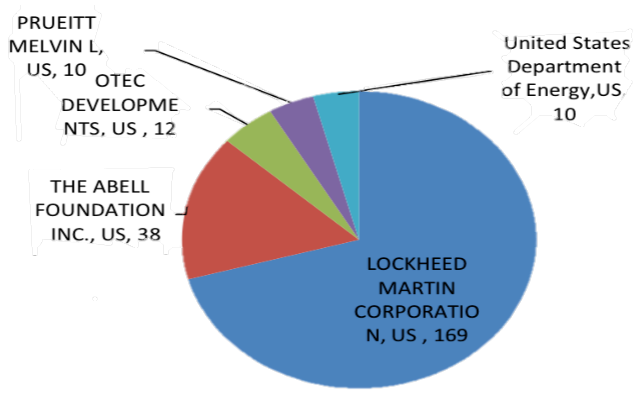


Figure 4.12 Patent distribution by companies (myForesight analytics, 2014)

Analysing the patents according to key technology area from the years 2009-2014, it was revealed that platform technology had the highest number of patents (50 patents), while mooring technology accounted for the lowest number (24 patents). In mooring technology, 24 patents were issued, distributed to 2 companies. For the pump technology, 48 patents were received, distributed among 3 companies. There were 43 patents issued for turbine technology, distributed among 4 companies, and 45 patents issued for the heat exchanger technology, distributed among 3 companies. Cold water pipe received 29 patents, distributed among 3 companies.

It was inferred that Lockheed Martin and the Abell Foundation Inc are companies diversified in their research, owning patents across all 6 key technology areas, whereas other players; OTEC Developments, United States Department of Energy, and PRUEITT Melvin L. have patents only 2 or 3 key technology areas, therefore are more concentrated in their specific research areas. The turbine and platform technology area has the most number of companies (4 companies) researching in this area, based on the patents issued. This could be due to the diverse applications of platform technology and turbines to other industries as well. The patent distribution by key technology areas are shown in Figure 4.13.

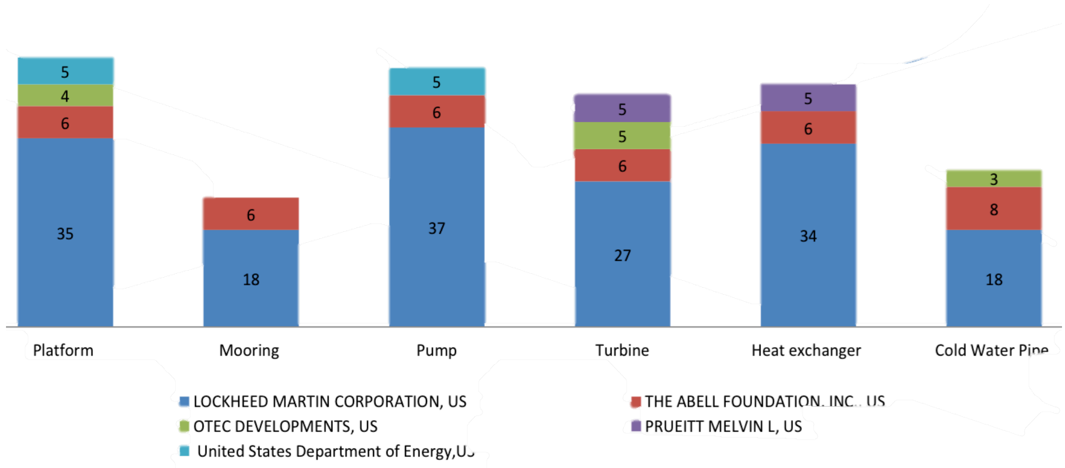


Figure 4.13 Patent Distribution based on key technology areas (myForesight analytics, 2014)

The patent distribution from the years 2009- 2014 recorded the highest number of patents in the year 2011. From the years 2011 to 2014, there has been a steady decline in total number of patents issued. Platform mooring technology recorded the highest number of patents in 2011 however; fell to the lowest in 2014. The patent distribution by key technology areas are shown in Figure 4.14.

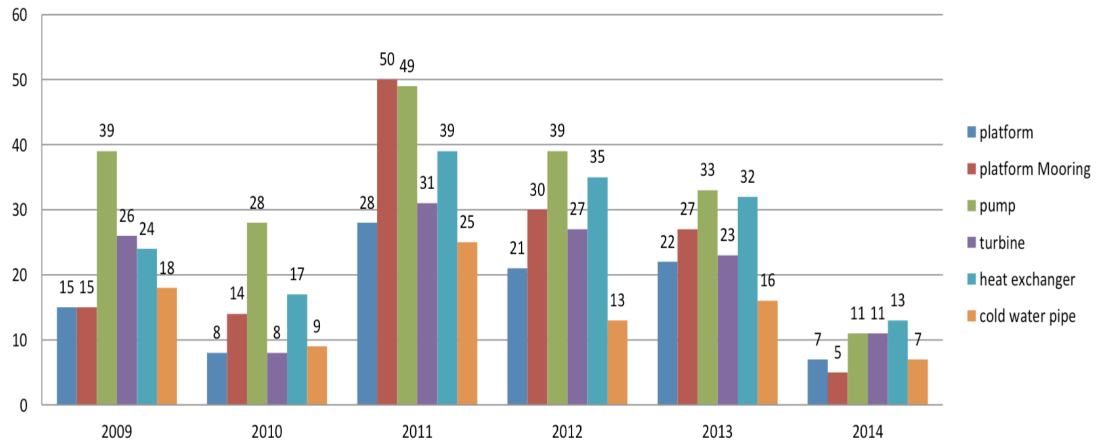


Figure 4.14 Patent distribution by key technology area, year 2009- 2014 (myForesight analytics, 2014)

Based on the patent analysis conducted, it can be observed that the growth of R&D activities in OTEC related areas thus gives a good indicator of the technology trends and, as well as understanding on the technological competency and readiness of this industry.

4.2.6 Programs

Programs to onset the OTEC industry range from a plethora of angles. This includes firstly, the development perspective, which involves the identification of the complete OTEC-Hydrogen value chain. It also includes baseline studies, collaboration platforms, and training courses. Secondly, from the marketing viewpoint, awareness programs need to be in place. Thirdly, targeting the consumers, product promotions and discounts were suggested. Finally, with the cumulative effects of these programs, OTEC development may support the establishment of 'smart cities'.

To plan for the immediate development of OTEC, it is crucial to identify the full value chain of the OTEC product. One respondent explained that the identification of the OTEC- Hydrogen value chain should include 'harvest', 'storage and transport', and 'application' stages. The respondent says:

> "Actually, I think better for us to identify what happens in the value chain. Start from harvest to end customer. So this is what I saw.. is start is harvest.. harvest the Hydrogen then transport the storage, and the application.. So probably we can brainstorm the project to support all the value chain that necessary for hydrogen.."
>
> (Respondent 3/ industry/ male)

Other studies that need to be conducted are risk assessments, an EIA study, and standards development. These studies are necessary to kick-start the OTEC project. According to a respondent, there are two quantifications for risk assessment. They are probability, and severity of the risk. Said the respondent:

> "Risk assessment is uhh.. there are 2 quantifications. Risk assessment is equate to probability and severity. Probability is maybe tomorrow,.. maybe not.. Severity is maybe cut, maybe that, maybe 1 person, maybe 10 persons.. So this thing we have to re-adjust. They have some contour mapping. Like how deep.. so from there we can not totally eliminate, but reduce [the risk]. This reduce will be the acceptable risk. That will be the quantification."
>
> (Respondent 10/ government/ male)

There is a need to conduct an Environmental Impact Assessment (EIA) study in order to address the environmental impacts of the OTEC plant. This is the basic requirement of any new development, since the potential environmental impacts are unknown. Explained one respondent:

> "The first question that I want to ask anybody submitting an EIA report, is "What kind of monster is going to come out of the bottom of the sea?", and the marine biologists need to explain because we do not know what kind of flora and fauna or viruses in the water."
>
> (Expert 2/ academia/ male)

Adequate standards and regulation need to be developed, especially since there are no existing standards for hydrogen. Standards are important, because they ensure product performance, reliability, and safeguard consumer safety. For a start, oil and gas industry standards may be adapted and adopted, in example subsea, vessels, and transport. The respondent remarked:

> "Right now we don't have any standards for hydrogen. Maybe in the future, we can develop it"
>
> (Expert 5/ industry/ male)

Respondents agree that a common platform is needed to build OTEC consensus, direction setting, and leverage on various expertise. This may be achieved through the annual International OTEC Symposium, which involves various OTEC stakeholders, such as technology experts, academia, technology providers, and government. This program provides an avenue for the sharing of latest knowledge, developments, and collaboration opportunities.

The respondents collectively believe that OTEC-Hydrogen training courses are needed to support the talent development and the sustained growth of the OTEC industry. The training programs include university courses and technical certificates. Relevant courses may be offered in the subjects of OTEC, hydrogen commercial uses, and hydrogen exports. On the technical level, subject topics may encompass electrolysis, gaseous supply, liquid supply, and reforming aspects of hydrogen.

National OTEC training Workshops may also be used to bring public awareness on OTEC. These workshops may target current students, as well as working professionals. The scope depth of the workshop content may increase with the progressive awareness of the participants.

Awareness programs are pertinent to the OTEC and hydrogen industry development. Advertisements are a powerful tool to raise market awareness on hydrogen usage. Some avenues may involve advertisement on buses and various billboards. Exclaimed one respondent:

> "Like this bus like rapid kl, this bus is being apa.. powered by.. hydrogen fuel cell ke apa.."
>
> (Respondent 6/ academia/ male)

Another respondent described some creative marketing solutions, which include raising awareness through movies, dramas and entertainment channels. He explains:

> "similar to how the movie 'Interstellar' promoted wormholes and blackholes."
>
> (Respondent 3/ industry/ male)

In the medium term, respondents stressed the importance of having hydrogen product promotions and discounts to encourage consumer adoption of hydrogen products. It was reiterated that consumers are strongly motivated by the price factor, and product discounts. As remarked by a respondent:

> "Customer mesti nak diskaun.."
>
> (Respondent 12/ academia/ male)

As suggested by the respondents, the government may support the hydrogen economy with the initiative of providing 'subsidized hydrogen products' for customers. In addition, the industry players need to be encouraged, and some government tax incentives may compel foreign direct investments (FDI) towards the Malaysian hydrogen economy. The pull of the international players will strengthen the position of the local hydrogen economy. Said one of the respondents:

> "Kita kena encouraged the industry jugak.. untuk bagi diorang invest…"
>
> (Respondent 1/ academia/ male)

In the long term, respondents believed that 'smart hydrogen cities' might develop as a result of OTEC. A smart city is one that plans for energy, efficiency and the environment. The OTEC industry, if fully developed, has the potential to produce sustainable energy, with little or no environmental effects. With the production of hydrogen as an energy carrier, the fuel cell technology will be highly utilized. There are multiple advantages of fuel cells in smart cities, such as implementation in the electricity grid, building efficiency, electric mobility, and telecommunications.

Finally, respondents have identified the corporate social responsibility (CSR) to support the hydrogen economy. This corporate initiative should be perpetual, spanning from the short term to the long term. By this, a business needs to monitor its active compliance with the law, ethical standards, and international norms. CSR encourages actions that have a positive impact on the environment and stakeholders including consumers, employees, investors and communities. Therefore, the OTEC project, which has immense positive impact on the environment and its stakeholders, are may be considered as a CSR initiative.

In summary, there are many facets to OTEC development. The programs suggested by the respondents encapsulate various initiatives in order to onset the OTEC industry. These include programs to identify the OTEC-Hydrogen value chain, provide baseline studies, create a common platform for dialog, provide training courses, and raise overall awareness. In the medium term, respondents suggest a program to compel more consumers, which are hydrogen product promotions and discounts. In the long term, OTEC may support the development of 'smart cities'.

4.2.7 Resources

Analysis revealed that the critical resources needed for initial OTEC development was an interplay of finance and policy advocacy. These are critical to the onset of the OTEC industry, because it provides the fundamental motion for steady private sector development. It is an indispensable condition for emergence, which will later involve various actors including the private sector, particularly leveraging on the oil and gas industry. In addition to these resources, human capital is a crucial resource to sustain the progressive development of the industry.

In the short term, respondents have identified some innovative financing possibilities, which involve the use of Islamic finances. This includes exploring *sukuk* (Islamic bonds) and other bonds to secure financial resources. Respondents also suggested the use of "*zakat*" (religious tax in Islam) for initial financing. This type of Islamic financing is appropriate for the OTEC industry, which may adopt the 'life-cycle costing' to absorb the high initial capital cost. Besides that, a respondent suggested that Malaysia, which is being categorized as an 'uppermost middle income country' may opt for the Official Development Assistance (ODA) loan (yen loan) offered by the Japan International Cooperation Agency (JICA). The yen loan provides funds at low interest rates for long terms, with repayment deferred, with preferential terms for 'Global Environmental Problems and Climate Change'. In summary, these terms are as shown in Table 4.3 (page 147).

Table 4.3: Terms and Conditions for Uppermost-Middle-Income Countries as of 1 April, 2015 (Japan International Cooperation Agency, 2015)

Terms	Fixed/ Variable	Standard/ Option	Interest Rate	Repayment Period (Years)		Conditions for Procurement
					Grace Period	
Preferential Terms	Variable	Standard	JPY LIBOR - 90bp	30	10	Untied
		Option 1	JPY LIBOR – 105 bp	20	6	
		Option 2	JPY LIBOR – 110 bp	15	5	

Note:	LIBOR	=	London Interbank Offered Rate (average interest rate estimated by leading banks in London that the average leading bank would be charged if borrowing from other banks)
	bp	=	Basis point (the smallest measure used in quoting yields on fixed income products. In interest rates, one bp is equal to one one-hundredth of one percentage point (0.01%). Therefore, one bp is equivalent to 1%.)

Other financial resources, according to Jian *et al.*, (2015):

> "Banking systems also offer green financing for green technology investor. More banks in Malaysia are going into green technology financing in view of the potential market for environmental business amid surging levels of greenhouse gases. The Government had set up an RM1.5bil Green Technology Financing Scheme (GTFS) under Budget 2010 to encourage the supply and usage of green technologies, especially in energy, water and waste management industries. CIMB Bank had also teamed up with Credit Guarantee Corp Malaysia Bhd to promote GTFS and would contribute up to RM150mil for the scheme."

Monetary resources are the crucial catalyst to OTEC development, and respondents emphasize that investments need to be channelled immediately. One respondent remarked:

> "Kalau kita nak maju, kita perlu invest dalam OTEC. Negara-negara lain baru nak invest, kita selalu slow sikit. Kalau kita nak on par, kita kena mula sekarang!"
>
> (Respondent 2/ academia/ male)

Experts reiterate the dire need for policy advocacy and industry incentives to encourage OTEC technology development and adoption. This is because currently, there are no specific OTEC (or hydrogen) policies and regulations in place. The policy-push may provide guidelines to support the development of the OTEC industry, and help to fulfil the hydrogen economy.

OTEC development requires the multi-actor involvement of various expertise. While the government role is crucial, the involvement of the private sector is also essential, since the private sector usually provides industry-specific expertise and financing. OTEC development may utilize expertise from cross-cutting industries, and also leverage on industry specific companies. Respondents believe that OTEC development and hydrogen production may be spurred by leveraging the sustainable competitive advantages of various companies, as the collective involvement of many may yield notable results. As noted by a respondent:

> "We can use the different expertise of many companies.. to develop OTEC. It needs the joint effort of all the industry players"
>
> (Respondent 5/ academia/ male)

The oil and gas industry is highly similar to the OTEC industry. In this view, there are various thoughts regarding the competitive landscape of these industries. Some respondents believe that the oil and gas companies will 'retaliate', whereas other respondents believe that the oil and gas companies will be the major players, in time to come. Economic advantage is the major factor that will induce this change. Respondents explained:

> "Somebody said just now that the oil & gas companies would retaliate. But actually, the oil & gas companies are the ones who will sell the hydrogen. They already started. The oil and gas companies are not going to retaliate."
>
> (Expert 2/ academia/ male)

> "But the moment they [oil and gas companies] discover that the investment can get you very far, that could be the game changer"
>
> (Expert 2/ academia/ male)

In actual fact, oil and gas companies are innovatively researching renewable alternatives, to prepare for the future energy scenario. According to a respondent, the oil and gas R&D efforts are focused on improving the existing fossil fuel related technology, and also developing renewables. These efforts ensure that oil and gas companies remain competitive in the changing energy landscape. The respondent explained:

> "Actually we in [name of oil&gas company] have this research [renewables] and yes we are looking into renewable energies. I think the last time we talked about it in these type of conference.. we talked about.. because definitely we as an oil and gas company we want to foresee what is coming in the future and also start subscribing to it.. we don't want to become obsolete. So definitely there is a portion of what we call.. our R&D money that is focused on it.."
>
> (Expert 6/ industry/ male)

> "How we see it is our company is an energy company right.. so if there's the next big thing, we will probably just move towards it. And we are trying to develop new stuff and hopefully something will come

> out of it. Don't forget we will still be spending a lot of money on fossil fuel and improving the technology too"
>
> (Expert 6/ industry/ male)

In the medium term, adequate financing continues to be the main resource needed. Sources of finance may be in the form of loans or government grants. Substantial funds are needed to finance the manufacturing facilities, advanced research, and technology development. For example, the industry may take loans to finance the manufacturing plant. Government funding and research grants may be used to study cost effective processes for hydrogen harvesting from OTEC and to study advanced materials for storage and transport.

> "It all depends on how much finance, or money we can get"
>
> (Expert 2/ academia/ male)

One of the key resources needed is human capital. Talent is needed for all research and development areas of OTEC. This includes hydrogen harvest experts, or OTEC skilled engineers, and hydrogen logistics experts. For more details on research scopes, refer to Section 1.2.6 OTEC Technology Development. Project management expertise is also needed to manage the OTEC project development. Besides that, know-how is needed from various angles including policy, legal, strategy, and the other development criteria covered in this study (see OTEC ecosystem).

It is important to note that adequate amount of critical mass is imperative to kick-start the OTEC industry. In fact, this may be one of the strategies for one of the OTEC technology providers. Other investors are hesitant and would prefer to observe the OTEC industry development before committing to it. As explained a respondent:

> "In Hawaii, I met Mr. [X], the Vice President of [OTEC tech provider company]. So I asked him "Ehh.. [Mr.X, company name] has been awarded 3 contracts to build the 3X 10 MW plant, one in Vago Garcia, Guam, and Hawaii..Then I asked him, "what happened, it's been 4

years already?", and he said "Do you play golf? We want to go for shotgun". This means [Mr.X] with 3 offers on hand, he is waiting for another 15 orders to start the whole thing. Maybe to them, time is not important."

(Expert 2/ academia/ male)

"They [Investors] are all just trying to 'wait and see'"

(Expert 4/ industry/ male)

To surmise, the critical resources to onset the OTEC industry are financial resources, and policy advocacy. Respondents believe that these fundamental resources will dispel the industrial inertia that the OTEC industry is currently facing, and pull the necessary resources for the next stages of OTEC industry development. This involves a significant amount of critical mass, and consistent financing. The continuous development of human capital will be key to provide added value to the OTEC industry.

4.3 Potential Barriers and Challenges for OTEC Development in Malaysia

Several barriers and challenges if addressed may help create a more effective environment for investment and OTEC development. The greatest barrier is the mindset barrier, which leads to various issues, such as difficulty in attracting pioneer investors, and gaining stakeholder interest. The lack of these key enablers results in industrial inertia, whereby developers in various parts of the value chain are hesitant to initiate development. The OTEC industry is also stifled by developmental challenges, such as limited operational knowledge, and the lack of a streamlined development timeline for commercialization. Other challenges that need to be addressed are the energy efficiency of OTEC, particularly for hydrogen, and the unknown biodiversity impacts.

Although OTEC is technologically proven and readily available (for a <10 MWe OTEC plant) and the demand for energy and by-products exist, there is no commercial OTEC power plant in Malaysia at the present. Three experts agree that mindset barrier is the main challenge, which leads to a superfluous of issues. As discussed in the previous sections, the mass market lacks awareness of OTEC, and hydrogen applications. Some misconceptions regarding the safety of hydrogen technology exist. As remarked by a respondent:

> "Kita assume tak meletup la"
>
> (Respondent 2/ academia/ male)

Attracting pioneer OTEC project developers and investors is one of the challenges, with regards to the mindset barrier.. Though OTEC incurs high capital cost, this can be offset by a much lower operating cost. Nonetheless, private financing will require a substantial demonstration to show performance, validate environmental predictions, confirm cost and schedule estimates, and collect operational data the focus has to be on a pilot plant. But this faces a dilemma, since a pilot plant will be a 'small' OTEC plant, and small OTEC plants are not economic. Therefore, government support or a federal budget is needed to support a pilot plant program.

In the context of hydrogen, one expert relates his experience in approaching a fuel cell technology project. As this is a new technology, various aspects (such as technology and applications) need to be proven and the standards developed. It is an iterative process, which will gradually become more mature, given increasing stakeholder interest and time. Similar to OTEC, it requires patient financing, however industry players 'may not always be that patient'. Related the expert:

> "We have a project with [gov body]. First the pilot project, or proof of concept. So hopefully.. I'm abit pessi… pessimistic, of whether the telco will actually uh.. take it up. We are just doing a pilot project. Coming up with an industrial standard for safety. After that, it's sort of like a next step lorh.. then the industry.. maybe they want to invest, maybe they don't want.

> We are coming up with a solution for BTS. At the moment they're using gen-set. Really oversized, so we have uh.. like an argument la.. saying if you have this you'll break even in like 5 years time...Something like that.. CAPEX is very high.. but the OPEX is very low.."
>
> (Expert 5/ Industry/ Male)

The expert explained that to develop an industry, the investments, technology maturity, and infrastructure needs to be ready. However, one expert termed this as the "chicken and the egg" situation. As he relates his experience in implementing a fuel cell project,

> "People always like to wait and see la.. They don't want to invest unless they know for sure they can get something out of it. The infrastructure developers say the hydrogen is not ready. And the hydrogen source producers say the infra is not ready, so how to distribute? Aiyah, it's like the chicken and egg situation laa.. "
>
> (Expert 5/ Industry/ Male)

As the respondent explained, the stakeholders need to know that infrastructure will be available on a timely and cost effective basis. Again, this is primarily an issue of clarity and certainty. The transportation charge associated with new infrastructure is directly related to the time period over which costs can be amortized. The high differentials reflect both the uncertainty in the timing for permitting new pipelines and an expectation that new infrastructure costs will be recovered over a shorter time period than the productive life of the new OTEC plants.

Presentations were made from the years 2007 to 2014, reaching 69 stakeholder institutions. Presentations were more effectively scheduled, or better received after the institutionalization of UTM OTEC, that is presenting to more than double the number of institutions recorded previously in half the amount of time.

This reflects the monumental role of an establishment, i.e. UTM-OTEC to facilitate OTEC development. This is illustrated in Figure 4.15.

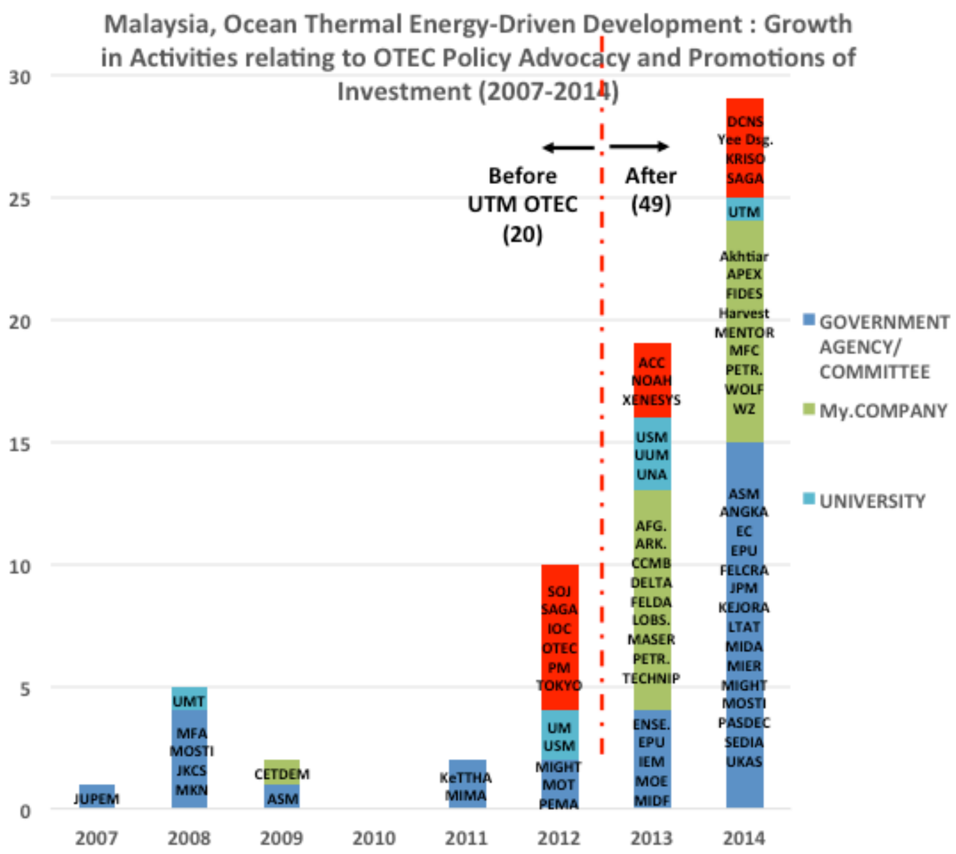


Figure 4.15 Malaysia, Ocean Thermal Energy-Driven Development: Growth in Activities relating to OTEC Policy Advocacy and Promotions of Investment (2007-2014) (Bakar Jaafar, 2015)

However, experts asserted that currently, there is also no corresponding agency with political ownership over the OTEC project. Although the university plays a vital role to research and development, political ownership provides the necessary push for a new venture such as this, requiring concerted multi-actor involvement, and significant financing. In this regard, it is most efficient and effective to have a single entitiy for all federal, state, city and country requirements, hence avoiding duplicity, contradictory requirements and jurisdictional disputes.

Common to any emerging technology, limited operational knowledge and experience of commercial plant at the local level is a hurdle. Although technology is readily available, some additional research is needed for large-scale pipes, bio-fouling of the pipes and the heat exchangers, cable to shore, the corrosive environment, and discharge of seawater. Existing platforms, platform mooring, pumps, turbines and heat exchanger technologies are modular, and can be scaled up easily. However, marine power cables, cold water pipes and the platform/pipe interface still present deployment changes for larger scale facilities (CRRC, 2010; Muralidharan, 2012). For example, based on experience from the offshore oil industry, cold water pipes for 10 MW facilities (4 m up to 7 m in diameter) can be constructed, but they have not been successfully demonstrated yet. Cold water pipes for 100 MW plants (10 meters diameter) have yet to be constructed. Other scaling issues that still need to be addressed are biofouling of heat exchangers, corrosion, frequency instabilities in generator and violent out-gassing of cold seawater in condensers (CSIRO, 2012; Lewis, *et al*., 2011).

Some respondents were concerned about the energy efficiency of converting electricity to hydrogen (for stationary use). This is because there are significant energy losses in converting the energy carrier each time. It was suggested, rather for hydrogen to be used in transportation, to power hydrogen fuel cell vehicles.

> "The energy loss to convert from hydrogen to electricity is too high for stationary use. They claim it's 40 percent loss here and 50 percent loss here.. For transportation, its 30% from hydrogen to mechanical energy"
>
> (Expert 7/ academia/ male)

Another challenge, as highlighted by the focus group, is unknown impact on biodiversity of the deep water. This includes the thermal and environmental effects of transferring large quantities of cold, nutrient rich deep-sea water. Marine life at the sea-bed may possibly be affected. Therefore, there is a need to conduct an EIA study, in order to address the environmental impacts of the OTEC plant. Said one respondent:

> “The first question that I want to ask anybody submitting an EIA report, is “What kind of monster is going to come out of the bottom of the sea?”, and the marine biologists need to explain because we do not know what kind of flora and fauna or viruses in the water.”
>
> (Expert 2/ academia/ male)

The potential environmental effects of OTEC installation that need to be investigated are listed in Table 4.4. For this purpose, the baseline information, predictive models, and expertise are needed (Kehoe, 2013).

Table 4.4 : Potential environmental effects of OTEC

Item	Potential environmental effect
Discharge water	Thermal/nutrient plume
Water intakes	Impingement/entrainment
Platform presence, noise, & electromagnetic field	Biota attraction & interference
Biocide/ammonia release	Biota toxic response
Installation of moorings, cables, & pipes	Habitat destruction

From the development perspective, the challenge for OTEC is to move from preliminary design & experimental plants→ pre-commercial phase→ 1st Generation Commercial. The permitting process needs to be streamlined to about 3 years for commercial projects. In this development, patient and consistent funding is needed.

In summary, the greatest barrier facing the OTEC industry is the mindset barrier. This leads to other issues, particularly in attracting pioneer investors, and gaining stakeholder interest. This causes industrial inertia, whereby developers in various parts of the value chain are hesitant to invest. The OTEC industry is also stifled by various challenges, such as limited operational knowledge, and the lack of a streamlined development timeline for commercialization. Other challenges that need to be addressed are the energy efficiency of OTEC, particularly for hydrogen, and the unknown biodiversity impacts.

4.3.1 OTEC risks associated with failure

Holistic development takes into account the technical risks and challenges anticipated in an OTEC plant. In particular, it is important to consider some OTEC technical risks and challenges associated with failure in the OTEC plant operation. Some mitigation actions are proposed, as detailed in Table 4.5.

Table 4.5 : OTEC Technical Risks and Challenges

Risks and challenges	**Mitigation actions**
Ammonia safety- leaks	Maintain Heat Exchanger to prevent leaks
	Codes and standards for refrigeration industry are applicable to OTEC
	Coastal ammonia facilities – codes, handling (e.g. ports, barge transp.,
Leak in piping system	Need sensors (refrigerator standards)
Air and water leakage	Sensors
Ammonia pump failure	Standby (redundancy to mitigate ammonia leak)
	No clear codes for water- NH_3 systems
	Periodically change/ calibrate sensors
	Low temp and pressure make for safer system than other industries
Tanks exposed to tropical sunlight	Need to be designed to consider this
Biofouling	
Chlorination failure	
Water leaking into ammonia (affecting turbine performance)	
Chloride into ammonia may affect turbine	
Pump failure	
Filters/ mist eliminator Leaking from one side to the other; turbine performance	
Very low efficiency cycle- high parasitic loss penalties	High efficiency heat exchangers
High water volumes- high pumping power demand from deep ocean	Efficient flow pattern of system design
Marine environment- survivability in major weather events; long term corrosion	Barge & spar designs; strategic partnerships
Utility integration- diversified generation sources; small island grids	Limited capacity battery storage
Environmental impacts- general and project site specifics	Design mitigations; strategic partnerships

4.4 Summary

The Industry Technology Roadmap for Hydrogen Production from OTEC is driven by major trends and drivers, which can be categorized as social, technological, economic, environmental, and political factors. It was revealed that the social and economic factors were the main market drivers that could affect the OTEC industry. In addition, the political factor plays a major role in pushing the OTEC industry, particularly hydrogen as a product. In this regard, policy may be used as a tool to effectively prompt a new market.

Analysis of the major applications of hydrogen reveals that currently, there is a ready market for hydrogen as an energy carrier. However, significant investments are needed to develop the entire value chain and supporting infrastructure. Technologies required supporting the Hydrogen-OTEC industry development are sufficiently available, and require the integration of existing technologies from various industries. Further research and development is proposed in the form of a 'C-D-R Technology Readiness Mapping table'. Patent analysis revealed that there was an overall decline in patents granted from the years 2011-2014. The reason for this decline remains unknown, but can only be inferred to mean that the technology has reached a reasonably advanced level. The programs suggested largely target awareness building in the initial phases, followed by hydrogen product promotions and discounts in the later phases of development, to attract consumers. It was emphasized that the essential resource needed to onset the OTEC industry was significant, steady and patient financial resources. The main barrier and challenge to the development of OTEC industry in Malaysia is the perception barrier, whereby there are various misconceptions regarding the safety and development of the OTEC and Hydrogen industry. The lack of awareness regarding these industries cause investors to be hesitant, and also poses challenges to develop the entire OTEC-Hydrogen value chain.

CHAPTER 5

CONCLUSION

5.1 Summary

The primary purpose of this research was to propose an Industry Technology Roadmap for Hydrogen Production from the OTEC industry in Malaysia. This roadmap captures the perception hydrogen, as a selected OTEC product. By applying a strategic future planning method such as Industry Technology Roadmapping, this research identified a possible 10-year market landscape for hydrogen, showed critical OTEC technology requirements, and various industry-level solutions to achieve these goals. This was accomplished by taking into consideration a number of factors, such as technology, infrastructures, regulations, consumers, and the economy. In achieving the research objective, the research questions below were addressed:

i. What are the critical elements in the OTEC ecosystem that need to be considered in the development of the OTEC Industry Technology Roadmap?
    a. What are the key elements that play major role in ensuring the success planning, implementation, execution and monitoring in the OTEC ecosystem?
    b. How did the Malaysian energy and research community perceive OTEC future potential, particularly on hydrogen production?
    c. To what extent are the OTEC-related technology readily available?
    d. How may the development of OTEC industry be hindered, in the context of Malaysia?

ii. What would be a feasible Industry Technology Roadmap to be adopted for the development of OTEC industry in Malaysia?

An Industry Technology Roadmap was created by gathering a wide array of stakeholders' knowledge and opinions, as well as through document analysis. In theoretically considering the Roadmapping process, a structure based on complexity theory was achieved as well.

Depending on the target product or industry, the Roadmapping process and format need to be customized, Garcia and Bray (1997) provided a typical process of the Roadmapping and a conceptual framework for roadmapping was reviewed (Bray & Garcia, 1997; Phaal, Farrukh & Probert, 2001; Probert & Randor, 2003). More specifically, this research followed the guidelines from Phaal *et al*. (2001) to adapt the Roadmapping process and created the Industry Technology Roadmap for Hydrogen Production from the OTEC industry through its own process consisting of three Phases; detailed in the following.

As a strategy, this research used the qualitative approach and case study method, including both primary and secondary data. Phase 1 was an environmental scan of the OTEC industry and the identification of a target product. Presentation sessions with the energy and research community and a literature review were conducted. The results of Phase 1 formed the foundation for identifying the current landscape of the OTEC industry. Hydrogen was selected as the target product. The scope of the Roadmap was decided based on the previous research and existing OTEC company roadmaps: 10 years.

Phase 2 was a focus group session among the energy and research community. One important characteristic of Technology Roadmapping is that this method considers both market pull and technology push. To understand the technology push, this research conducted document analysis from industry expert technical readiness workshop outputs. To understand market pull, a focus group session was conducted. For the focus group session, 58 individuals were invited to participate, and from this group, 13 participated in the hydrogen group. They included academia, government agencies, non-governmental agencies, and industry associations. Discussions revolved around consensus building, and the outputs were captured through post-it notes along a prepared framework and timeline.

For data validation (Phase 3), the researcher conducted semi-structured interviews with an expert panel including; 2 technical experts, and 2 business strategists in UTM. Each sample for the industry expert interviews was selected using a purposive sampling method. The experts represent not only the technology field but also the business field, and the experts were in management positions with extensive experience and a broad viewpoint, supporting the value and validity of this research. In addition to interviews, a document analysis including patent analysis was conducted.

In the Phase 4, data collected from Phase 2 and Phase 3 were analysed, and the results incorporated into this thesis.

Finally, in Phase 5, the Industry Technology Roadmap for OTEC was created based on the results of Phase 1 to Phase 4. Through the five Phases, an attempt was made to identify collaborative ways among stakeholders and the role of UTM-OTEC.

5.2 Objectives and Key Findings of the Study

This research successively achieved both research questions and provided other findings for the OTEC industry as follows.

5.2.1 Research Objective

To develop and propose an Industry Technology Roadmap on hydrogen production for the OTEC industry in Malaysia

This research was successful in achieving its stated purpose of proposing an Industry Technology Roadmap on Hydrogen Production for the OTEC industry. Through this research, critical technology components and its stage of readiness were identified. To better anticipate the potential OTEC product landscape, hydrogen was selected as a target product and explored from various perspectives including market, applications, technology, and resources.

According to the respondents, the energy supply will continue to rely mostly on traditional sources over the coming years, but the current push for innovation and growth in the OTEC development will affect the degree of this reliance.

Reaching higher targets will be challenging, given the scale and complexity of the energy system. Although technology has become more developed over the years, OTEC may remain more expensive than conventional energy in a number of applications. Today, the future of OTEC is primarily determined at the level of policy and politics, but it may be set to become a significant part of the energy mix in coming years. The projected development highlights are depicted in Figure 5.1.

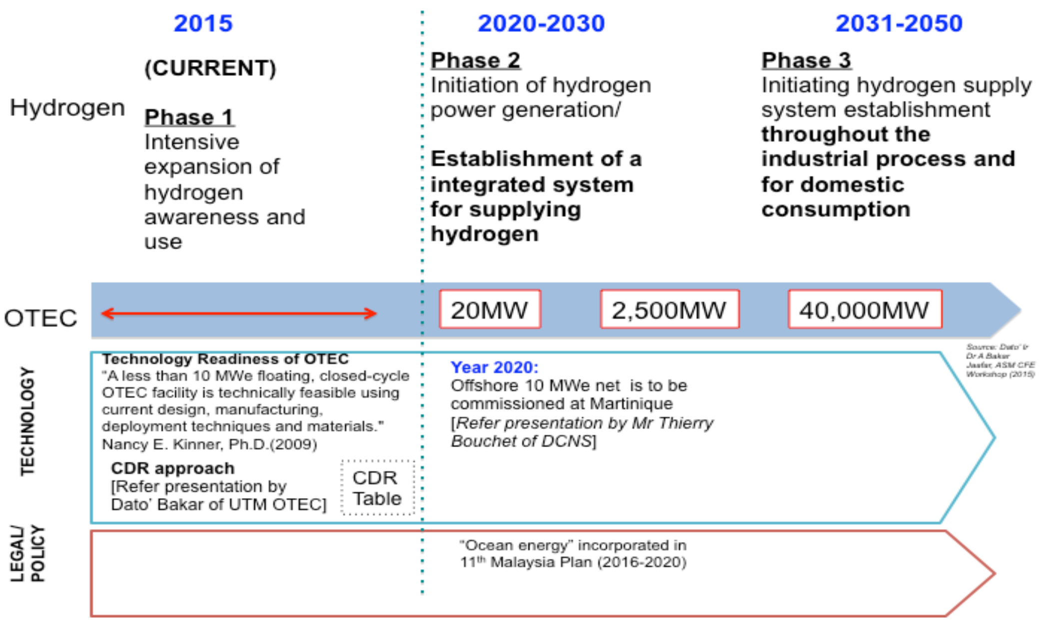


Figure 5.1 OTEC- Hydrogen Integration Highlights

5.2.2 Research Question 1

What are the critical elements in the OTEC ecosystem to be considered in the development of the OTEC Industry Technology Roadmap?

5.2.2.1 What are the key elements that a play major role in ensuring the successful planning, implementation, execution and monitoring in the OTEC ecosystem?

The OTEC ecosystem can be conceptualized by identifying the key elements that contribute to its onset and development (see Figure 5.3, page 164). Various actors are involved, reflecting a combination of existing agents leveraging on their core competencies, and also new entrants into the OTEC industry. While it was useful to identify key stakeholders that form the OTEC industry, added value was created through the perspective of how these agents may contribute to the industry development. An OTEC Industry Onset Framework (Figure 5.2, page 163) was modelled after an envisioning the various stages from production to the market.

As an emerging industry, the development of the OTEC industry may be catalysed by several core enablers. This includes the local authorities, which may provide a policy push and controlled development through adequate regulations. In addition, credible risk management studies are necessary to build stakeholder confidence and facilitate informed decisions. Finance and tax diligence is another aspect that should be given due consideration, in order to gain private sector interest and support investments. With that, potential project investors need to be identified, matching the project criteria with investor priorities. The synergy of all the actors in the OTEC enablement ecosystem model may very much depend on the Project Developers, who in theory, have extensive roles in securing government service contracts, permits and licences, and financial closing.

Deployment and production is the next stage of OTEC development, whereby the Technology Provider plays a clear-cut and fundamental role in Engineering, Procurement, and Construction. Some key activities at this stage, involve technology intelligence and strategy, technology transfer, and research and development. The technology provider's role is explicit in OTEC deployment and production; however it is not limited to this stage of development only. In some cases, since OTEC is considered an emerging industry, the technology provider may also play a role in building market awareness and promoting the technology, thereby also serving as a core enabler of the OTEC onset ecosystem.

In the distribution stage, the involved agents must provide for storage, transport, and distribution. The distribution channel may go through retailers, or distributors, meaning through a specialized channel, or through direct procurement. One of the major products is hydrogen, thus, cross-cutting industry expertise is needed, namely from the oil and gas sector, which are the current producers of hydrogen.

Commercialization is the final step in developing this value chain, which involves bringing the end-products to the consumers. The focus of this study envisions hydrogen as a high value product; however the OTEC industry offers various spin-off products including fresh water, and deep sea water applications.

It is important to highlight that throughout the entire process, intensive marketing activities need to be performed, thereby creating mass market awareness at every stage of the OTEC industry development. This may be achieved through the early assistance and support of media partners. After the initial OTEC onset, several actions are needed to ensure industry sustainability. This includes continuous R&D, licensing & IP, network and collaboration, competitive intelligence, safety and standards, CSR initiatives, talent management, and innovation processed that improve efficiency.

To surmise, the development and sustained growth of the OTEC industry is an iterative and evolving process. Like roadmapping, it is not a 'one size fits all' model, therefore it needs to customized according to local climate and situational needs.

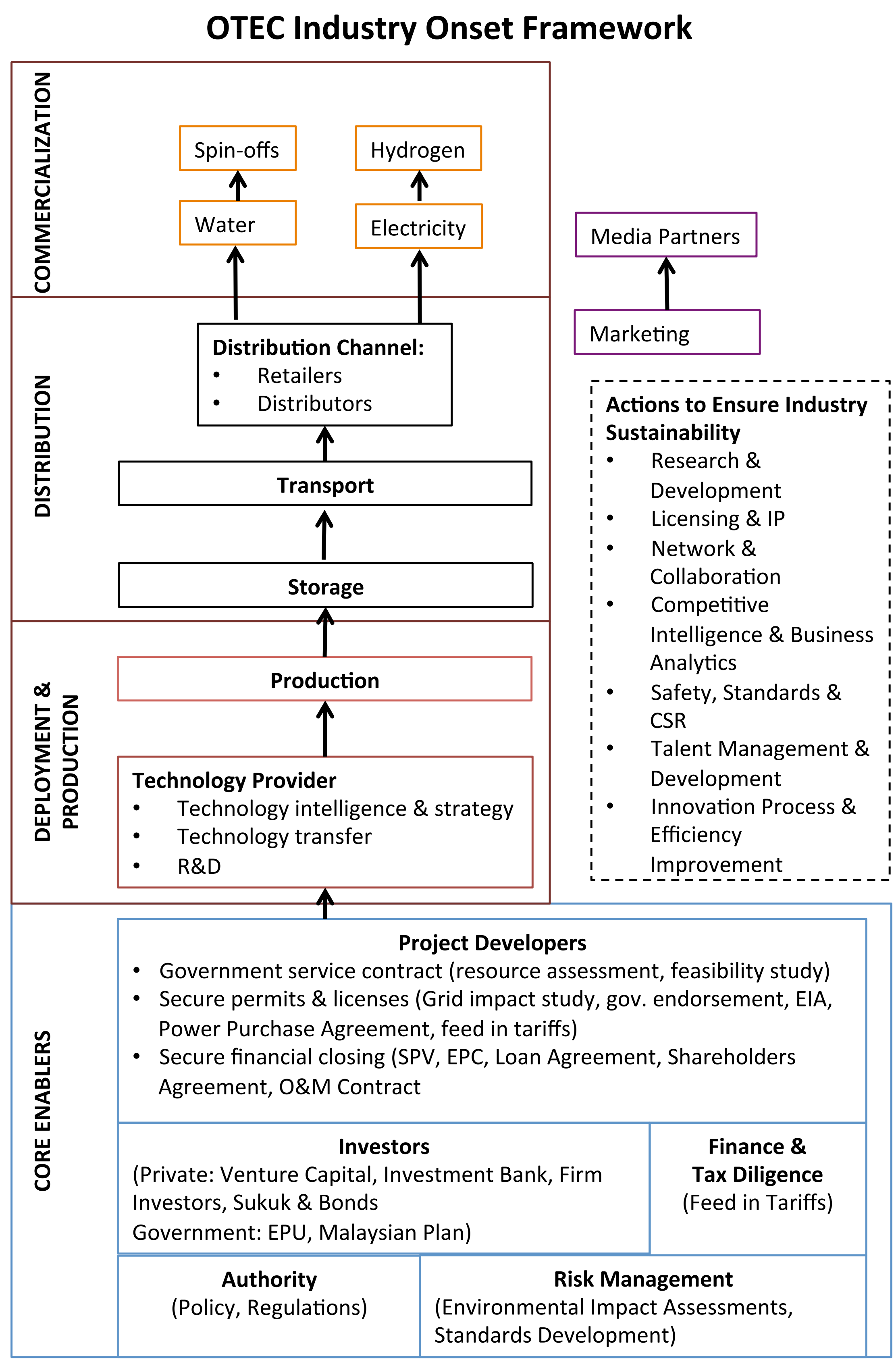


Figure 5.2 OTEC Industry Onset Framework

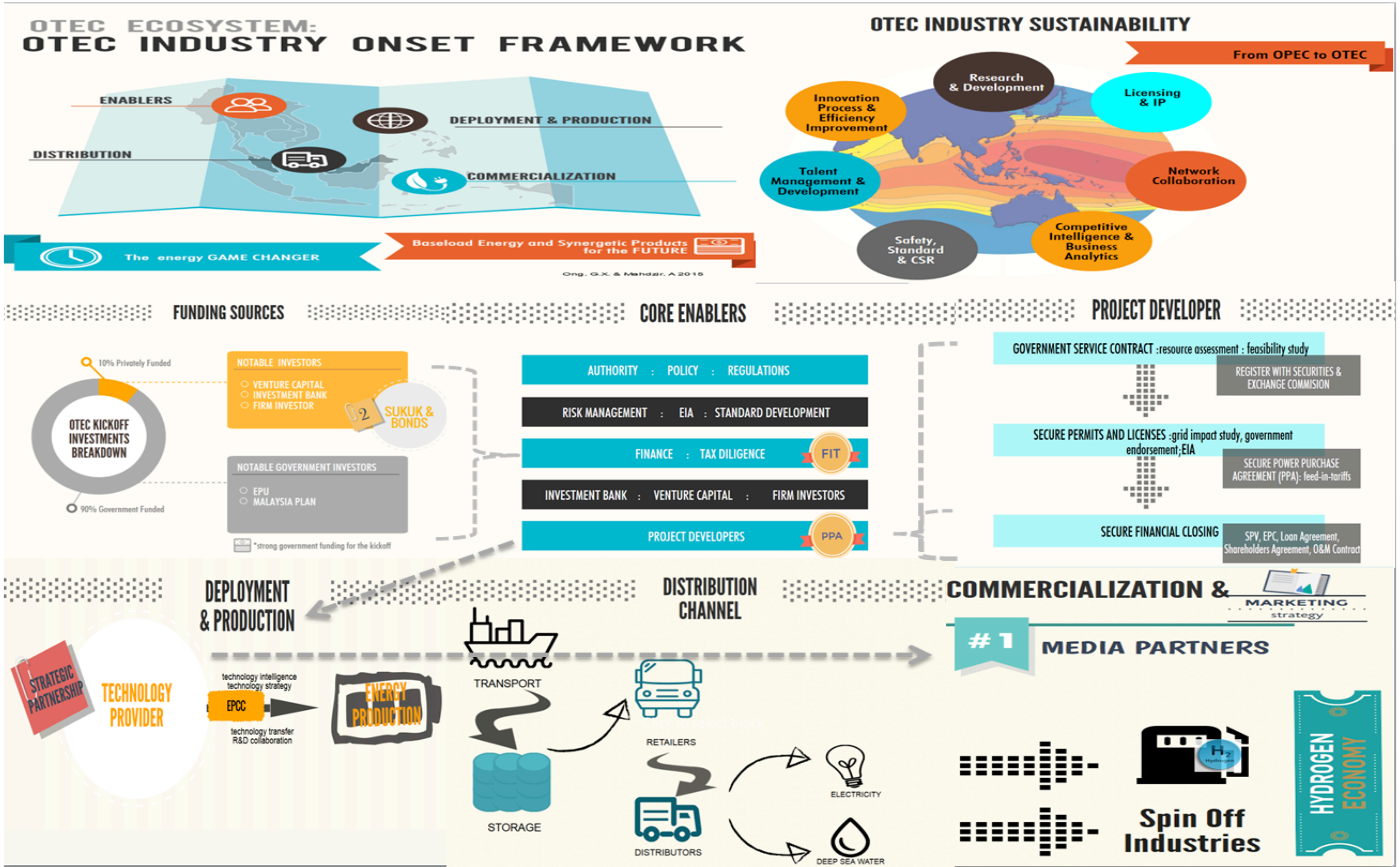


Figure 5.3 Highlights of OTEC Ecosystem

5.2.2.2 How did the Malaysian energy and research community perceive OTEC future potential, particularly on hydrogen production?

One unique factor in this research was that for OTEC, which is an emerging industry, regulations could be used as a tool to prompt a new market. Usually, regulations limit an industry's and its individual companies' business opportunities, but in the case of OTEC, creating regulations and standards were considered a tool to help to create new markets. The need for OTEC guidelines was identified a catalyst that can achieve industry consensus and concerted growth.

Potential market drivers of hydrogen are most prominently social and economic factors. Currently, consumers pay little attention to energy source when making their purchases. Advantages and purchase-driving factors of hydrogen driven products are consumer awareness, environmental sustainability, economics, convenience, and better health (consequently from less pollution). Consumer unawareness and indifference to energy sustainability may lead to increased environmental pollution, with current reliance on fossil fuels. This may also expedite new market opportunities for the hydrogen industry.

Many consumers show sensitivity to price increases, and a higher price for clean energy does not seem to be very attractive to the consumers. To penetrate markets, hydrogen as an energy carrier must be available as a drop-in-product and at reasonable cost. That can be achieved by technological advancements, government support and incentives, and consumer education.

Cost-effectiveness and usability are the most desired criteria for the hydrogen, which needs more technological advancement. Even though various technological possibilities already exist, such as electrolyzers, there are lacks of economically viable hydrogen sources and also lacking of hydrogen supporting infrastructures for the masses. Hence, there needs to be significant enhancements to the value chain, considering OTEC as a potential economically viable source for hydrogen production. In addition, the supporting infrastructure should be robust enough to meet the user requirements of a seamless ‘drop-in-product’. One solution to increase cost-effectiveness, especially at the initial phase of development is for government support and incentives. Consumers are concerned about after-sales support, discontinued technologies.

The energy and research community wants academia to provide basic research to produce more efficient and cost effective OTEC systems. Significant technical advancements combinative to the OTEC plant may result in what is termed as the “3rd generation OTEC plant”. The UTM-OTEC Centre may function strategically to research and develop these next generation technologies for more efficient and cost effective OTEC systems. For an immediate readily deployed OTEC plant, the commercially available technology may be leveraged. Focus group also expected educational support and technology consulting. This includes providing new, relevant courses and or degree programs that can meet the needs of the OTEC industry.

Government support is one of the most important requirements for pushing OTEC industry with hydrogen as a spin-off product. The increasing energy demands and constant depletion of fossil fuels hastens the need for alternative sources of energy. Renewable energy, such as hydrogen supports the global objective of reducing green house gas, ie. Malaysia is to reduce green house gas emission by 40% by the year 2020, as per COP15 pledge.

5.2.2.3 To what extent are the OTEC-related technologies readily available?

Firstly, OTEC is technologically viable. Analysis of the technical readiness of the OTEC industry reveals that a “less than 10 MWe floating, closed-cycle OTEC facility is technically feasible using current design, manufacturing, deployment techniques and materials." Nancy E. Kinner, Ph.D.(2009)

Industry-wide basic technologies for an OTEC plant can be categorized into platforms, platform mooring systems, heat exchanger, pumps and turbines, cold water pipe, and power cable. Other areas that should be considered for enhancing the OTEC plant are working fluid, electrical generator, and capital investments (per MW). Literature revealed heat exchangers to be one of the key technology areas for OTEC development. However, the patent analysis reflects a decline in patent filing.

For the context of hydrogen production, electrolysers need to be integrated, into the OTEC plant. Besides that, the freshwater generation technology component may be considered, as a high value spin-off product.

OTEC is in an early growth stage, and is a niche industry. Therefore, there are a limited number of players in the market, and theoretically one that is easily monopolized by first to entry. For example, a patent search revealed that one company holds about 70% of all OTEC patents. This may potentially reflect an industry dominant energy provider.

5.2.2.4 How may the development of OTEC industry be hindered, in the context of Malaysia?

Malaysian cultural inclinations hinder institutions from taking the lead to be a major pioneer project investor. This lack of initiative causes the industry development to remain slow or stagnant, and for OTEC to be perceived as a risky investment. Several doubts exist, especially regarding the sustainability of this technology and the robustness of the product value chain. Since OTEC potential is tremendous and yet very early in its development lifecycle, it is especially vital for multi-actor collaborations, which will result in a more strategic movement and avoid duplication of roles.

While some experts said that due to confidentiality and intellectual property collaboration between companies is unlikely to happen in a capitalistic system, other industry experts said companies need to work together to solve or build a consensus on OTEC system, addressing cultural, economic, technology, legal, and marketing-issues.

Some key barriers in the hydrogen market include uneducated consumers, lack of policy regulations, and lack of cost-effective technology, and lack of existing robust value-chain for producing hydrogen

5.2.3 Research Question 2

What would be a feasible Industry Technology Roadmap to be adopted for the development of OTEC industry in Malaysia?

The resulting Roadmap provided a range of information to help OTEC companies to proactively plan and construct their future rather than just passively accepting the results of current uncertainty. The industry may set future goals and understand challenges, opportunities, resources and requirements, with credible solutions to accomplish these goals. The proposed industry technology roadmap for the development of OTEC industry in Malaysia is depicted in Figure 5.4.

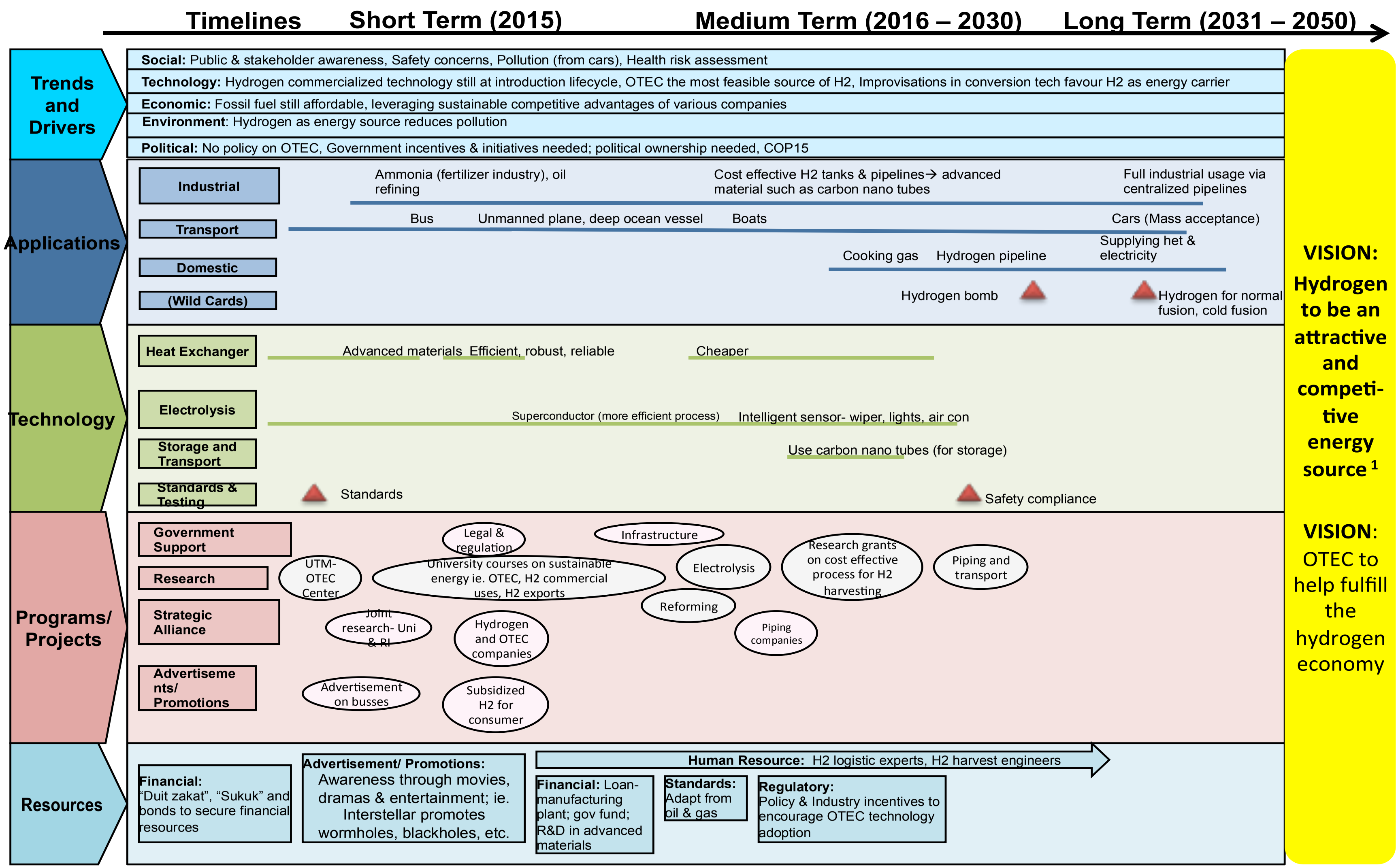


Figure 5.4 Industry Technology Roadmap on Hydrogen Production from OTEC

5.3 Roadmap Validation

The Industry Technology Roadmap was validated by a panel of 30 experts, who represent international OTEC industry stakeholders and pioneers, comprising of academia, technology providers and government. Analysis on the degree of agreement (refer Table 5.1) reveals that 83.3% of the respondents agreed with the proposition of the drivers for Trend & Drivers, followed by 66.7 % on the projection of the Technology drivers. Both Application and Program and Projects showed 63.3% agreement. It is interesting to note that although 60% of the respondents agree with the proposed Resource drivers, based on Rasch Analysis (refer to Figure 5.5, page 171), this element seems to be the least agreed by these panel of experts.

Table 5.1 : Degree of Agreement (percentage)

Trends & Drivers	Applications	Technology	Programs	Resources
83.3	63.3	66.7	63.3	60.0

Based on the comments from the panel, it was asserted that the viability of the roadmap (and the momentum of OTEC development) will be strongly dependent on the availability of financial resources, human capital, and political push. Thus, in future research, these aspects need to be more rigorously explored.

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Figure 5.5 OTEC Roadmap Validation, Rasch Analysis

5.4 Implications of the Findings

The contribution of this research is grouped according to its contribution to the theory and body of knowledge, to the research methodology, and to the practice, or OTEC industry. The contribution to the body of knowledge is explained in the context of theory building and knowledge development. The contribution to research methodology refers to the Foresight methodology. Contribution to practice provides input for the OTEC industry.

5.4.1 Contribution to the Theory and Knowledge

The research contribution in the body of knowledge is in the aspect of theory development. A meaningful linkage was achieved between the theory of complexity and the OTEC industry roadmap. Previous research discusses complexity through concept of emergence that is a function of synergism. To further illustrate this concept, this study modelled the theory of complexity into the construction of an OTEC industry roadmap. Thus, further specification of the theory is provided, with context of developing and application of a multi-actor planning tool.

In addition, through the observations of this research process, the concept of complexity may be defined more effectively, particularly in the context of an emerging industry in Malaysia. By this, it can be postulated that the thorough understanding of this underpinning theory facilitates illustration of the phenomena of social process in the real world. It suggests dynamic relationships about the nature of (social) processes in the real world, and accounts for when such processes are "truly bottom-up", as evident in this research.

From the theory of complexity, it was found that facilitating the optimal amount of structure for partially connected systems could strengthen Industry Technology Roadmapping. Adopting the optimal amount of structure for the planning and development of the OTEC Industry Roadmap allows organizations to be more adaptive and efficient, since far-future plans are not in a grid-lock blueprint, but yet clear enough to depict adequate direction with confidence.

The resulting Industry Technology Roadmap increased the knowledge base of the OTEC industry, which could not have been achieved by only a single individual or company. By visualizing each entity as 'complex adaptive systems', diverse information collected from various sources, including the energy and research community, were analysed and synthesized, when then became a credible new knowledge base for the OTEC industry and its spin-off product; hydrogen. Many researchers indicated uncertainty in planning for an emerging industry, and the need for more structured and tangible support systems, such as government policy and regulations.

During this research, it was observed that the Technology Roadmapping can also serve as an effective inter-organizational learning and knowledge creation tool for firms in a cluster to share their knowledge, develop their knowledge base, solve their common problems, and find collaborative solutions. The learning and new knowledge achieved through Roadmapping can occur not only within restrictedly networked companies in an industry, but also involving multiple-industries, for instance the oil and gas industry and the OTEC industry. In addition, because Roadmapping starts with identifying common goals of an industry, it can provide more systematic guidance to firm's strategy and positioning within an industry.

5.4.2 Contribution to the Methodology

This research shows that Industry Technology Roadmapping works well to proactively and collaboratively create new knowledge about future industrial common goals and solutions to achieve the goals at the inter-organizational or industrial level by sharing each organization's knowledge. Industry Technology Roadmapping could create new knowledge by considering most variables that may impact a strategy and answer what areas create bottlenecks for market growth, including technological issues, standards, and consumer education, and how they need to be addressed.

This research showed the effectiveness of the Industry Technology Roadmapping that considers both market perception and technology readiness and its applicability in the OTEC industry. Learning from this research can be applied not only to the hydrogen industry but also to other spin-offs of the OTEC industry as a strategic planning method to prepare for their future.

The sampling of Industry Technology Roadmaps typically involve an expert panel, or key decision makers. However, the implication of the theory of complexity, which involves ‘bottom-up’ synergies, motivated the researcher to instead, include various ‘levels’ of individuals in the data collection, to provide a more holistic viewpoint. Thus, the theory of complexity created an appropriate paradigm for overall inclusiveness in the research sampling.

The qualitative approach and concurrent-triangulation of data were very effective research strategies, whereby data collection and validation could be achieved. This research included triangulations approaches from document analysis, focus group, interviews, and a Delphi survey.

Organizing seminars or workshops provide opportunities to observe current trends and industry information. It provides an avenue to meet industry experts, who are able to provide valid information. Personal contact was one of the most important driving forces attracting industry experts’ participation, whereas multiple follow-up e-mails and phone calls could also increase the response rate for focus group participation.

Another research contribution to the methodology development is using focus group communication to build consensus within complex landscapes. The OTEC industry is an emerging industry. During this research, focus group discussions were facilitated as a direct communication tool, and the energy and research community were asked to participate in the discussion. Since the participants were dealing with an emerging industry with limited knowledge available, it was effective to 'build on the ideas of others' through these discussions. Differing opinions were encouraged and debatable, before finally drawing to a consensus.

It was proven that triangulation of data through focus group discussions, document analysis as well semi-structured interview were a effective approaches to collect information for an emerging industry. It was learnt that leadership direction was required to motivate industry experts to meet and share their knowledge, especially for an emerging industry, (such as OTEC) which lacks initial exposure and public awareness.

5.4.3 Contribution to Practice

The contribution to industry, or the field of OTEC is the development of a proposed OTEC Industry Technology Roadmap as well as clarifying the OTEC Ecosystem through the OTEC Industry Onset Framework to support development in Malaysia. To achieve business success, a technology strategy should be developed interdependently with the business strategy. Through this research, the Industry Technology Roadmapping showed some success in combining both the business perspectives and the technology perspectives in balance. Consumers' interest on market (market pull) and providers' expectation (technology push) could be different, and manufacturers should understand market needs. The Roadmap also identifies some critical requirements not only for technologies but also for infrastructures, regulations, marketing, and consumer awareness.

The resulting Industry Technology Roadmap was created by collecting knowledge and opinions of industrial experts and stakeholders, who also serve as potential consumers. With the added consumer perspective, the resulting information and solutions can be more credible and it allows companies to develop an adequate view of the current OTEC industry landscape.

This research provides industry-level information, which addresses OTEC Industry issues from a macro level. Based on that, each company can make their own firm-level Technology Roadmap as an implementing process. This research identifies critical basic technologies that multiple companies can work on together, which can be a starting point for companies to meet and initiate new collaborations.

5.5 Suggestions for Future Research

Due to the evolutionary nature of markets and technologies, to make the Roadmap valid, periodical updating of Roadmapping is critical. Future research could focus on updating the results of this research. Involvement of a greater number of participants from various fields and regions would give a more complete understanding of markets and technologies.

Mapping the detailed strategy chart by major tasks is imperative to bring to OTEC products to market. Another foresight study may facilitate a more detailed strategy development, which identifies business, manufacturing, financial and marketing objectives.

Since OTEC is an emerging industry, with hydrogen as a radically innovative product, its localized market needs and socio-economic impacts are unknown. Hence, a detailed study on localized market needs and socio-economic impact may be further explored, to plan for the coherent development.

Financial implications remain a key hindrance for OTEC and Hydrogen deployment. Further study is needed to identify estimated costs of producing hydrogen from OTEC, detailing the entire value chain process of capital investments, labour, storage, transportation, and distribution.

Finally, to strengthen the case for OTEC, further research may consider quantitatively accounting for the positive and negative externalities of developing

OTEC, comparative to other energy generation technologies. A negative externality, or external effect, occurs when a production or consumption activity has unintended damaging effects, such as pollution, on other firms or individuals, and no compensation is paid by the producer or consumer to the affected parties. A positive externality occurs when activities have beneficial effects for others who do not pay the generator of the effect, such as freely available research results. Some points of analysis may include CO_2 emissions (during fuel extraction, construction, and operation), and renewable energy CO_2 displacement projections.

5.6 Conclusion

This research builds the case for OTEC as an alternative source of hydrogen. Based on the proposed OTEC-Hydrogen integration landscape, the replacement of fossil fuels with hydrogen production from OTEC will occur gradually, in tandem with the stages of development and growing demand for hydrogen economy. Alternative energies such as OTEC must be investigated, due to the fact that fossil fuels are non-renewable, and depleting. Therefore, to meet the development timelines (Akademi Sains Malaysia, 2015), it is imperative to further explore the OTEC industry, starting with a pilot project of a 10MW OTEC pilot plant. The call to action is urgent, since it takes time to develop the technology maturity and its supporting infrastructure, to establish an industry. In order to meet societal growing energy requirements and in helping to fulfil a sustainable hydrogen economy (Kamarudin *et al.*, 2009), OTEC should be dully considered as one of the effectual energy sources to invest in.

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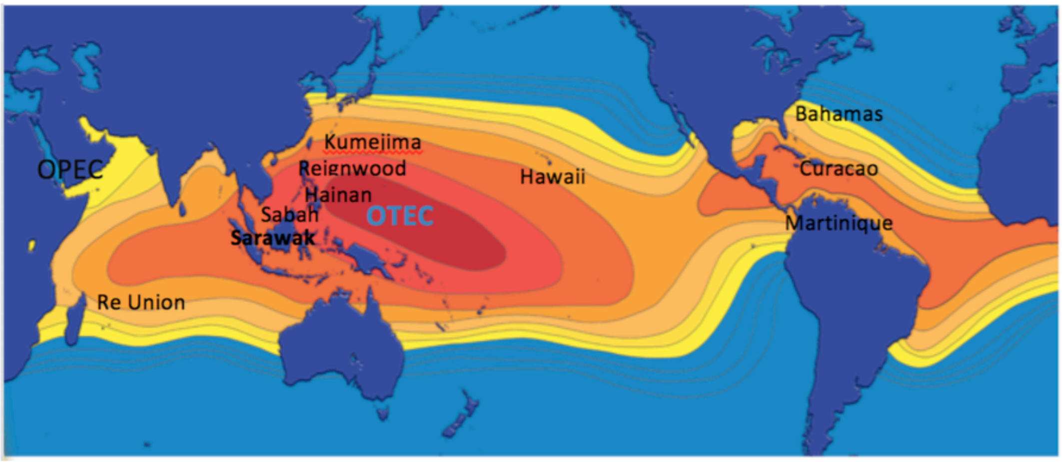
APPENDIX A

Invitation to OTEC Short Course & Workshop | View this email in your browser



UTM.JIL.1.14 (57)

26 November 2014

Dato' Seri/ Datuk/ Dato'/ Prof/ Dr/ Mr/ Mrs,

INVITATION TO OCEAN THERMAL ENERGY CENTRE OF UNIVERSITI TEKNOLOGI MALAYSIA (UTM OTEC) SHORT COURSE AND WORKSHOP PROGRAM.

With regard to above-mentioned matter.

2. We are pleased to invite you and the distinguished members of your organization to attend this program. For your details:

Date	:	10 -11 December 2014 (2 Days)
Duration	:	8.30 am - 6.30 pm
Venue	:	Bilik Ilmuan 1, Menara Razak, Universiti Teknologi Malaysia Kuala Lumpur, Jalan Semarak, 54100 Kuala Lumpur, Malaysia
Program 1	:	Short course on OCEAN THERMAL ENERGY CONVERSION (OTEC) Global Energy, Renewable and Non-Renewable, in Perspective: Ocean Thermal Energy-Driven Development for Sustainability
Program 2	:	Workshop on TECHNOLOGY ROADMAP FOR THE FUTURE: OTEC AND HYDROGEN

3. UTM OTEC is pleased to invite YBhg. Dato' Seri/Datuk/Dato'/Prof/Dr/Mr/Mrs, to attend the program. Please refer to the brochure and tentative program for more details.

We are eagerly looking forward to your participation and cooperation for the program. If you have any enquiries or concerns, please do not hesitate to contact Ms. Suzanne Ong at 016-9938300 or suzanneong888@gmail.com.

CLICK TO REGISTER FOR THIS EVENT

(Please register by 8th December, 2014)

Thank you.

'BERKHIDMAT UNTUK NEGARA'

Yours Sincerely,

PROF. DR. MD NOR MUSA
Director
Ocean Thermal Energy Converstion Centre
Universiti Teknologi Malaysia

Forward

Our website:
http://utmotec.wordpress.com

Our mailing address is:
OTEC-UTM
Universiti Teknologi Malaysia
Jalan Semarak
Kuala Lumpur, Kuala Lumpur 54100
Malaysia

APPENDIX B

Please Check Your Name, if There is no name, please fill in details.

11. DECEMBER 2014 2nd Day Workshop

		First Name	Last Name	E-mail	Contact Number	Company	Designation	Title	Category	Signature
	Yes	azreen	rusnan	azreen@motac.gov.my	193612569	Ministry Of Tourism and Culture	Mr	Mr.	Goverment	
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APPENDIX C

1. To what extent do you agree with the proposed roadmap?