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FEASIBILITY STUDY OF A FIXED OFFSHORE OTEC PLANT FOR COST-EFFECTIVE POWER GENERATION IN MALAYSIA

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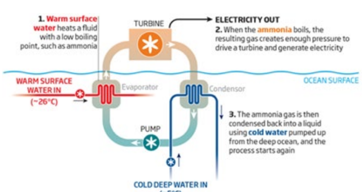
Graphical abstract



Abstract

Ocean Thermal Energy Conversion (OTEC) is a renewable energy technology that harnesses the temperature differential between warm surface water and cold deep ocean water to generate electricity and freshwater. Technological advancements have made OTEC increasingly viable, positioning it as a potential solution for sustainable energy generation in Malaysia. Despite its promise, OTEC development in Malaysia is challenged by the need for suitable sites and the high capital costs associated with traditional floating OTEC platforms. Additionally, efforts to attract anchor partners for OTEC projects have been met with limited success, slowing progress in implementation. This study assessed the feasibility of OTEC plant development in Malaysia through the analysis of sea temperature profiles, identifying five potential sites. A multi-criteria analysis was conducted considering factors such as cold water intake pipe length, proximity to power transmission lines, and environmental impact. The study also proposes a fixed offshore OTEC platform with a single-legged caisson structure, incorporating a braced substructure and dual-level production decks to optimize space for equipment and reduce CAPEX. Kuala Baram (Location C) was identified as the most favorable site due to its optimal conditions for cold water intake and proximity to transmission infrastructure. The proposed fixed platform design offers significant CAPEX reductions compared to floating alternatives, enhancing OTEC's economic potential. The study's findings support the immediate application of OTEC in Malaysia, particularly in ongoing projects off the coast of Sabah. Further research, including modeling and testing of the platform design, is necessary to advance commercialization and establish OTEC as a key component of Malaysia's renewable energy strategy.

Keywords: Ocean Thermal Energy (OTEC), Offshore Structure, Marine Renewable Energy, Power Plant, Cost Optimisation.

1.0 INTRODUCTION

Following the passage of the Ocean Thermal Energy Conversion Act of 1980, significant optimism surrounded OTEC technology. Initial forecasts projected over 10,000 megawatts of electrical (MWe) power generation by 1999 (Kish, 1980). Studies by Pelc and Fujita (2002) suggested a potential capacity of 88,000 terawatt-hours per year (TWh/yr) without impacting ocean thermal balance. This resource potential surpasses other ocean energy forms (Bhuiyan et al, 2022; Samsó et al, 2023).

While electricity is the primary output, OTEC's potential extends to numerous co-products. Desalination, mariculture (aquaculture), hydrogen production, and air-conditioning are all possibilities that enhance economic viability and reduce dependence on fossil fuels (Avery & Wu, 1994; Vega, 1995). For instance, an OTEC plant can generate electricity for hydrogen and desalination processes. At the same time, the nutrient-rich, cool deep seawater (around 10°C) becomes a resource for mariculture (fish, shellfish farming) and other applications like cosmetics, pharmaceuticals, and mineral water production (Cohen, 1982; Plocek et al., 2009). This co-production exemplifies OTEC's ability to contribute to a more sustainable energy future.

Strategic site selection is crucial for OTEC facilities. The ideal location offers access to warm surface waters and deep, cold water (minimum 20°C temperature difference) (Vega, 2003). Land-based plants are an option near continental shelves with rapid depth changes but require long cold-water intake pipes (Etemadi et al, 2011). Currently, five operational land-based plants generate between 15 kW and 105 kW (see Table 1).

Alternatively, offshore, floating, moored platforms with vertical cold-water intake pipes offer greater practicality. Advancements in the offshore oil industry have made these platforms a viable option (Jamaluddin et al, 2014). They can be positioned over deep water with proper mooring and power cable connection to a land-based grid (National Oceanic and Atmospheric Administration, 2010). Notably, two majors floating OTEC facilities are under construction in La Martinique (France) and Tarawa Island (Kiribati), with potential outputs of up to 11 MW. Table 1 summarizes key developments in OTEC technology.

Table 1 Current development of Ocean Thermal Energy-driven (IRENA, 2014).

Development Status	Location	Description	Output Energy	Water Depth	Structure Type	OTEC Technology
Operational	Port Dickson, Malaysia	Operational since 2024 - with the purpose of research and development	3kW	1000 m	Land based	Hybrid cycle
	La Réunion, France	Operational since 2012 - with the purpose of research and development	15kW	1000 m	Land based	Closed cycle
	Gosung, Korea	Operational since 2012 with the purpose of research and development	20kW	1300m	Land based	Closed cycle
	Saga, Japan	Operational since 1980 with the purpose of research and development	30kW	1000m	Land based	Hybrid cycle
	Kumejima Island Okinawa, Japan	Operational since 2013 with the purpose of research and development and for electricity production	100kW	600m - 1000m	Land based	N/A
	Big Island, Hawaii	This is the first true closed-cycle ocean Thermal Energy Conversion (OTEC) plant to be connected to a U.S. electrical grid. Capable of generating enough electricity to power 120 homes a year	105kW	1000m	Floating plant	Closed cycle
Under Constructi on	La Martinique, France	2016- pilot plant Awarded under NER300 programme by the European commission for NEMO project. Nominal capacity of 16MW to be operate by 2019.	11MW	1000m	Floating plant	Closed cycle
	Tarawa Island, Kiribati	The first practical level of plant on a pathway to building a 100MW commercial system.	1MW	1300m	Floating plant	N/A
Planned & Proposed	Int. Airport, Curacao	Expected to provide reduction of approx. 2.500 tons of CO2/year is expected with implementation of the Curacao Ocean Eco Park alone.	500kW	1000m	Pilot plant	Closed cycle
	Zambales, Philippine	The Philippine's first ocean energy facilities are expected to start operating commercially by 2018.	10MW	1000m	Floating Pilot plant	Closed cycle
	Kumejima Island Okinawa, Japan	For a 1MW plant, the plant would make 1.3 - 1.5MW of power and sell 1 megawatt of net power.	1MW	1000m	Land based	Closed cycle
	St. Croix & St. Thomas, US Virgin Island	Memorandum of Understanding (MOU) signed for feasibility study for world's first US-based commercial on-shore OTEC plant and Sea Water Air Conditioning (SWAC) systems.	8MW 15MW	1000m	N/A	N/A
	Maldives	The first commercial OTEC system to be installed in an eco-resort in Maldives. It is expected to be completed by early 2018.	2MW	1000m	Floating plant	Closed cycle

2.0 OCEAN THERMAL ENERGY CONVERSION (OTEC) SYSTEMS OVERVIEW

Ocean Thermal Energy Conversion (OTEC) harnesses the temperature differential between warm surface seawater and cold deep ocean water to generate electricity. Sunlight warms surface waters, creating a thermal energy source, while deep ocean currents remain much cooler. Using a working fluid, OTEC plants exploit this temperature gradient through a thermodynamic process. Warm surface water serves as the heat source, vaporizing a low-boiling-point fluid (often ammonia) within a closed-loop system (Figure 1). The resulting vapour drives a turbine, generating electricity. The vapour is then condensed using cold, deep seawater pumped from the ocean depths, and the resulting liquid is recycled back to the heat exchanger, completing the cycle (Uehara et al, 1996).

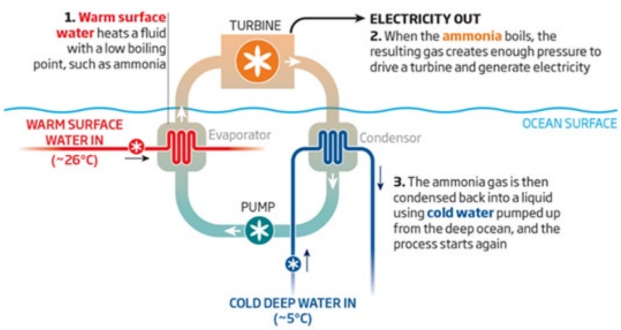


Figure 1 Schematic of OTEC system (Source: districtenergy.org)

Three primary OTEC cycle designs exist: closed-cycle, open-cycle, and hybrid (Uehara and Ikegami, 1990).

- **Closed-Cycle Systems**: These systems utilize a working fluid with a low boiling point, such as ammonia. Warm surface seawater is circulated through a heat exchanger, transferring thermal energy to vaporize the ammonia. The high-pressure ammonia vapour drives a turbine for electricity generation. The vapour is then condensed by the cold deep seawater, returning it to a liquid state for recirculation. Closed-cycle systems offer higher thermal efficiency than open-cycle systems due to using a secondary working fluid that operates at a higher pressure, allowing for smaller turbines (Uehara et al, 1996).
- **Open-Cycle Systems**: These systems directly utilize warm surface seawater as the working fluid. The warm seawater is introduced into a low-pressure chamber, causing it to boil. The expanding steam drives a low-pressure turbine coupled to a generator for electricity production. The process also produces freshwater as a byproduct since salt precipitates within the low-pressure chamber. Cold deep seawater condenses the steam back into liquid form for recirculation (Vega, 2003).
- **Hybrid Systems**: These systems combine elements of both closed-cycle and open-cycle systems. Warm seawater is introduced into a vacuum chamber, similar to an open-cycle system, where it evaporates into steam. This steam then vaporizes a low-boiling-point fluid in a closed-loop cycle, driving a turbine for electricity generation (Uehara et al., 1996).

OTEC plants can be deployed in various configurations, including onshore (land-based), floating platforms, or fixed offshore structures. This versatile technology offers a clean and reliable energy source capable of baseload electricity generation 24/7. A heat exchanger and turbine extract power from the surface and deep ocean temperature differential. According to the National Oceanic and Atmospheric Administration (2010), floating plants positioned near land appear to be the most promising configuration, transmitting electricity to shore via submarine power cables. The environmental benefits of OTEC are significant, offering a sustainable and reliable energy solution for the future.

3.0 COMPARATIVE ANALYSIS FOR VARIOUS OTEC PLANTS

3.1 Onshore OTEC Plant (Land-based)

Land-based OTEC plants currently represent the majority of operational facilities (Figure 2). These facilities offer several advantages. First, they eliminate the need for complex mooring systems, lengthy power cables, and extensive offshore maintenance (National Oceanic and Atmospheric Administration, 2010). Second, their sheltered location minimizes risks associated with storms and heavy seas. This proximity to land also facilitates co-location with industries requiring desalinated water or benefiting from mariculture integration.

Figure 2 Okinawa Prefecture deep sea water ocean thermal energy conversion (OTEC) demonstration facility. (Source: OTEC Okinawa).

However, land-based OTEC plants have drawbacks. One major challenge is the requirement for protective trenches to shield them from extreme weather events and prolonged heavy seas. Additionally, the discharge of mixed cold and warm seawater may necessitate long outfall pipes (several hundred meters) to reach appropriate depths, incurring significant construction and maintenance costs (Pelc and Fujita, 2002).

The potential of nearshore OTEC plants to overcome some of the challenges is promising. By being constructed in nearshore waters, typically between 10 and 30 meters deep, they allow for shorter, more economical intake and discharge pipes while avoiding the dangers of turbulent surf zones. However, nearshore plants still require protection from the marine environment, including breakwaters and erosion-resistant foundations. Furthermore, power transmission infrastructure is necessary to deliver electricity to the shore, but the benefits outweigh these challenges (Plocek et al., 2009; Vega, 2003).

3.2 Floating Offshore OTEC Plant

Floating OTEC platforms offer greater flexibility in site selection compared to land-based plants. Three primary platform designs are considered viable for OTEC applications: semi-submersible, spar, and monohull. Notably, these platforms are fine with manufacturing, operation, and deployment for OTEC use (Balakrishna et al, 2022; National Oceanic and Atmospheric Administration, 2010).

- Semi-submersible platforms leverage established offshore rig fabrication procedures, simplifying construction.
- Spar platforms require specialized manufacturing facilities compared to the other two options. Additionally, their deepwater installation and operation pose greater complexity. However, spar platforms offer a significant advantage for cold-water pipe attachment due to minimal motion at the connection point.
- Monohull platforms utilize existing Floating, Production, Storage, and Offloading Unit (FPSO) technology for construction (Figure 3).

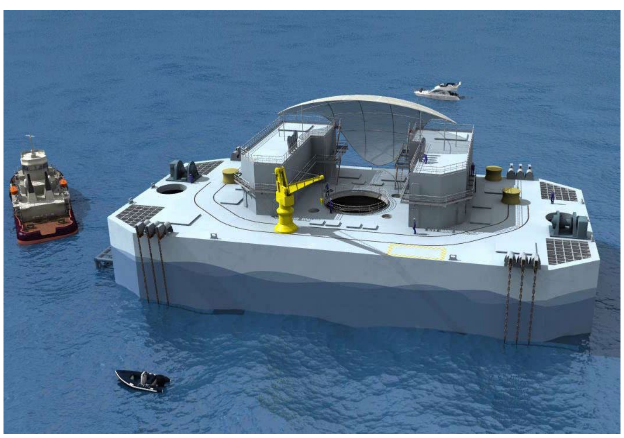


Figure 3 DCNS ocean thermal energy conversion NEMO project (Source: DCNS).

While existing platform technology can be readily adapted for OTEC applications, some challenges remain. A table summarizing the associated risks with each platform configuration is included (refer to Table 2).

Table 2 Challenges, Risks, and Cost Drivers (National Oceanic and Atmospheric Administration, 2010).

Platform Type	Motion / survivability risk	Cost	Technical Readiness
Semi-submersible	Small	Medium	High
Spar	Small	Medium-High	Medium
Monohull	Medium	Low	High

3.3 Fixed Offshore OTEC Plant

Fixed offshore OTEC plants offer a potential middle ground between land-based and floating platforms. Mounted on the continental shelf at depths up to 100 meters (Figure 4), this approach leverages existing technology from offshore oil rigs. While potentially more expensive than land-based plants due to deeper water operation, fixed platforms may be more economical than their floating counterparts (Mohd Zaki et al., 2013; Abu Husain et al, 2019).

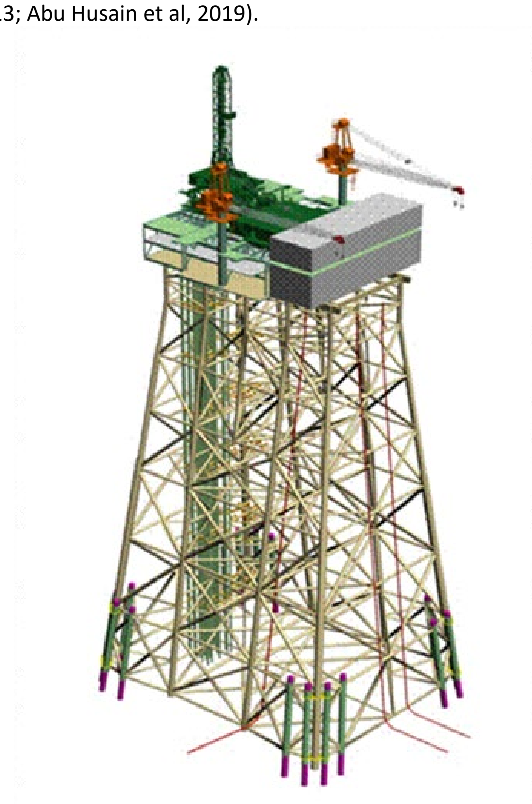


Figure 4 Fixed offshore OTEC plant configuration.

However, fixed offshore OTEC plants face unique challenges. The harsh open-ocean environment presents significant engineering considerations. Strong currents and large waves necessitate robust construction, leading to increased costs. Product delivery, particularly cold water and electricity transmission may require lengthy underwater cables, further adding to the economic burden. These factors contribute to the relative disadvantage of shelf-mounted plants compared to other configurations (Syed Ahmad et al, 2021).

Despite these challenges, fixed platforms possess inherent advantages. Their established presence in other industries, such as offshore oil and wind farms, demonstrates their technical viability (Mat Soom et al, 2015). Additionally, minimal additional manufacturing, operation, or deployment hurdles exist for adapting them to OTEC applications. Therefore, research and development efforts primarily focus on improving efficiency and cost-effectiveness. Developing more straightforward and lower-cost manufacturing and deployment techniques holds the key to unlocking the economic potential of fixed offshore OTEC plants.

3.4 Key Considerations for Selecting an OTEC Plant

While all three configurations – land-based, fixed offshore, and floating – offer options for deploying Ocean Thermal Energy Conversion (OTEC) plants, the optimal choice hinges on project specifics. Land-based plants boast easy construction and maintenance access but require extensive pipelines and suitable coastlines. Fixed offshore platforms, limited to shallow waters (up to 100 meters), eliminate the need for lengthy pipelines but restrict site selection. Floating platforms reign supreme in location flexibility (deeper waters) but are susceptible to wave motion (Gaidai et al, 2022).

Cost and efficiency considerations also vary. Land-based plants might incur the highest upfront costs due to expansive piping infrastructure. Fixed offshore platforms strike a balance between cost and efficiency, while floating platforms may have higher initial costs due to complex designs (Azman et al, 2021; Low, 2016). However, shorter cold-water intake needs can offset some of this expense. It's important to note that wave motion can negatively impact the efficiency of floating platforms.

Environmental impact presents another layer of complexity. Land-based plants introduce challenges with large pipelines disrupting ecosystems and require careful management of warm water discharge after use in the OTEC process. Fixed platforms have a localized environmental impact on the seabed ecosystem where they are anchored (Paul Kish, 1980). Floating platforms risk entanglement with marine life due to their anchor systems. All three options necessitate responsible management of the warm water discharge to minimize environmental harm.

Technical feasibility is another crucial factor. Land-based options face limitations due to the availability of suitable coastal locations and the potential hurdles of obtaining environmental permits. Fixed platforms require expertise in offshore construction and maintenance (Mukhlas et al, 2018; Auwalu et al, 2022). In contrast, floating platforms offer the most location flexibility and demand expertise in designing and operating structures that can withstand the rigours of the marine environment.

To select the most suitable and sustainable OTEC platform, a thorough analysis, considering project requirements, site characteristics, and budget, is necessary (Bai et al, 2016; Mohd Zaki et al, 2018; Syed Ahmad et al, 2021). Table 3 provides a summary comparison of these three different OTEC plant options.

Table 3 Comparison of Land based, Fixed and Floating Platforms for OTEC Plants

Feature	Land-Based	Fixed Offshore	Floating
Location	Coastal	Shallow Shelf (up to 100m)	Variable (deeper waters)
Flexibility	Lower	Moderate	High
Construction Complexity	Moderate	Lower	Higher
Maintenance Accessibility	High	Moderate	High
Upfront Cost	Potentially Highest	Lower	Higher
Efficiency (Potential)	Lower	Higher	Lower
Environmental Impact	High (pipelines)	Localized (seabed)	Potential entanglement risk
Technical Feasibility	Moderate (location)	Moderate (depth)	High

4.0 MALAYSIA'S OCEAN THERMAL ENERGY CONVERSION (OTEC) POTENTIAL

4.1 Potential OTEC Site Identification

Previously, Malaysia was not considered a viable candidate for OTEC development on global maps. However, a 2008 South China Sea marine survey revealed significant potential for utilizing OTEC technology for electricity generation and hydrogen fuel production (Banerjee et al., 2017). This finding has spurred interest in OTEC development within the country.

The selection of suitable OTEC sites depends on various factors. Oceanographic conditions, such as temperature gradients, water depth, and oceanic currents, constitute critical considerations. Environmental factors, including marine ecosystems and regulatory frameworks, must also be meticulously evaluated. Economic factors, such as market demand and infrastructure, exert a significant influence on project feasibility. Technological considerations, including OTEC system type and plant scale, shape site requirements. Moreover, social factors, such as community acceptance and cultural heritage, are indispensable for successful project implementation. By carefully evaluating these factors, potential OTEC sites can be identified for sustainable and efficient energy production.

Five potential locations within Malaysia have been identified as suitable for OTEC plant construction, as shown in Figure 5. These sites are concentrated in the Sabah Trough area (Kuala Baram (KB2E), Pulau Layang-Layang (LL2H), Kuala Penyu (GK1E), and Pulau Balambangan (PB3E)) and Semporna province (Sipadan Island). The total area with potential for OTEC development in Malaysia is estimated to be around 130,000 km², offering a theoretical electricity generation capacity of approximately 105,000 MW. Among these potential sites, this study identifies Kuala Baram as the most promising location for developing a pilot fixed offshore OTEC power plant.

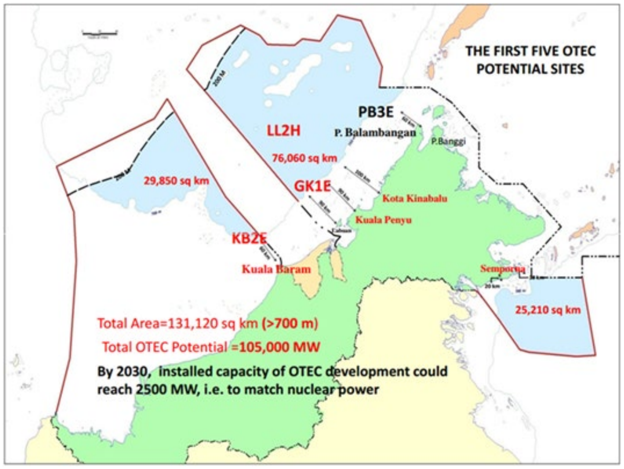


Figure 5 Location of potential OTEC in Malaysia (Jaafar et al, 2020).

The Sabah Trough, a promising location for OTEC development in Malaysia, is situated approximately 100 kilometres off the coast of Sabah. This undersea valley boasts an estimated width of 60 kilometres, a length of 100 kilometres, and an average depth of 2,500 meters (Figure 6). As illustrated in Figures 7 and 8, this study reveals significant temperature differentials within the trough. At a depth of 2,900 meters, the bottom exhibits temperatures around 5°C, while surface water temperatures range from 26°C to 30°C. Figure 9 further highlights the variation in water depth as distance increases from land. At approximately 120 kilometres offshore, the seafloor reaches a depth of 1,000 meters.

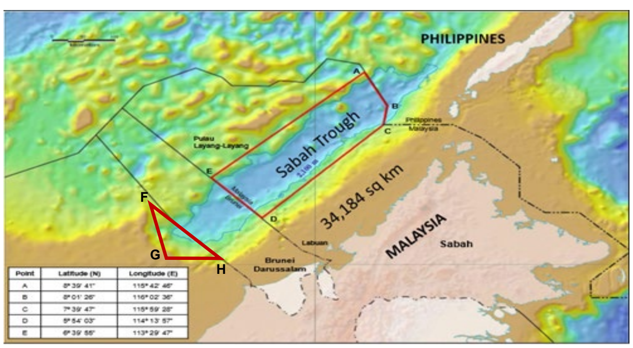


Figure 6 The location of Sabah Trough.

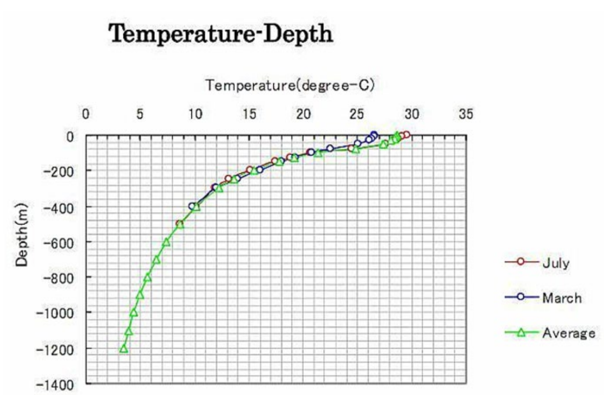


Figure 7 Variation of seawater temperature with depth at Sabah Trough.

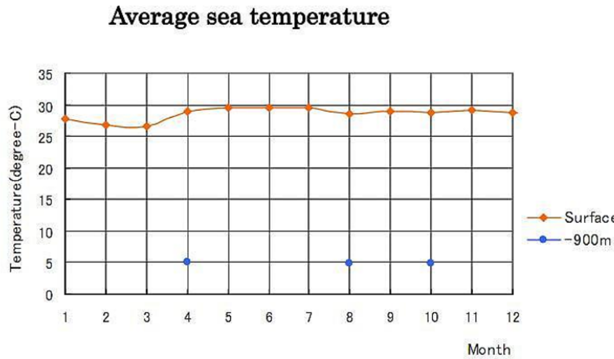


Figure 8 Average monthly surface seawater temperature at Sabah Trough.

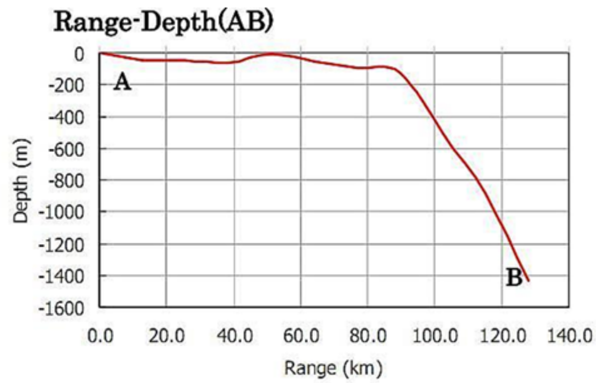


Figure 9 Variation of water depth with range at the Sabah Trough.

4.2 Site Selection for Fixed OTEC Platform Deployment

The OTEC platform will be situated in the Baram Field, approximately 50 kilometres from Kuala Baram (Figure 10). Three potential locations with a maximum water depth of 100 meters were identified for this study (refer to Figure 10). However, colder deep ocean water is required for optimal OTEC efficiency. Therefore, the cold-water intake for this project will be located at the 700-meter isobath, where the water temperature is around 6°C.

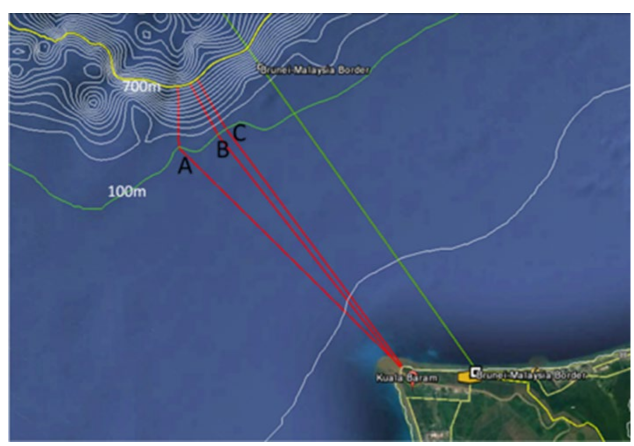


Figure 10 Proposed platform location at Kuala Baram Field.

Table 4 provides a detailed analysis of the proposed platform locations. Based on this analysis, considering factors like cold water pipe length (47.6 km) and subsea electricity cable length

(9.24 km), location C was the optimal choice for platform installation. Consequently, Location C has been selected for further study in this project.

Table 4 Proposed Coordinate of OTEC platform.

Proposed Location	Coordinate (deg)	Distance to Kuala Baram (km)	Distance to 700m isobaths (km)
A	4°56'37.71"N / 113°42'51.22"E	51.1	9.71
B	4°56'7.07"N / 113°42'2.23"E	47.7	9.45
C	4°56'37.71"N 113°42'51.22"E	47.6	9.24

4.3 Environmental Conditions and Design Criteria

To ensure the structural integrity of the OTEC platform, a comprehensive in-place analysis was conducted, incorporating various environmental factors. This analysis accounted for extreme environmental events with recurrence intervals of one year and 100 years, based on site-specific criteria detailed in Table 5 (refer to the environmental loads at the Baram Field). Additionally, nominal operating conditions for wind, wave, and current were included to simulate typical operational scenarios. The metocean data used in this study was obtained from a technical report prepared by ACTS Smart Solutions Sdn Bhd in 2021.

Table 5 Environmental data at proposed location C.

Environmental Data	100-year Event Storm Conditions	1-year Event Storm Conditions
Water depth	Approx. 100m	Approx. 100m
Mean sea level	1.20m	1.20m
Highest astronomical tide (HAT)	2.10m	2.10m
Lowest astronomical tide (LAT)	0.00m	0.00m
Maximum wave height (Hmax)	9.70m	6.10m
Wave period (Tass)	9.2s	8.2s
Surge (+)	0.60m	0.30
Wind 1 hr mean	25m/s	19m/s
Wind 1 min mean	29m/s	23m/s
Current (layer above seabed = 0.98)	180cm/s	140cm/s
Current (layer above seabed = 0.74)	164cm/s	127 cm/s
Current (layer above seabed = 0.49)	143cm/s	111 cm/s
Current (layer above seabed = 0.10)	84 cm/s	65 cm/s
Current (layer above seabed = 0.05)	66 cm/s	52 cm/s
Current (layer above seabed = 0.01)	39 cm/s	30 cm/s

The methodology involved the following steps:

i) Data Collection: Site-specific data were gathered, including water depth, mean sea level (MSL), highest astronomical tide (HAT), and lowest astronomical tide (LAT). Historical data were used to estimate maximum wave height (Hmax), wave period (Tass), storm surge (+), wind speeds, and ocean currents.

ii) Extreme Event Simulation: The platform was subjected to simulations for extreme events with recurrence intervals of one year and 100 years, to evaluate its performance under severe conditions.

iii) Operational Conditions: Nominal conditions for wind, wave, and current were incorporated to assess the platform's stability and performance during regular operations.

iv) Configuration Assumptions: The analysis assumed that all structural components, including appurtenances and the cable guying system, would be in place during the simulations. This ensured a realistic assessment of the platform's resilience under various conditions.

This methodology ensures a thorough evaluation of the platform's structural integrity by considering both extreme environmental scenarios and typical operational conditions, thus validating the design against a range of potential impacts.

5.0 FIXED OFFSHORE OTEC PLANT CONFIGURATION FOR 1 MW POWER GENERATION

5.1 1MW Closed-cycle OTEC System Specification

This study investigates the feasibility of using a fixed offshore platform for a 1 MW OTEC power plant. Fixed platforms offer several advantages, including their established technology, cost-effectiveness, and the availability of many critical components from the oil and gas industry (Giraldo et al, 2019; Gao and Low 2016). This approach has the potential to significantly reduce capital expenditure for OTEC facilities, thereby improving their overall economic viability. Due to the complexity of OTEC technology and the numerous components involved in energy production, a 1 MW closed-cycle plant would require the installation of the following significant operational components (detailed in Table 6 and Figure 11):

Table 6 List of OTEC equipment and specification.

Component	Unit	Dimension (m)	Remark
Condenser	2	5.5m(L) x 0.2mØ	Approximate weight of equipment = 310 metric tonnes
Ammonia Evaporator	2	5.5m(L) x 0.2mØ	
Turbine Generator	2	4.5m(L) x 0.2mØ	
Water Production Evaporator	1	4m(H) x 2mØ	
Water Production Condenser	1	4m(H) x 2mØ	
Warm Water Inlet	1	1.5m x 50m	
Cold Water Pipe	1	1.5mØ x 120m (L)	
Effluent Mixed Water Discharge Pipe	1	1.5mØ x 70m(L)	

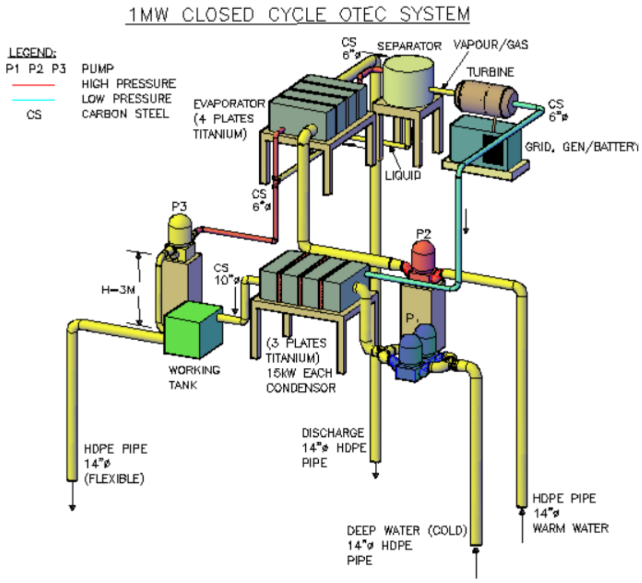


Figure 11 An equipment layout for OTEC.

5.2 Conceptual Design for 1MW Fixed Offshore OTEC Platform

A conventional jacket platform consists of two main sections: the topside (upper section) and the substructure (lower section) (Mat Soom, 2015; Abu Husain, 2014). The substructure, a jacket, is a vertical steel structure supported by driven piles anchored to the seabed. It provides the foundation for the topside deck, which houses crew quarters and the OTEC plant's production facilities.

The topside is crucial, accommodating all the processing equipment (production skids) and the working deck. This section is positioned above the water level, typically at mean sea level (MSL). The substructure, located underwater on the seabed, utilizes leg piles to support the foundation piles, cold water inlet pipe, warm water inlet pipe, and other essential components. Axial forces from the topside structure are transferred down to the piles at the top of the substructure (Jimenez-Martinez, 2020).

A comprehensive evaluation of environmental conditions, operational requirements, and cost considerations has identified a monopod platform as the most suitable design for this 1 MW OTEC system. Environmental factors such as water depth, wave height, current, wind load, and seabed conditions are all crucial considerations. Operational requirements must also be factored into the design selection, including the system's production capacity and required functionalities (Pilotto et al, 2002; Umar et al, 2021). Finally, cost considerations like construction complexity, fabrication costs, and installation expenses play a significant role in platform selection.

Monopod platforms, characterized by a small deck supported by a single, large-diameter caisson and a braced substructure (Figure 12), offer several advantages for this application. Their cost-effectiveness for shallow water deployments aligns well with the anticipated water depth of the OTEC system. Additionally, the potential for local fabrication (Mohd Zaki et al, 2018; Zhao et al, 2020) can further reduce project costs and support regional economic development.

For this conceptual study, the monopod OTEC platform was designed through an iterative process that considered site-specific conditions and anticipated load requirements. This single-leg design provides a robust and stable structure, particularly in areas with moderate wave conditions (as stated in Table 5) and can accommodate this 1MW closed-cycle OTEC facility. Moreover, this platform allows for faster fabrication and installation, offering a relatively cost-effective method compared to other platform types. Established industry standards (i.e., API RP2A and ISO 19902) guide the design process to ensure the platform can withstand extreme weather events, particularly 100-year storms. Key design considerations focus on maintaining structural integrity and OTEC operational efficiency (API, 2014).

Firstly, the design strives to limit topside deflections within acceptable tolerances. Excessive deflections can compromise equipment functionality and crew safety. Secondly, the platform's natural period, which refers to its inherent vibration frequency, is kept below 3 seconds. This mitigates resonant amplification of wave-induced motions, improving platform stability.

As part of the study's objectives, cost-effectiveness is a significant aspect of monopod designs. They are engineered to prioritize simplicity, utilizing readily available materials and minimizing complexity during fabrication. Moreover, the design strategy focuses on the use of minimal offshore installation equipment. This approach, coupled with the limitation of the number of components and keeping individual component weights within the lifting capacity of standard crane barges (single-hook lifts), enhances installation efficiency and reduces overall project costs. As an example, a typical monopod platform can accommodate an operating deck load of approximately 500 tons (Zee, 2000).

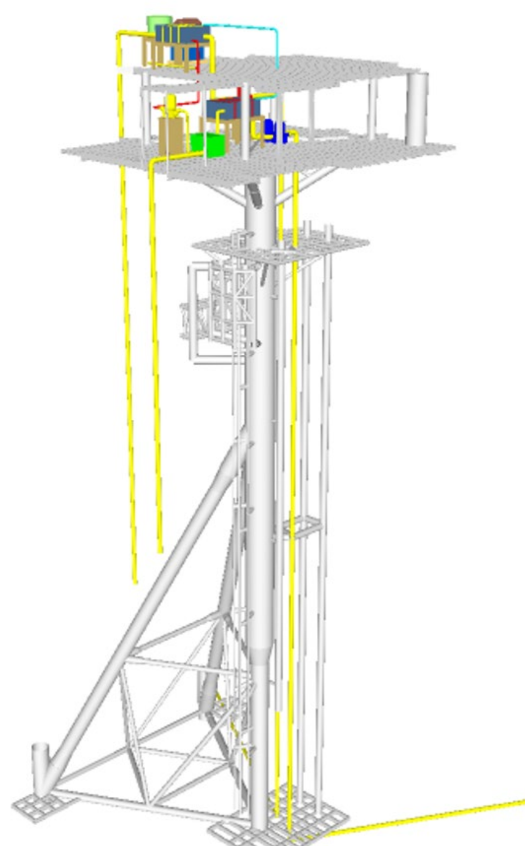


Figure 12 Schematic of 1MW fixed OTEC offshore platform.

5.0 CONCLUSIONS

This study successfully assessed the feasibility of utilizing Ocean Thermal Energy Conversion (OTEC) technology for electricity generation in Malaysia. The analysis of temperature profiles identified five potential sites suitable for OTEC plant development. Among these sites, Kuala Baram (Location C) emerged as the most favorable option, considering factors like cold water intake pipe length and power transmission line distance.

Furthermore, the study proposes the application of a fixed offshore OTEC platform with a single-legged caisson structure. This platform would incorporate a braced substructure and dual-level production decks to ensure adequate space for OTEC equipment. This novel design presents a significant opportunity to reduce capital expenditure (CAPEX) compared to traditional floating OTEC plants, thereby enhancing the economic viability of OTEC technology.

The findings from this study hold immediate application potential for the ongoing OTEC project proposed for the coast of Sabah, Malaysia. While the proposed platform structure offers a promising path towards cost reduction, further research efforts are crucial for commercialization and development. These efforts may involve modelling and testing initiatives, with the aim of publishing the outcomes in due course.

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Conflicts of Interest

The author(s) declare(s) that there is no conflict of interest regarding the publication of this paper

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