2ND NATIONAL WORKSHOP & TRAINING COURSES ON OCEAN ENERGY

“OCEAN ENERGY & OCEAN THERMAL ENERGY: AN OVERVIEW

By

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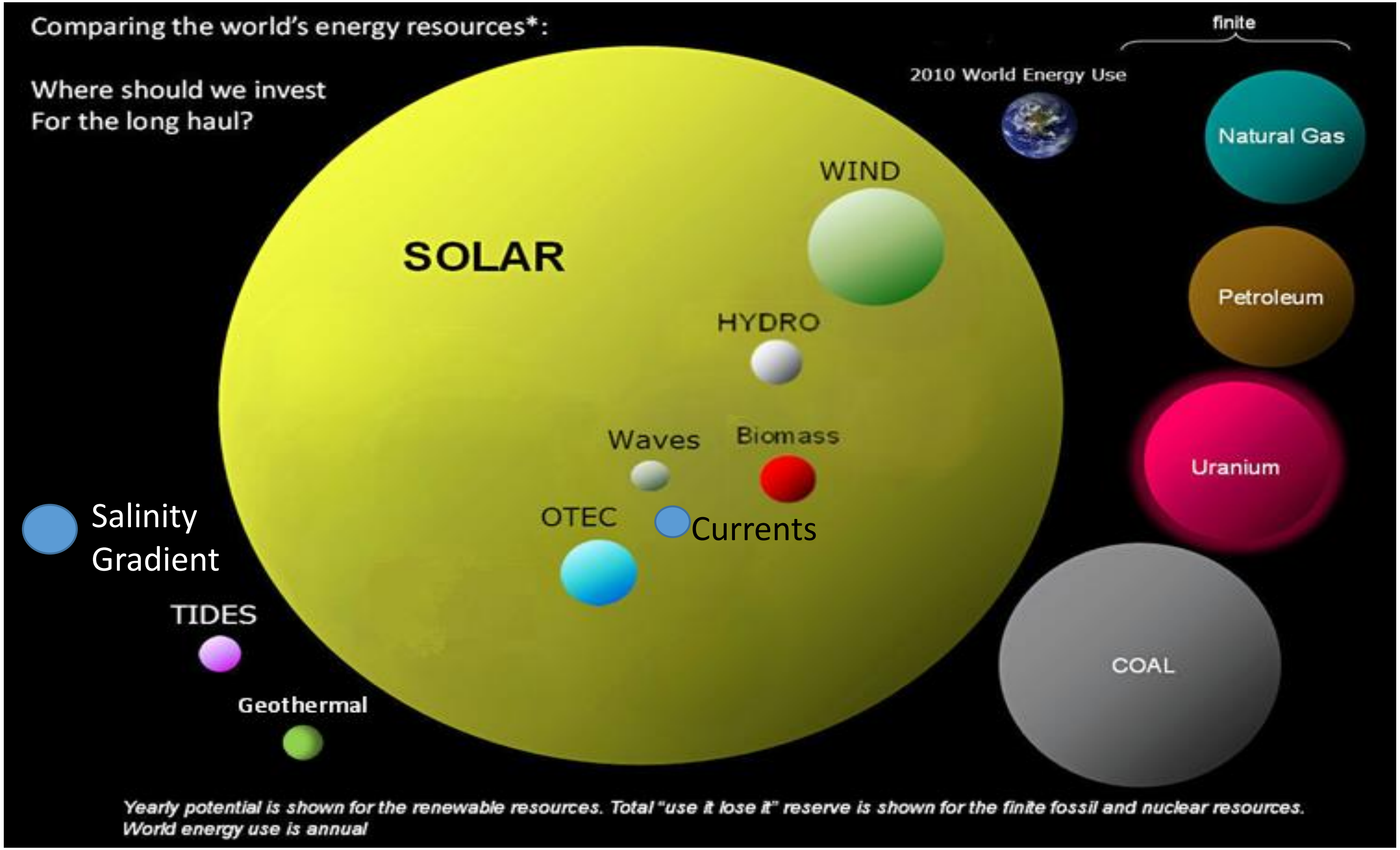
OUTLINE OF PRESENTATION

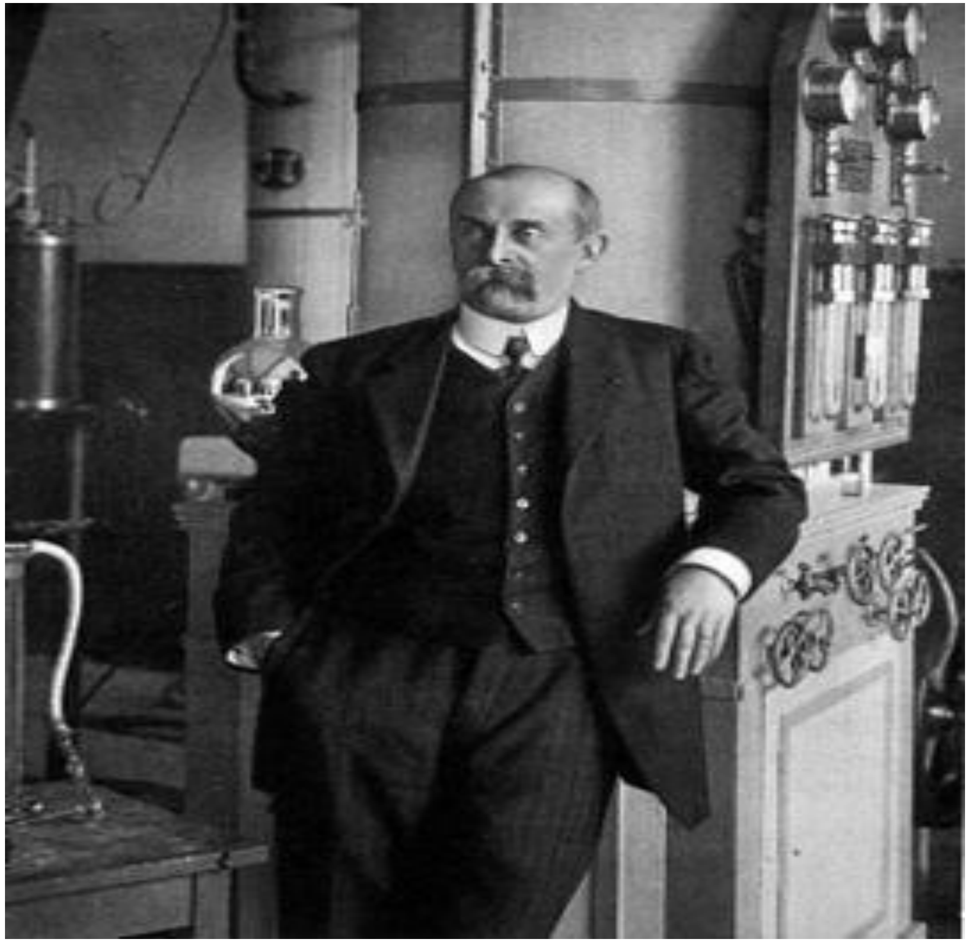
1. INTRODUCTION
2. ENERGY SOURCES, RENEWABLE & NON-RENEWABLE
3. OCEAN THERMAL ENERGY CONVERSION (OTEC)
4. BENEFITS: SECURITY *[ENERGY, WATER, FOOD, CYBER*], ENVIRONMENT,
5. GLOBAL OTEC POTENTIAL & DEVELOPMENT
6. THE ECONOMICS OF OTEC vis-à-vis FOSSIL-FUELS
7. OTEC POTENTIAL IN BRUNEI DARUSSALAM & IN MALAYSIA
8. AN OVERVIEW OF OCEAN ENERGY BY TYPE
9. THE WAY FORWARD

GLOBAL SOURCES OF ENERGY, RENEWABLE & NON-RENEWABLE, IN PERSPECTIVE



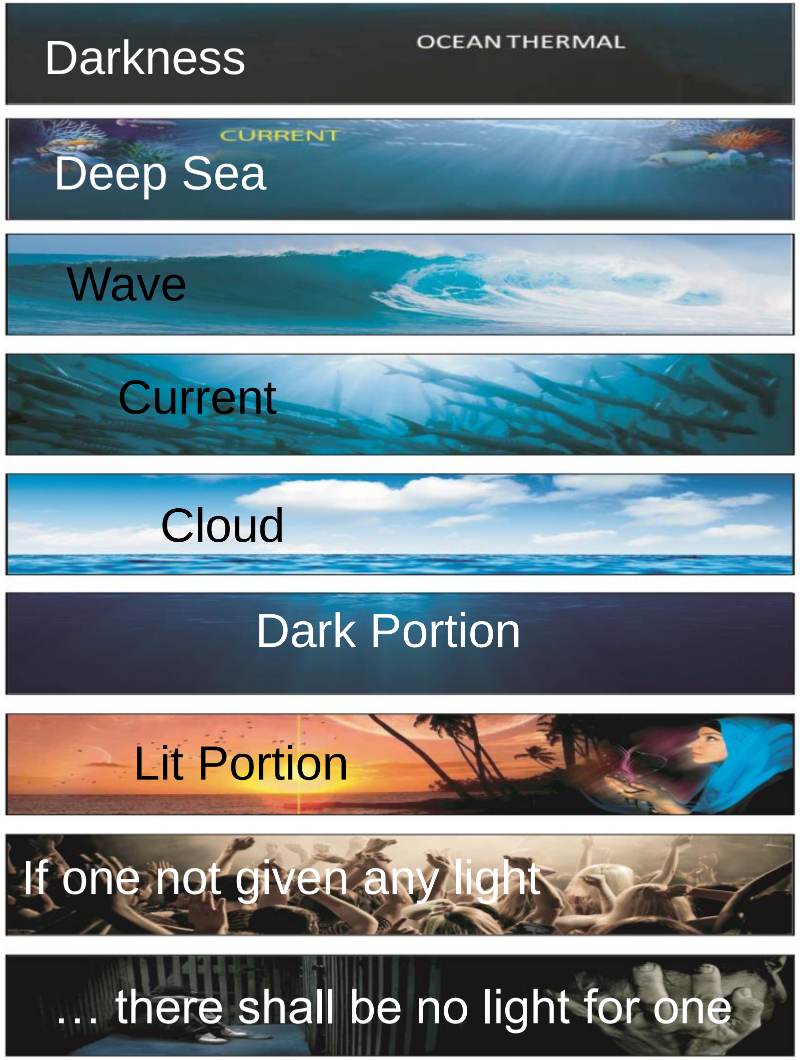
“The SIFU”

1881: Jacques-Arsène D’Arsonval (French physicist) proposed the concept of OTEC using ammonia as a working fluid to drive a turbine-generator (the *closed-cycle OTEC system*). The concept was considered economically non-viable at the time.



Jacques-Arsène D’Arsonaval, 1851 – 1940

An-Nur 24:40



أَوْ كَظُلُمَٰتٍ
Atau kah — seperti keadaan gelap-gelita

فِي بَحْرٍ لُّجِّيٍّ
di — lautan — yang dalam

يَغْشَىٰهُ مَوْجٌ مِّن
meliputinya — oleh ombak — dari

فَوْقِهِۦ مَوْجٌ مِّن
atasnya — ombak — dari

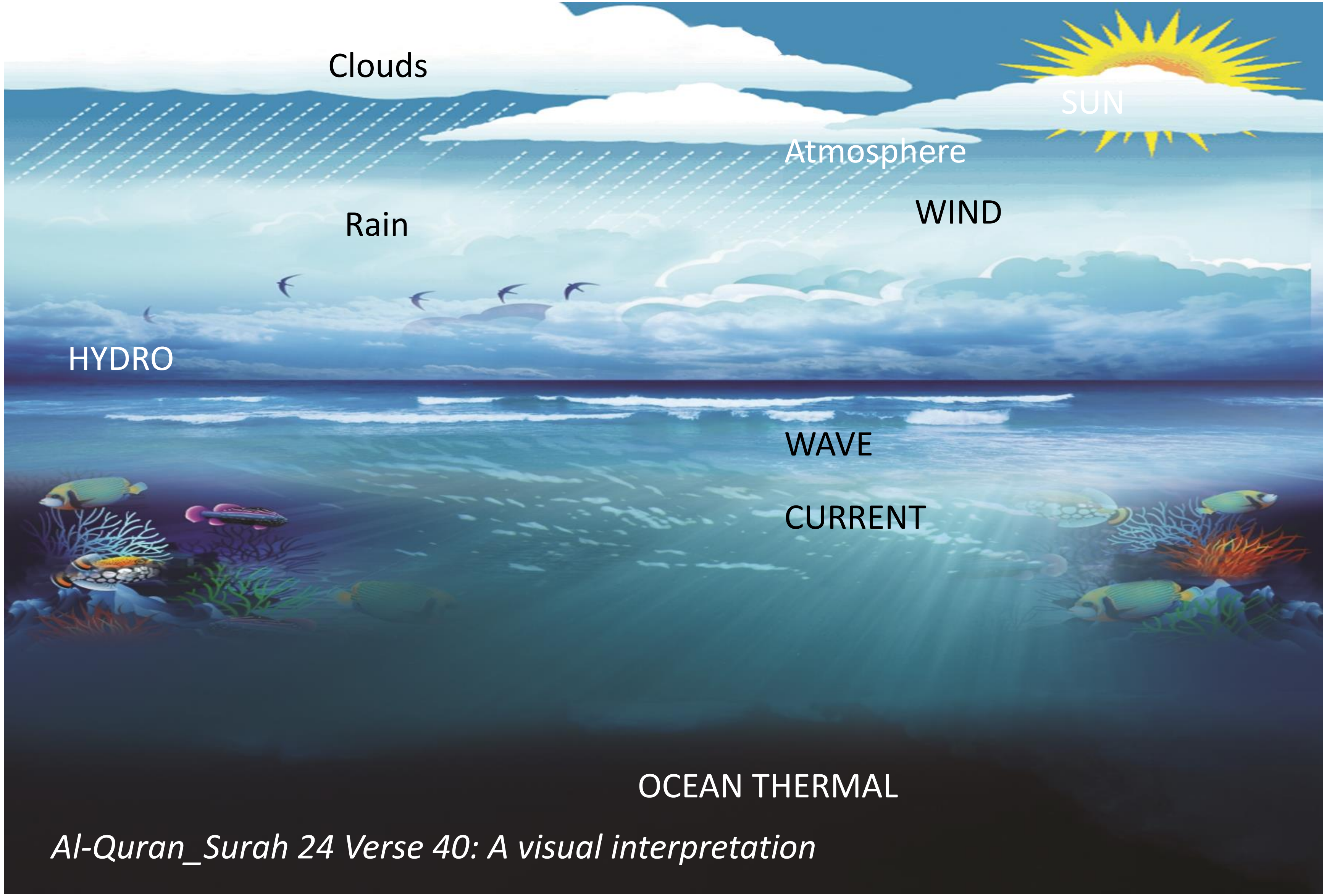
فَوْقِهِۦ سَحَابٌ
atasnya — awan

ظُلُمَٰتٌۢ بَعْضُهَا
gelap-gelita — sebahagian-nya

فَوْقَ بَعْضٍ إِذَآ أَخْرَجَ يَدَهُۥ
atas — sebahagian yang lain — apabila — orang itu mengeluarkan — tangan-nya

وَمَن لَّمْ يَجْعَلِ ٱللَّهُ لَهُۥ نُورًا
dan sesiapa yang — tidak — diberikan — oleh Allah — bagi-nya — cahaya

فَمَا لَهُۥ مِن نُّورٍ
maka dia tidak — bagi-nya — dari-pada — sebarang cahaya


Clouds
SUN
Atmosphere
WIND
Rain
HYDRO
WAVE
CURRENT
OCEAN THERMAL
Al-Quran_Surah 24 Verse 40: A visual interpretation

8 SECONDARY FORMS OF SOLAR ENERGY

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from the Sun

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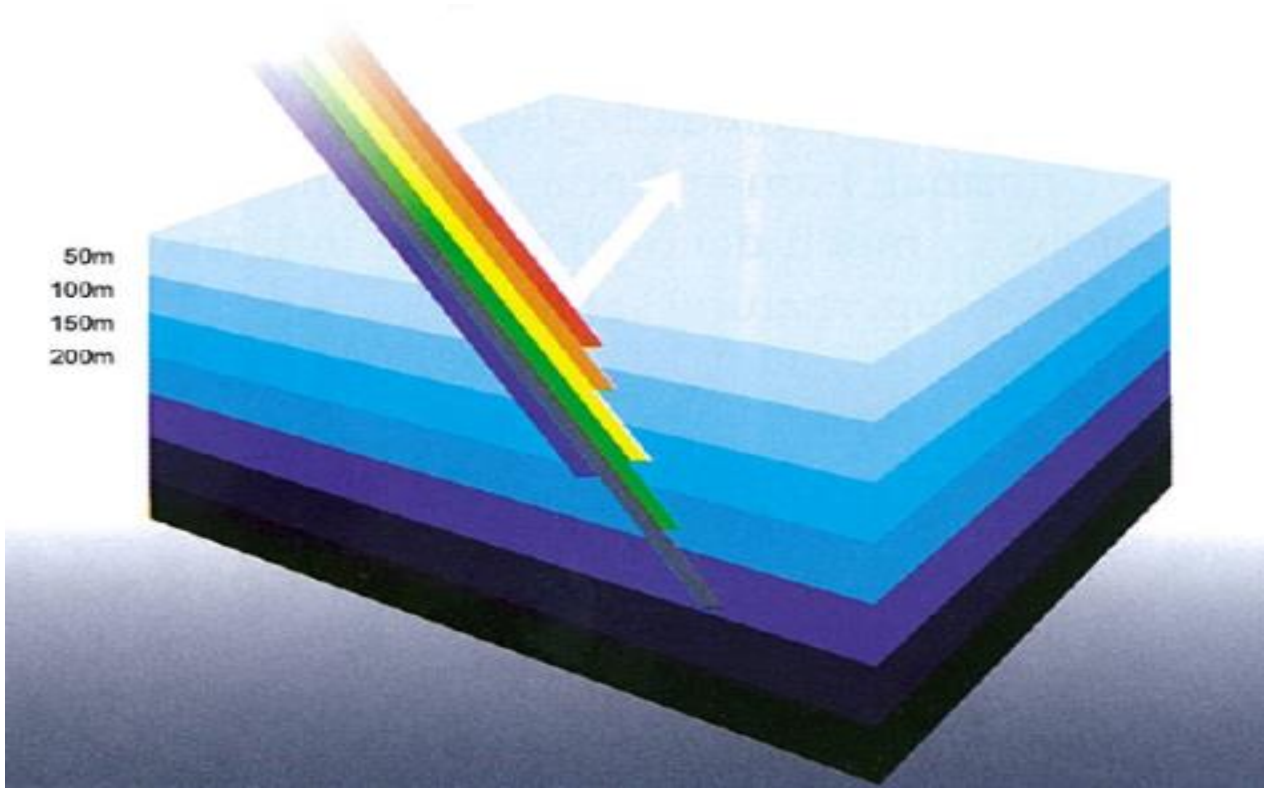
OCEAN THERMAL ENERGY: A PRIMARY SOURCE



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Zakir Naik (2007). The Qur'an and the Modern Science: Compatible or Incompatible? Riyadh: Darussalam p.39

3. OTEC Legal Definition:

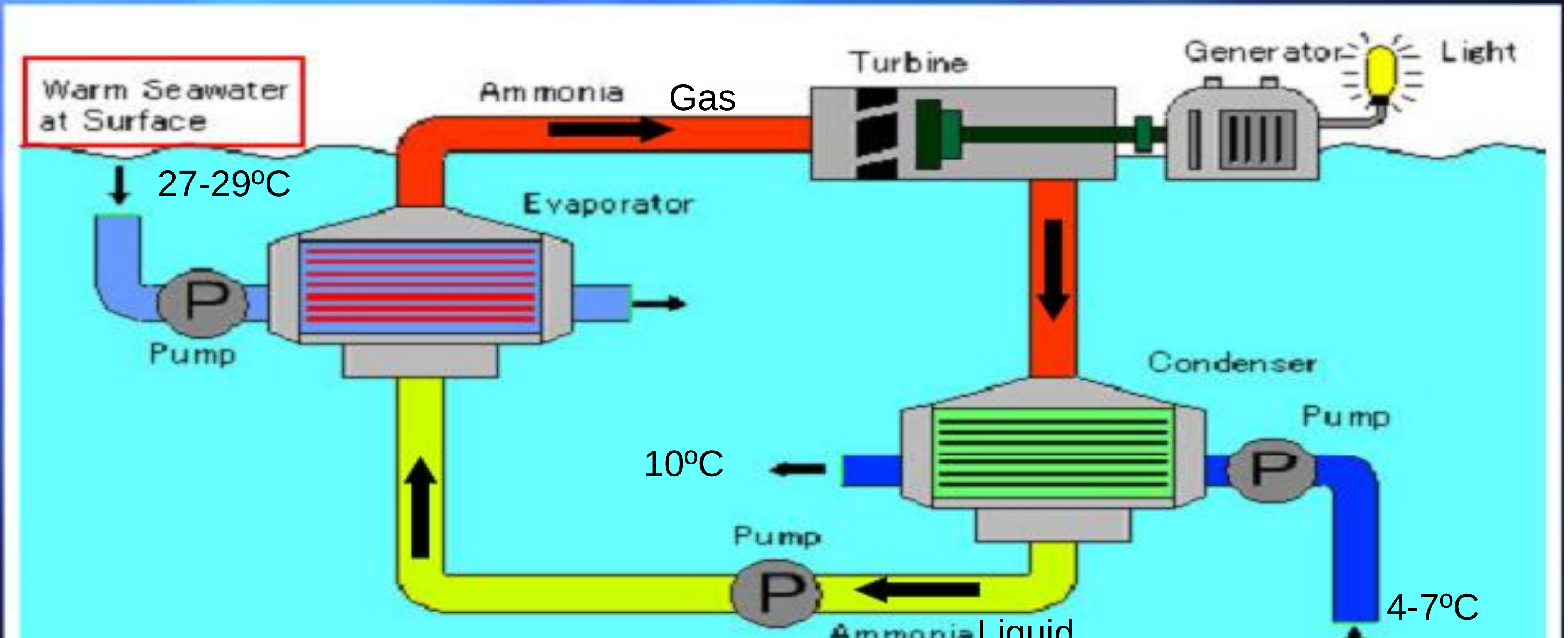
"OCEAN THERMAL ENERGY CONVERSION"

"… a method of converting part of the heat from the Sun which is stored in the surface layers of a body of water into electrical energy or energy product equivalent";

[Pub. L. 96-310, Sec. 9, July 17, 1980, 94 Stat. 946.]

Ref: http://uscode.house.gov/download/pls/42C98.txt

Principle of OTEC

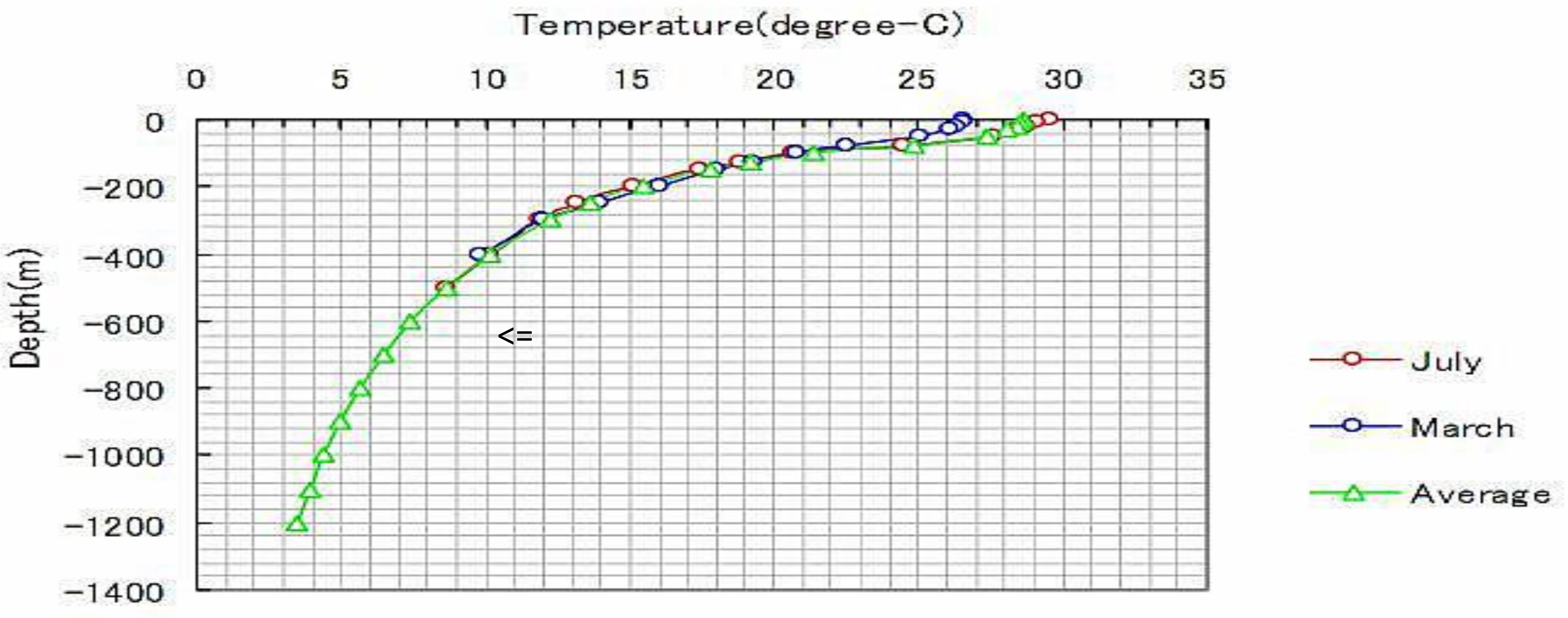


Al-Quran 24:40 (610-632)

Rankine (1851)
D'Arsonval (1881)
Claude (1930)

Off Sabah:

Temperature-Depth Profile



4. BENEFITS TO THE COUNTRY

- **SECURITY [ENERGY, WATER, FOOD, CYBER],**
- **BIODIVERSITY, CLIMATE CHANGE, THE ENVIRONMENT *ETC***
- **MEDICAL & HEALTH CARE**
- **TRANSPORTATION & URBANISATION**
- **COMMODITIES**

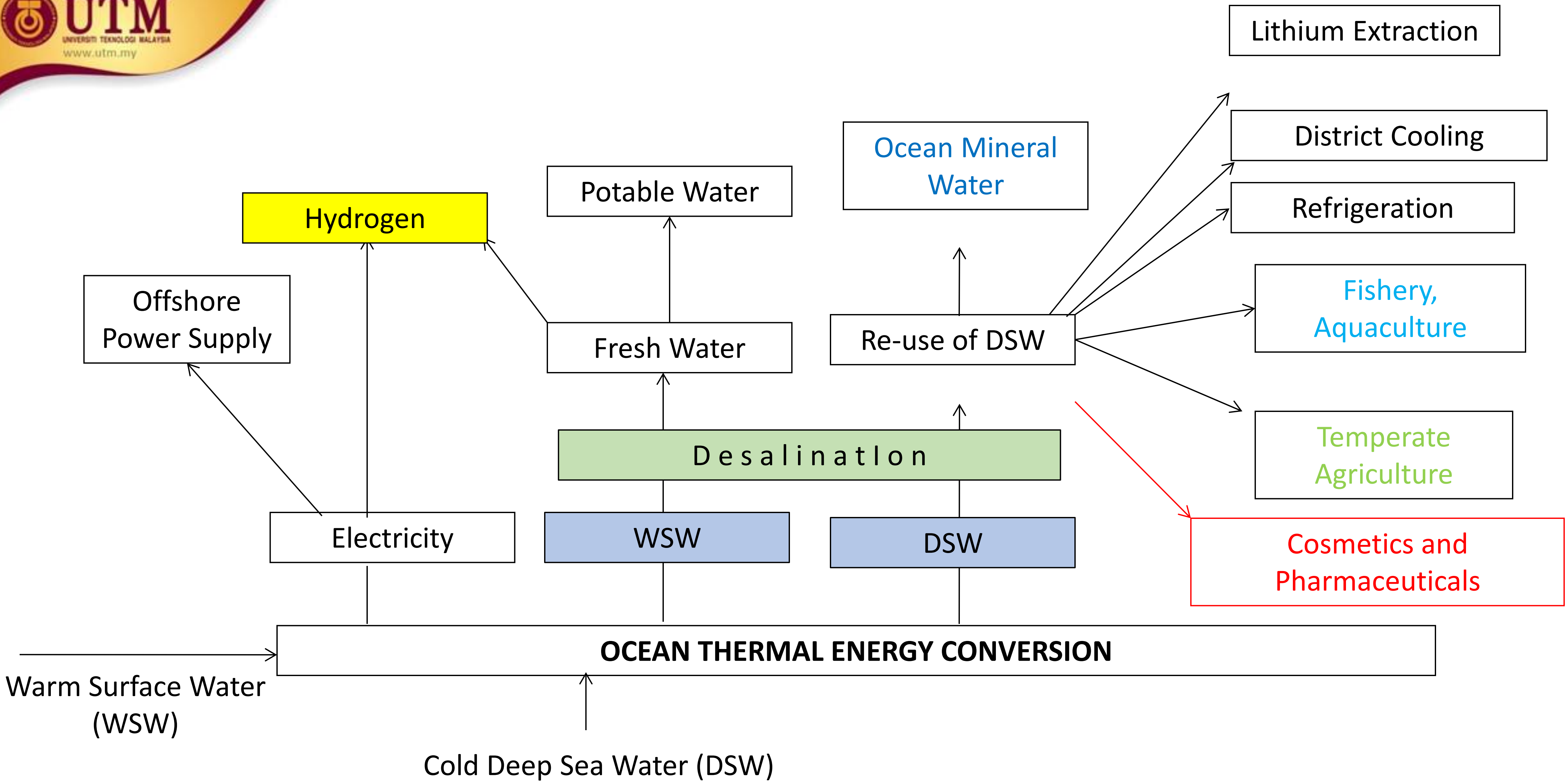
IMPACTFUL FOCUS AREAS

Issues

9. BIODIVERSITY
7. CYBER SECURITY
1. ENERGY SECURITY
8. ENVIRONMENT & CLIMATE CHANGE
3. FOOD SECURITY
5. MEDICAL & HEALTHCARE
4. PLANTATION CROPS & COMMODITIES
6. TRANSPORT & URBANISATION
2. WATER SECURITY

Enablers

- CROSS CUTTING TECHNOLOGIES
- GREEN TECHNOLOGY
- FUNDAMENTAL SCIENCES
- SOCIAL SCIENCES AND HUMANITIES

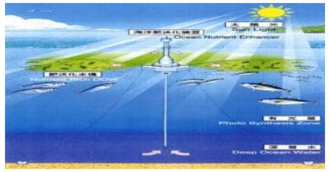

Lithium Extraction
District Cooling
Ocean Mineral Water
Potable Water
Hydrogen
Refrigeration
Offshore Power Supply
Fishery, Aquaculture
Fresh Water
Re-use of DSW
Temperate Agriculture
D e s a l i n a t I o n
Electricity
WSW
DSW
Cosmetics and Pharmaceuticals
OCEAN THERMAL ENERGY CONVERSION
Warm Surface Water (WSW)
Cold Deep Sea Water (DSW)

OTEC SPIN-OFF INDUSTRIES

Temperate Produce

"Import Substitutions"

High Value Produce



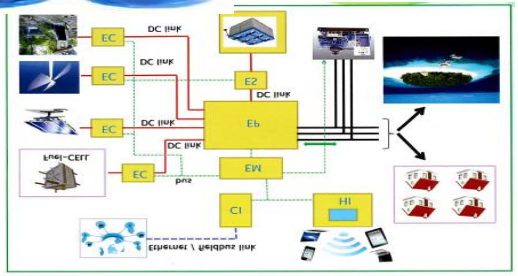
Health & Cosmetics

Lithium Production

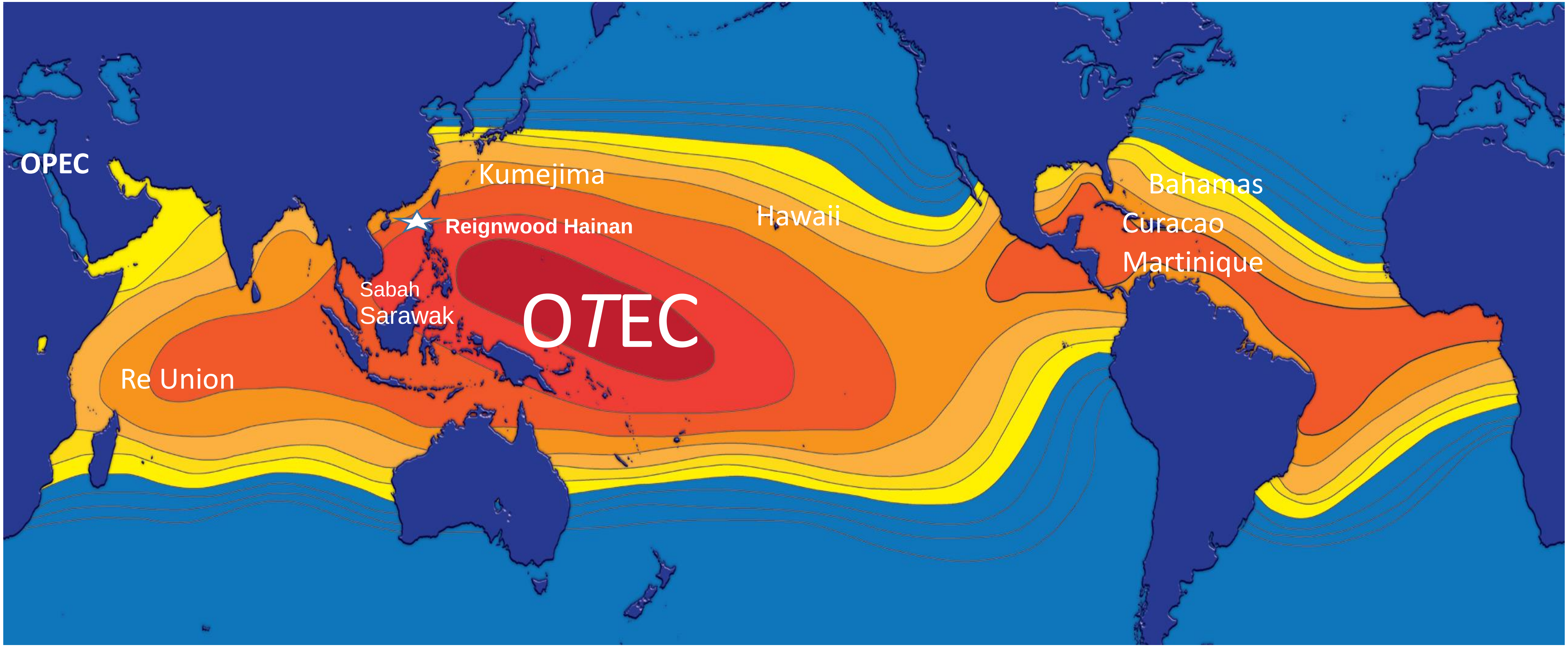

Picture 5: Lithium extraction facility

Mineral H20

OTEC-H2



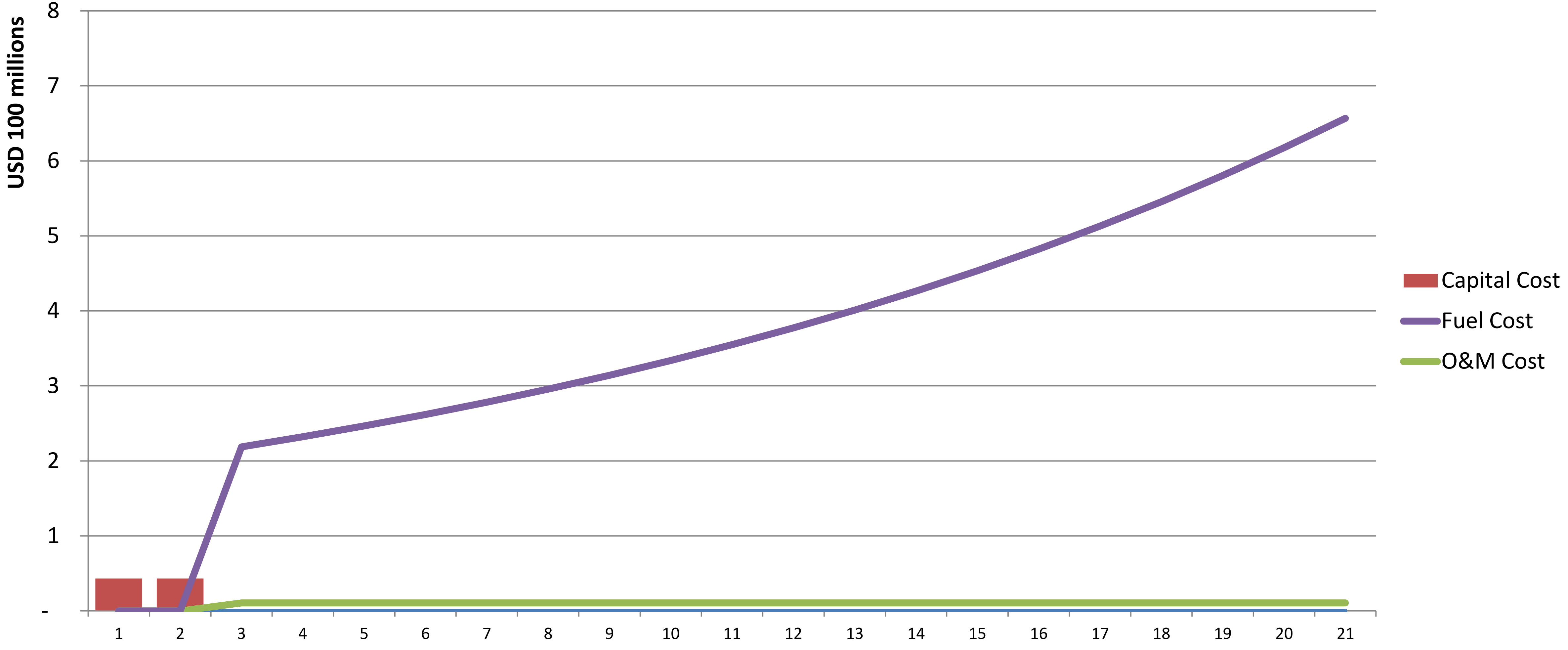
5. Global OTEC Potential & Development: From OPEC to OTEC



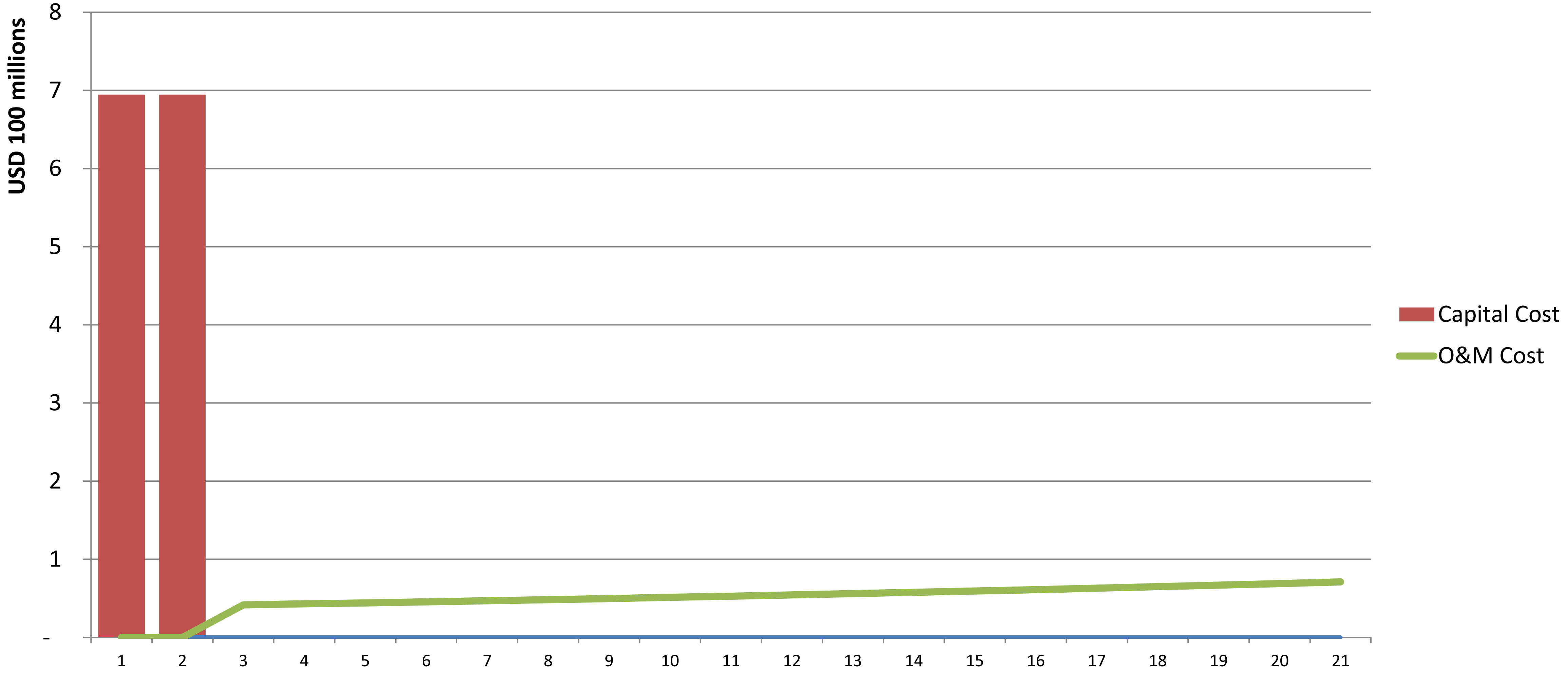
6. THE ECONOMICS OF OTEC vis-à-vis OIL

Investment in OTEC will save more money than that of oil-fired power plant, by 5 times over

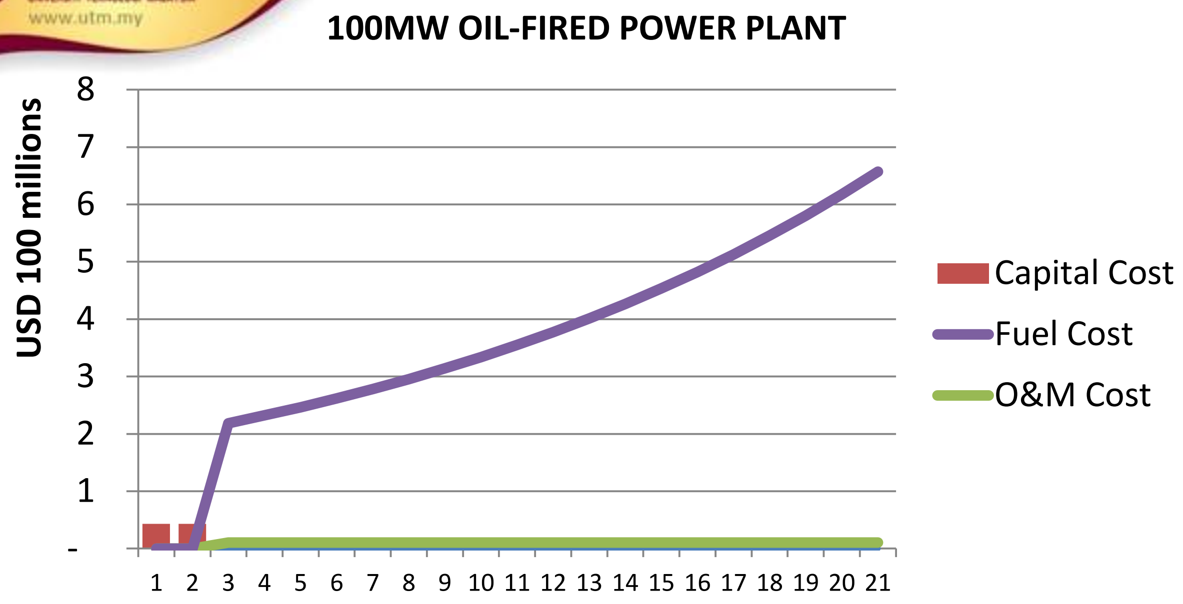
CAPITAL & OPERATING COSTS OVER PROJECT LIFE CYCLE OF 100MW OIL-FIRED POWER PLANT @USD 5 MILLION/MW

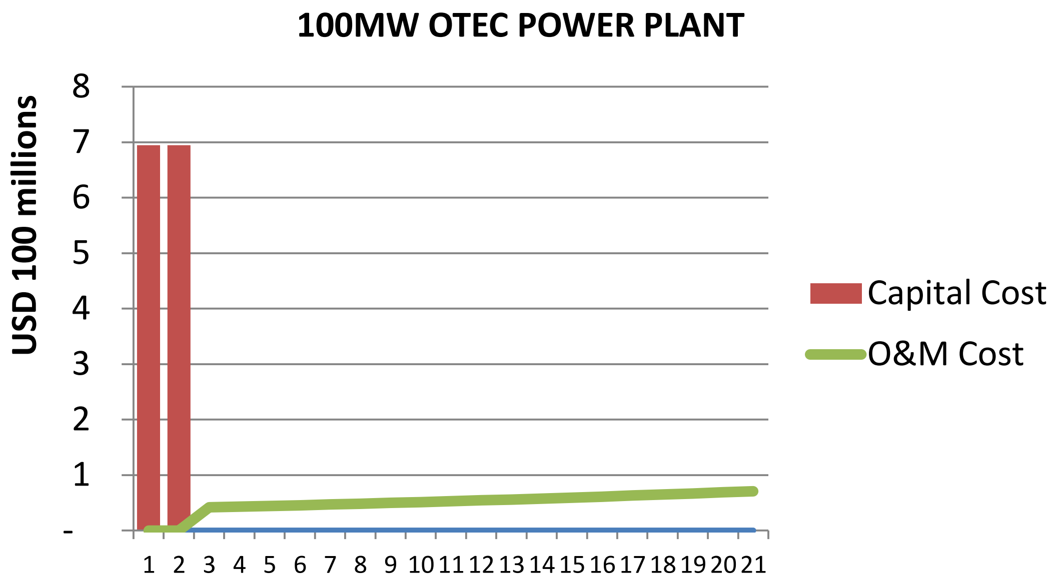


CAPITAL & OPERATING COSTS OVER PROJECT LIFE CYCLE OF 100MW OTEC POWER PLANT @USD 14 million/MW



COMPARATIVE CAPITAL & OPERATING COSTS OVER PROJECT LIFE CYCLE





Total costs (USD) over 21 years of operation

OIL-FIRED POWER	OTEC-POWER
USD 7.5 billion	USD 1.5 billion

Assumptions:
Oil-Fired Power Plant

- O&M Cost relatively stable, at 12% of capital cost, based on feasibility study report
- Capital cost: USD 5 million/MW
- Fuel cost (price of crude oil) increases 6.5% annually, based on geometric mean of past 67 years.
- All crude oil is used to generate electricity, instead of various mixes/ uses.

Assumptions:
OTEC Power Plant

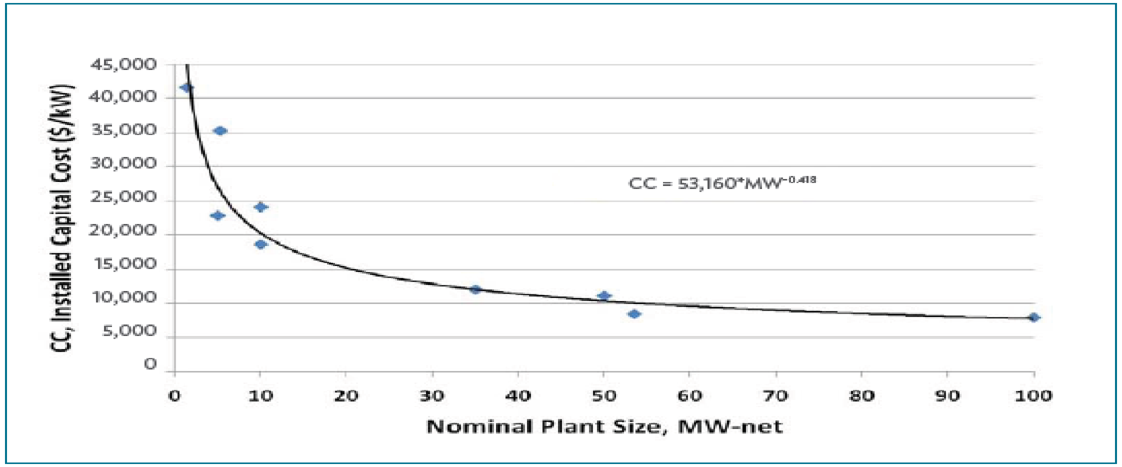
- Cost of O&M is about 3% of capital cost
- Capital cost: USD 14 million/MW

Capital Costs

- These estimates are applicable for equipment purchased in Europe, Japan, or the United States and with installation by United States firms.
- Deployment and installation costs are included.
- Based on the implementation of similar technologies, later-generation designs could reach cost reductions of as much as 30%.

CC (\$/kW) = 53,000 x $MW^{-0.42}$

Figure 12 Capital Cost Estimated for First-Generation Closed-Cycle Ocean Thermal Energy Conversion Plants



CC= capital cost, kW = kilowatt, MW = megawatt.
Source: L. Vega. 2010. Economics of Ocean Thermal Energy Conversion (OTEC): An Update. Paper presented at the Offshore Technology Conference. Houston. 3–6 May.

Table A1.1 First-Generation Ocean Thermal Energy Conversion Plant Capital Cost Estimates

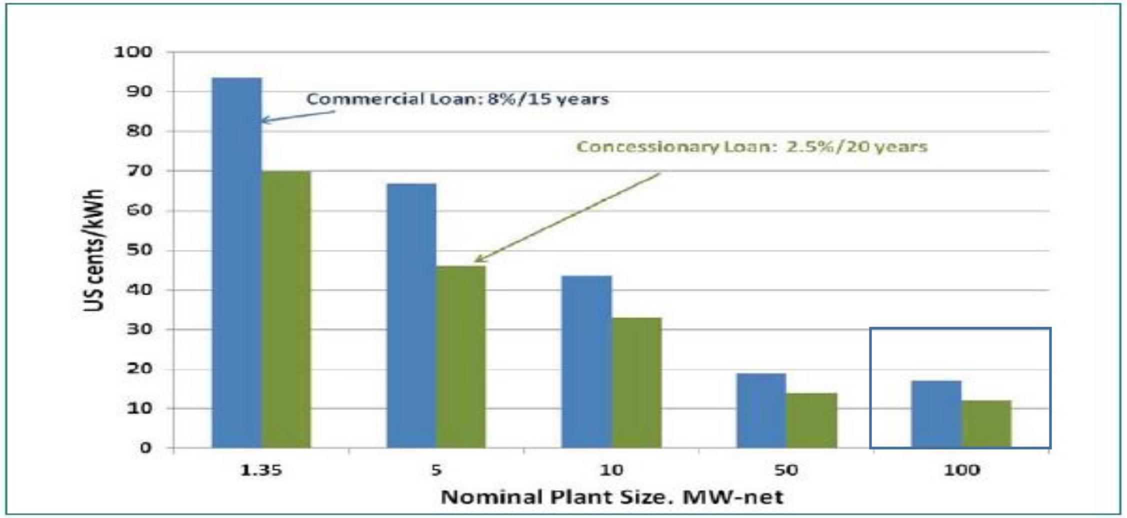
Nominal Plant Size (MW-net)	Installed Capital Cost (\$/kW)	Land/Floater	Source (Extrapolated)
1.4	41,562	L	Vega (1992)
5	22,812	L	Wenzel (1995)
5.3	35,237	F	Vega et al. (1994)
10	24,071	L	Vega (1992)
10	18,600	F	Vega (2010)
35	12,000	F	"
50	11,072	F	Vega (1992)
53.5	8,430	F	Vega (2010)
100	7,900	F	"

kW = kilowatt, MW = megawatt.
Note: Extrapolated archival estimates (1 –50 MW) and current estimates (10–100 MW) in \$/kW-net.

Levelized Cost

- The annual costs for operation and maintenance, are estimated **at $40 million.**
- Electricity could be produced at a levelized cost of less than **$0.17/kWh**.
- If the plant could be funded via a concessionary loan with a rate of 2.5% over 20 years, the levelized cost of electricity would be **$0.12/kWh.**
- Power purchase agreement from the national utility at around **$0.20/kWh** would provide an ample return on investment.

Figure 13 Levelized Cost of Electricity Production for First-Generation Closed-Cycle Ocean Thermal Energy Conversion Plants as a Function of Plant Size with Loan Terms as Parameters



kWh = kilowatt-hour, MW = megawatt.
Note: Annual inflation assumed constant at 3%.

Table A1.2 Levelized Cost of Electricity for Closed-Cycle Ocean Thermal Energy Conversion Plants

Identifier Nominal Size (MW)	Capital Cost ($/kW)	O&M ($ million/ year)	R&R ($ million/ year)	COE_{cc} (¢/kWh)	$COE_{omr\&r}$ (4/kWh)	COE (¢/kWh)
1.35	41,562	2.0	1.0	60	38.7	94.0
5	22,812	2.0	3.5	33	17	50.0
10	18,600	3.4	7.7	26.9	16.8	44.0
53.5	8,430	3.4	20.1	12.2	6.7	19.0
100	7,900	3.4	36.5	11.4	6	18.0

8%/15 years

COE = cost of electricity, kW = kilowatt, kWh = kilowatt-hour, MW = megawatt, O&M = operation and maintenance
OMR&R = operation maintenance repair and replacement, R&R = repair and replacement.

Notes: With capital costs amortized through an 8%, 15-year loan and annual inflation at 3%, considering United States labor rates for operation and maintenance and first-year repair and replacement cost as indicated. The first two entries are land-based with lower operation and maintenance.

Source: L. Vega. 2010. Economics of Ocean Thermal Energy Conversion (OTEC): An Update. Paper presented at the Offshore Technology Conference. Houston. 3–6 May.

50MW Capital Cost Estimate

Table A1.3 50-Megawatt Closed-Cycle and Open-Cycle Ocean Thermal Energy Conversion Capital Cost Estimates

	Closed Cycle				
Size	53.5 MW-net				
Date	Feb 2009				
Component	$ million	$/kW	Percentage	Ops 1st Year ($ million)	Replacement 1st Year ($ million)
Floating Vessel	100	1,869	22%		3.3
Mooring	24	449	5%		0.8
Submarine Power Cable (10 km)	41	766	9%		1.4
Seawater Pipes Installed	60	1,121	13%		2.0
Seawater Pumps Installed	24	449	5%		1.6
Power Block (15 MW-gross modules)					
Heat Exchangers	95	1,776	21%		6.3
Turbine-Generator	33	617	7%		2.2
Electrical/NH3/Cl2/Controls	31	579	7%		1.0
Installation Mechanical and Electrical	43	804	10%		1.4
All Components Total	**451**	**8,430**	**100%**	**3.4**	**20.1**
					15-year 30-year

Cl2 = chlorine, km = kilometer, kW = kilowatt, MW = megawatt, NH3 = ammonia.

Notes:

Capital Cost

* Vega's archival information for manufacturers from the European Union, Japan, and the United States.
* At the conceptual level, the capital cost for the open cycle plant will double the cost of a floating vessel.
* Assume the sum of all other cost are equivalent to closed cycle. Therefore, the capital cost for the open cycle plant is $551 million.

Operations, Maintenance, Repair, and Replacement (OMR&R)

* A total staff of 17 is required to manage and operate the floating plant in shifts 24/7.

Using United States labor rates, the operations and maintenance portion for the first year is $3.4 million (for both open cycle ocean thermal energy conversion and closed cycle ocean thermal energy conversion).

* To estimate the repair and replacement (R&R) portion for the first year: pumps, heat exchangers, and turbine generators replaced in 15-years; all other components in 30 years.

First-year estimate for R&R portion is (as given in table) $20.1 million for CC-OTEC and $23.4 million for OC-OTEC.

If vessel and heat exchangers are manufactured in the People's Republic of China, the R&R portion would be $17.7 million instead of $20.1 million.

Source: Author.

50 MW Production rates of OTEC

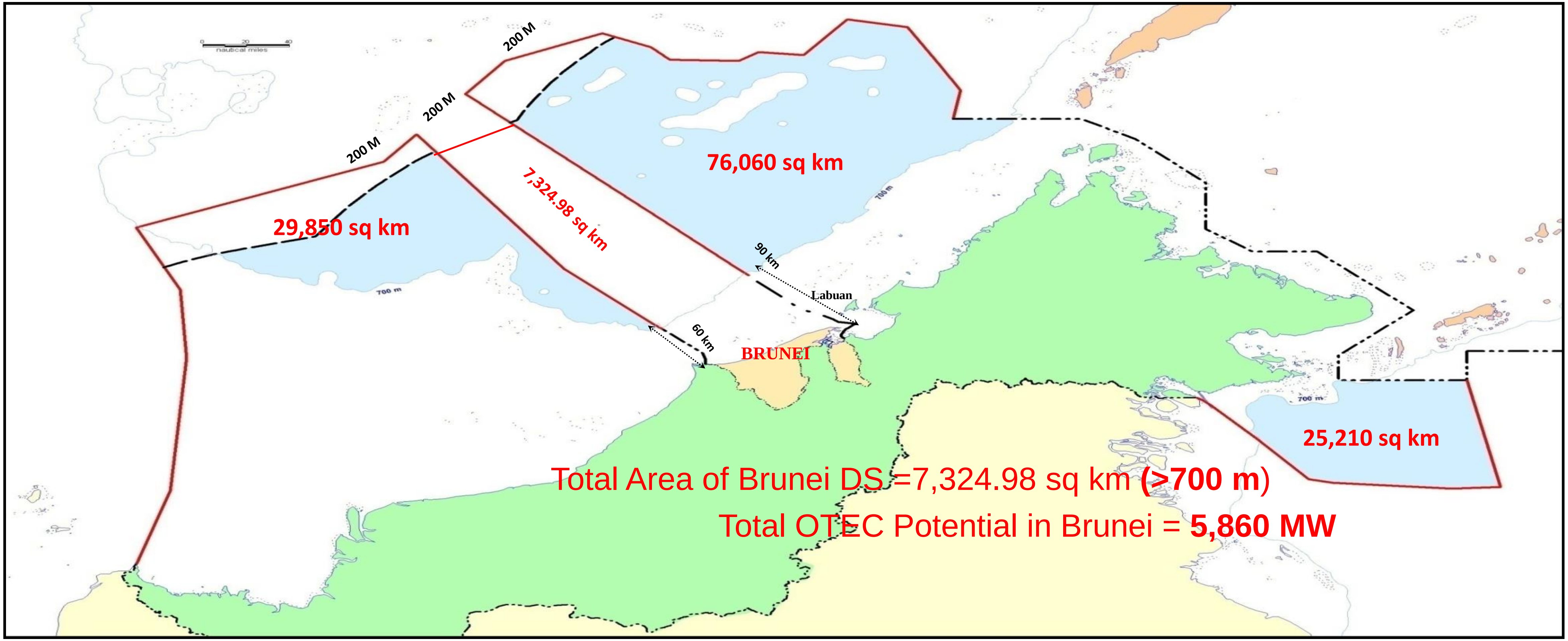
Table 10 Electricity and Desalinated Water Production Rates for Ocean Thermal Energy Conversion

System	Electricity (MWh/year)	Water (m^3/day)	Capital Cost ($/$kW_{net}$)
Closed Cycle	**432,609**	**0**	**8,430**
(53.5 MW)			
Open Cycle	**414,415**	**118,434**	**10,751**
(51.25 MW)			
(1,485 kg/s)			

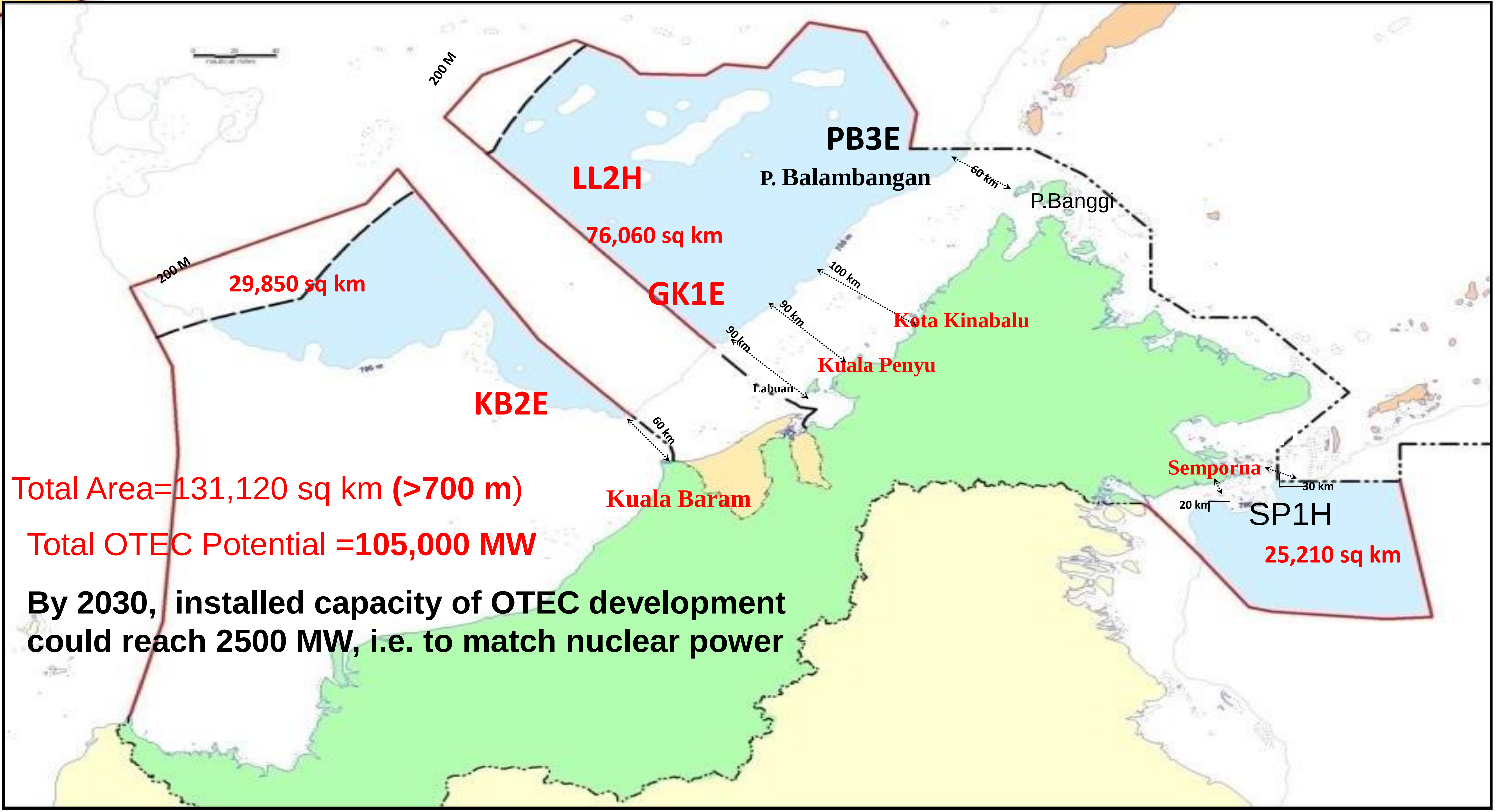
kg = kilogram, kW = kilowatt, m^3 = cubic meters, MW = megawatt, MWh = megawatt-hour, s = second.
Data generated by author.

100 MW ~ 828,830 MW h/year Electricity
100 MW~ 236,868 m^3/day Water

7. OTEC Potential Malaysia & in Brunei DS



OTEC POTENTIAL IN MALAYSIA &THE FIRST FIVE OTEC POTENTIAL SITES

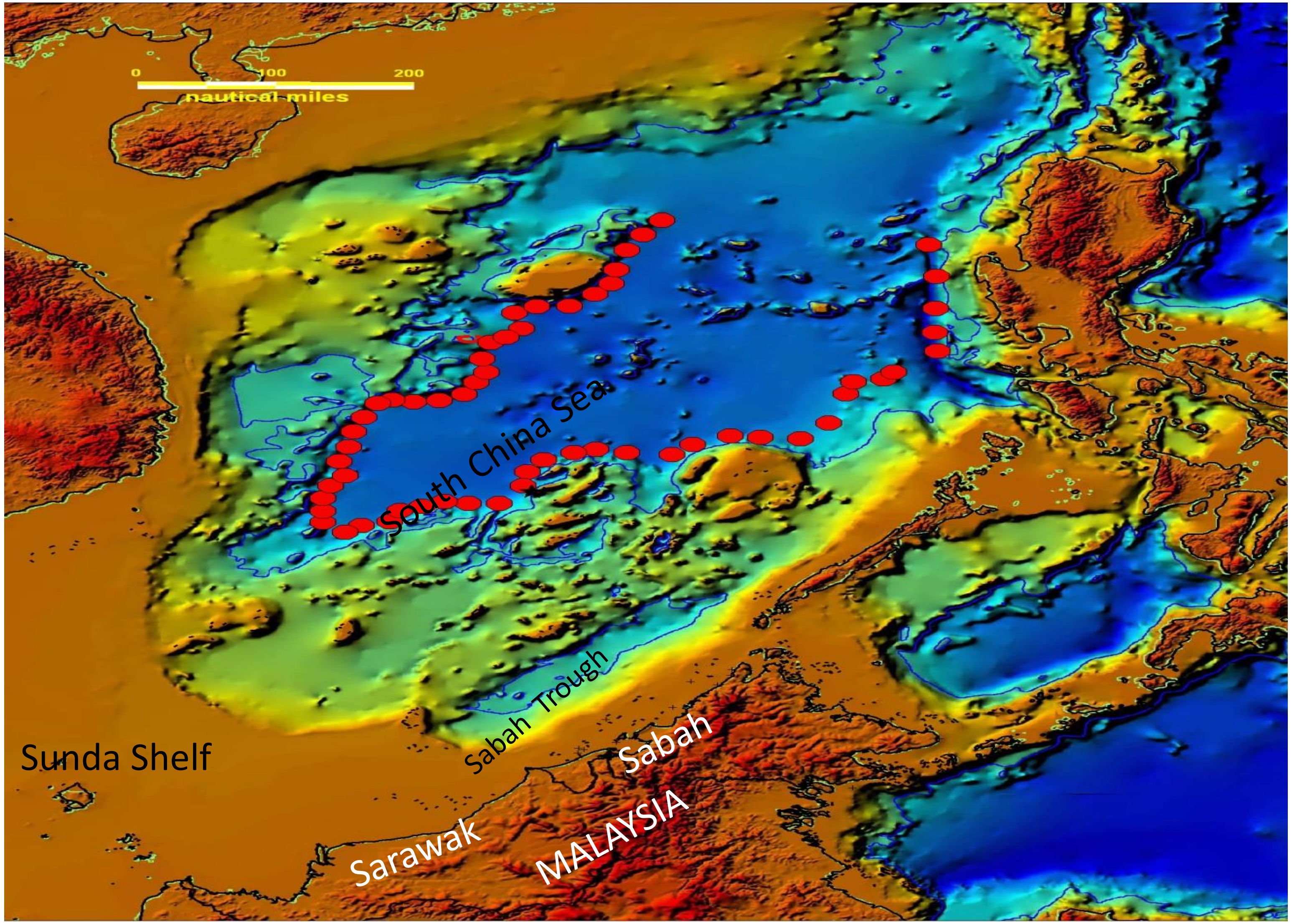


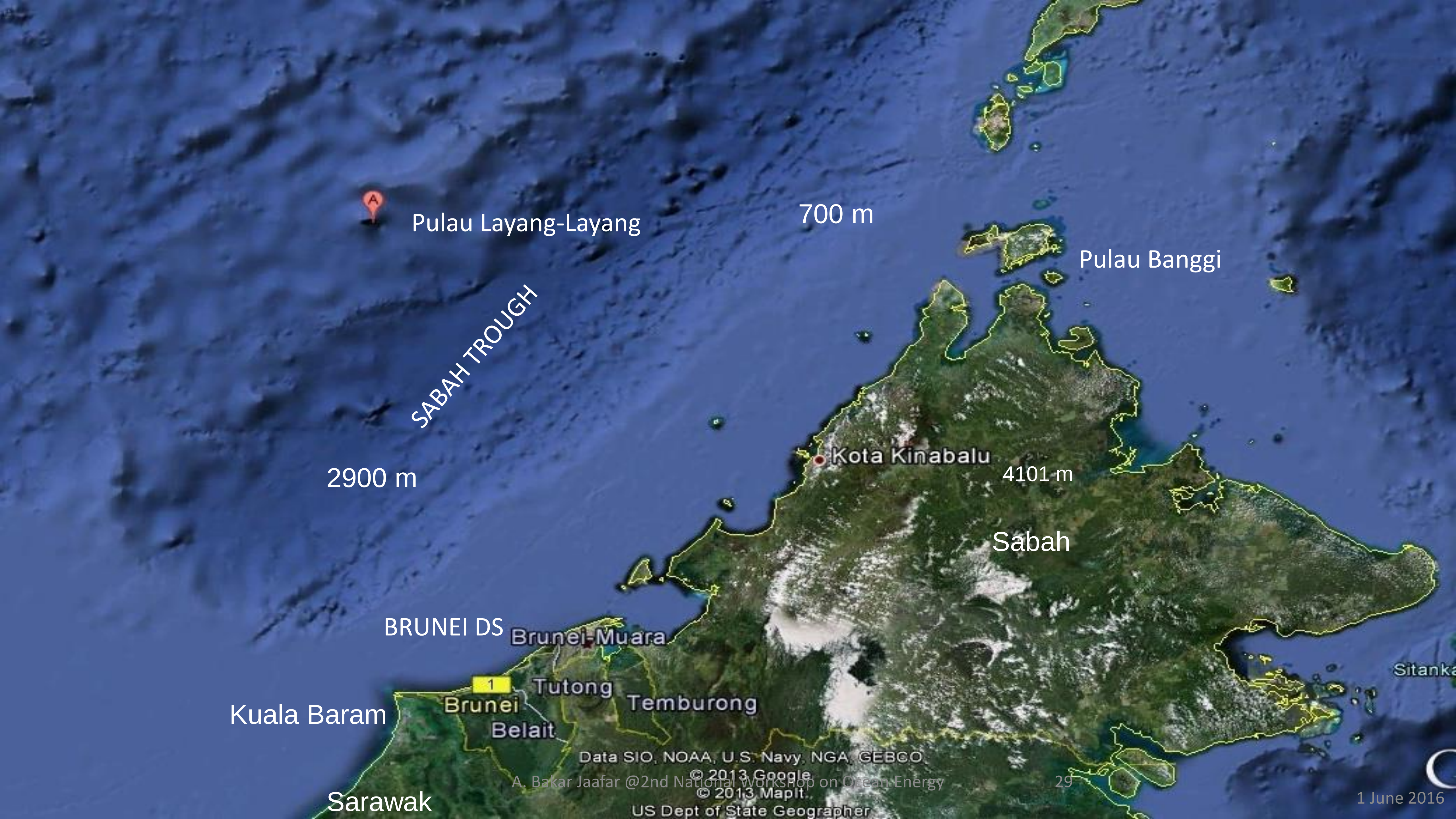
Total Area=131,120 sq km **(>700 m)**

Total OTEC Potential =**105,000 MW**

By 2030, installed capacity of OTEC development could reach 2500 MW, i.e. to match nuclear power

Malaysian Marine Survey of South China Sea (MyMRS) 2006-2008




Pulau Layang-Layang
700 m
Pulau Banggi
SABAH TROUGH
Kota Kinabalu
4101 m
2900 m
Sabah
BRUNEI DS
Brunei-Muara
Tutong
Temburong
Brunei
Belait
Kuala Baram
Sarawak
Data SIO, NOAA, U.S. Navy, NGA, GEBCO
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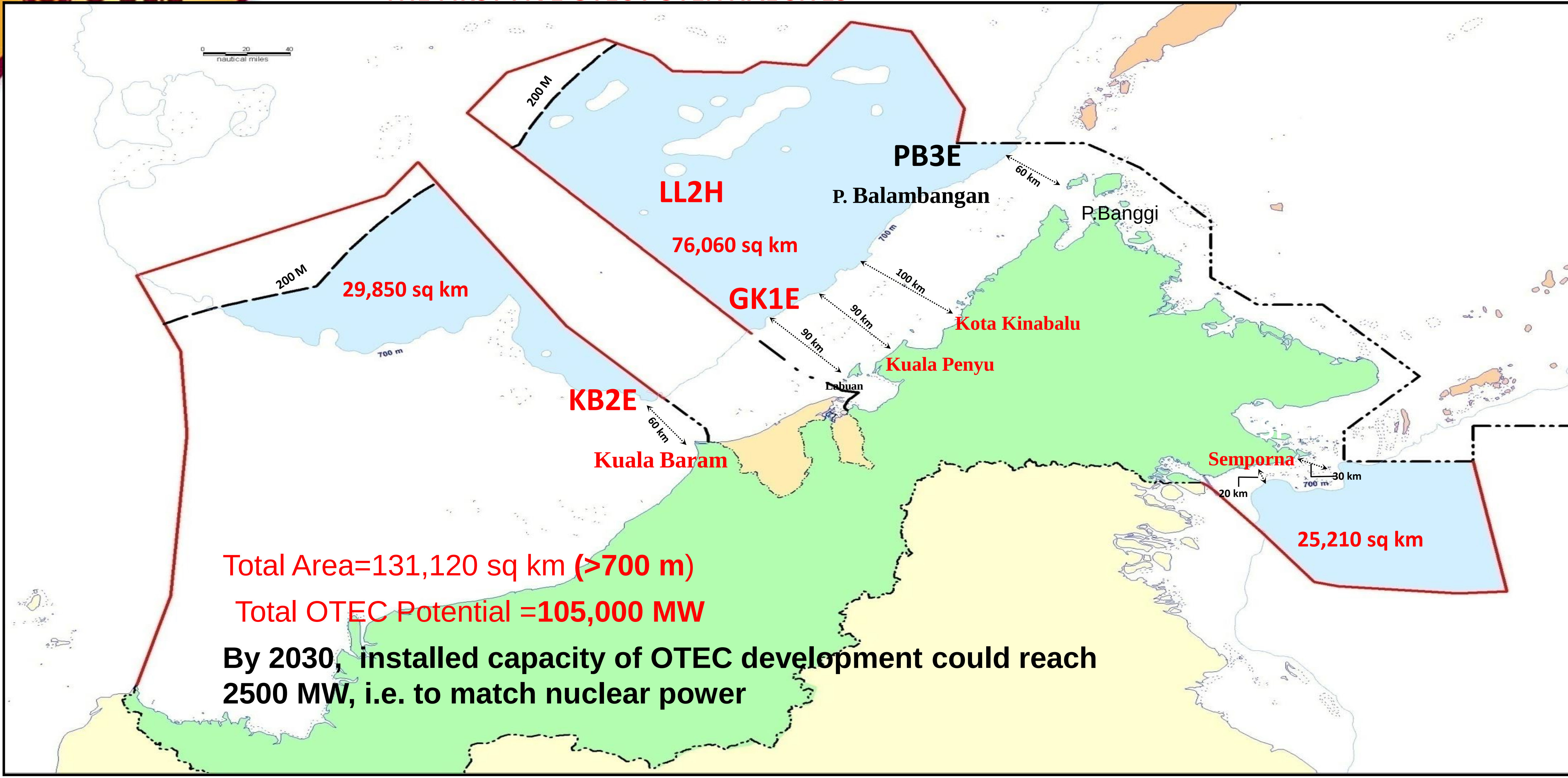
US Dept of State Geographer

THE FIRST FIVE OTEC POTENTIAL SITES



Total Area=131,120 sq km (**>700 m**)

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Innovative ● entrepreneurial ● global

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Baseline 50 MW- Closed OTEC System

Table 11 Baseline 50-Megawatt Closed-Cycle Ocean Thermal Energy Conversion for Levelized Cost of Electricity under a Commercial Loan

Current-Dollar Levelization (constant annual cost)		
Inputs in Blue	Output in Red	
System Net Name Plate	53.5 MW	SOA Components
System Availability	92.3%	4 weeks downtime/ module
Site Annual Average Capacity Factor	100.0%	Design Selection
Annual Electricity Production	432,609 MWh	
Daily Desalinated Water Production	0.00 MGD	
	0 m^3/day	
Installed Cost (CC)	$451.00 million	8,430 $/kW
1st Year OMR&R	$23.50 million	
I, interest (current-dollar discount rate)	8.00%	
ER, annual escalation (inflation) rate for entire period	3.00%	All elements
N, system Life	15 years	
Capital Payment		
Investment Levelizing Factor for I and N (Capital Recovery Factor)	11.68%	
Levelized Investment Cost (CC x CRF)	$52.690 million	"Annual Amortization"
COE_{cc} : Fixed CC Component of COE	0.122 $/kWh	
OMR&R Costs		
Expenses Levelizing Factor for I, N, and Escalation (ELF)	1.22	
Capital Recovery Factory, f (I,N)	11.68%	
Present Worth Factor accounting for Inflation, f (I,ER,N)	10.5	
Levelized Expenses Cost (OMR&R x ELF)	$28.780 million	"Annual Levelized OMR&R"
$COE_{omr\&r}$: Levelized OMR&R Component of COE	0.067 $/kWh	
Total (CC + OMR&R) Levelized Annual Cost of Electricity Production	$81.470 million	

Total Levelized Cost of Electricity (no profit; no environmental or tax credits)
$COE = COE_{cc} + COE_{omr\&r} = 0.188$ $/kWh

CC = capital cost, COE = cost of electricity, CRF = capital recovery factor, kW = kilowatt, kWh = kilowatt-hour, m^3 = cubic meter, MGD = million gallons per day, MW = megawatt, MWh = megawatt-hour, OMR&R = operation and maintenance repair and replacement costs.

Source: Author.

Baseline 50 MW- Open OTEC System

Table 12 Baseline 50-Megawatt Open-Cycle Ocean Thermal Energy Conversion, Break-Even Electricity, and Water Rates Required under a Commercial Loan

Current-Dollar Levelization (constant annual cost)		
Inputs in Blue	Output in Red	
System Net Name Plate	51.25 MW	SOA Components
System Availability	92.3%	Experimental Plant
Site Annual Average Capacity Factor	100.0%	Design Selection
Annual Electricity Production	414,415 MWh	
Daily Desalinated Water Production	31.29 MGD	
	118,434 m^3/day	
Installed Cost (CC)	$551.00 million	10,751 $/kW
Yearly OMR&R	$26.80 million	
I, interest (current-dollar discount rate)	8.00%	
ER, annual escalation (inflation) rate for entire period	3.00%	All elements
N, system Life	15 years	
Capital Payment		
Investment Levelizing Factor for I and N (Capital Recovery Factor)	11.68%	
Levelized Investment Cost (CC x CRF)	$64.373 million	"Annual Loan Amortization"
OMR&R Costs		
Expenses Levelizing Factor for I, N and Escalation (ELF)	1.22	
Capital Recovery Factor, f (I,N)	11.68%	
Present Worth Factor accounting for Inflation, f (I,ER,N)	10.5	
Levelized Expenses Cost (OMR&R x ELF)	$32.821 million	"Annual Levelized OMR&R"
Total (CC + OMR&R) Annual Cost of Electricity and Water Production	**$97.194 million**	
		Rates
Breakeven Annual Sales (no profit, no credits)		
Electricity	$62.991 million	0.152 $/kWh
Water	$34.263 million	3.0 $/kilogallon
Total Annual Sales	**$97.254 million**	

CC = capital cost, COE = cost of electricity, CRF = capital recovery factor, kW = kilowatt, kWh = kilowatt-hour, m^3 = cubic meter, MGD = million gallons per day, MW = megawatt, MWh = megawatt-hour, OMR&R = operation and maintenance repair and replacement costs.

Source: Author.

8. AN OVERVIEW OF OCEAN ENERGY BY TYPE

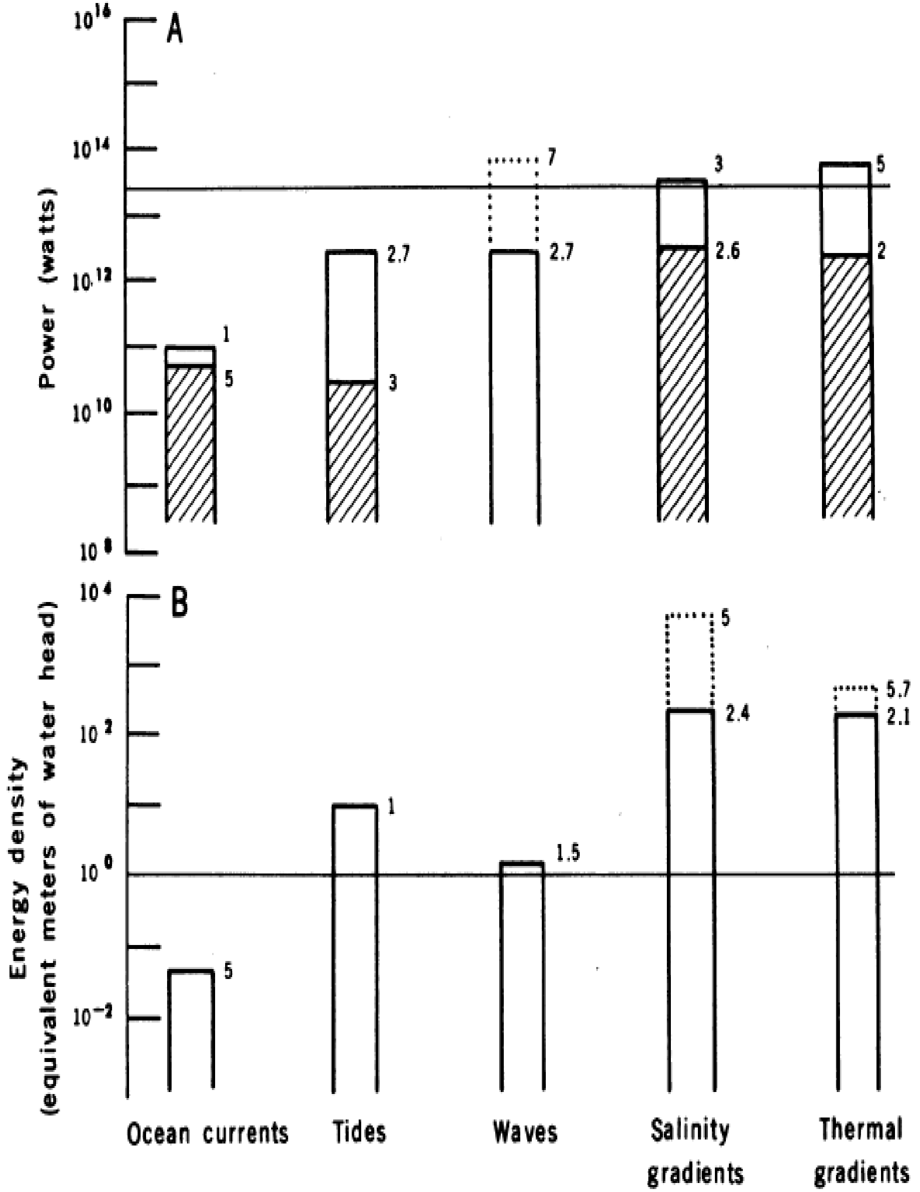

Fig. 1. (A) Power or energy flux for ocean energy. On the "ocean currents" bar, the shading represents the power contained in concentrated currents such as the Gulf Stream. Estimated feasible tidal power is also shaded. The dotted extension on "waves" indicates that wind waves are regenerated as they are cropped. "Salinity gradients" includes all gradients in the ocean; the large ones at river mouths are shown by shading. Not shown is the undoubtedly large power that would result if salt deposits were worked against freshwater or seawater. On "thermal gradients," the shading indicates the unavoidable Carnot-cycle efficiency. The horizontal line at 30×10^{12} watts is a projected global electricity consumption for the year 2000. (B) Intensity or concentration of energy expressed as equivalent head of water. "Ocean currents" shows the velocity head of major currents. For tides, the average head of favorable sites is given. For waves, the head represents a spatial and temporal average. The salinity-gradients head is for freshwater versus seawater, the dotted extension for freshwater versus brine (concentrated solution). The thermal-gradients head is for 12°C; that for 20°C is dotted; both include the Carnot efficiency. [From Wick and Schmitt (22)]

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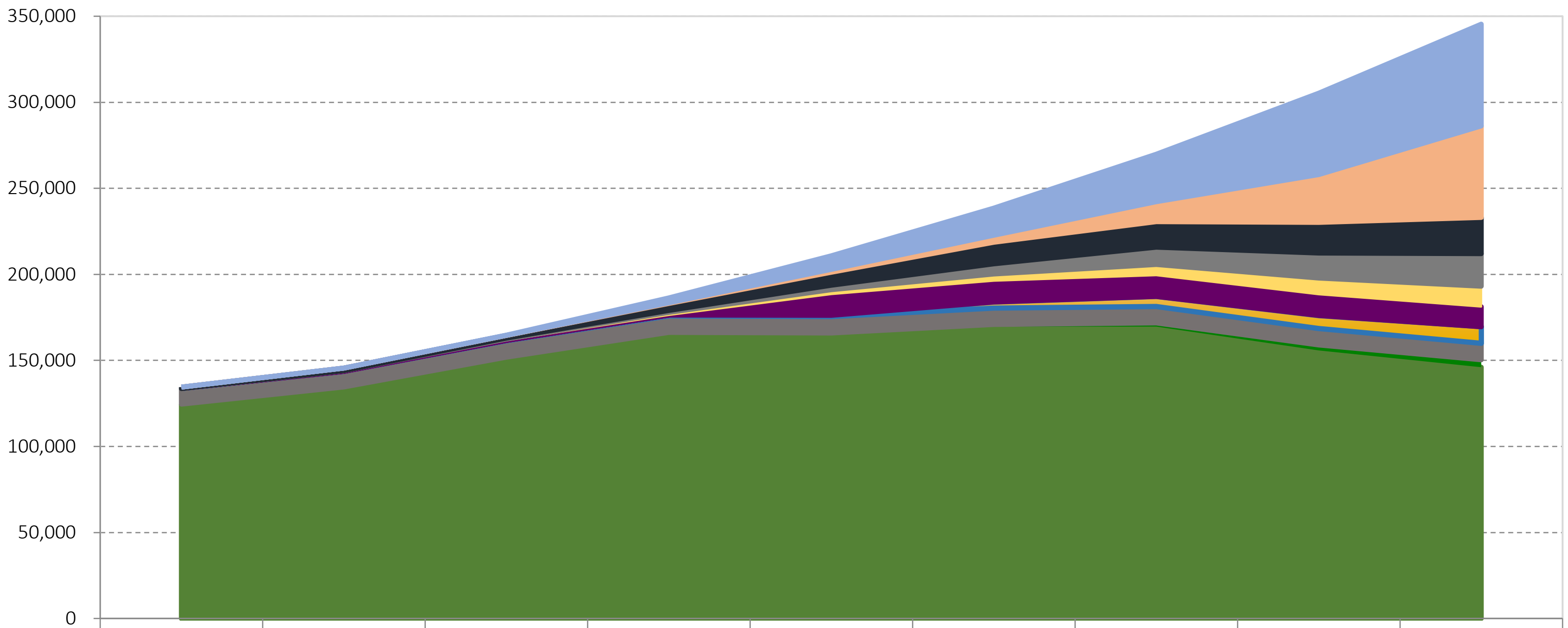
9. THE WAY FORWARD FOR OCEAN ENERGY DEVELOPMENT IN THE TROPICS: ORDER OF PRIORITY

1. Ocean Thermal Energy Conversion (OTEC)
2. Tidal & Ocean Currents
3. Offshore Wind
4. Salinity Gradient, OTEC SpinOff
5. Marine Algae, OTEC SpinOff
6. Wave

Future Target and Proposed Roadmap for OTEC in Malaysia 2020-2050 [As at 24 April 2015][Revised after ASM CFE Workshop by Dato' Ir Dr A Bakar Jaafar]

Year	Capacity (MW)	Growth Rate (%)	Remark
2020	20	-	2x10 MW public-private RMK-11
2025	850	-	For 7% reduction in carbon intensity
2030	2500	14	To match nuclear power
2035	5000	14	To match nuclear power
2040	10000	14	To meet H2 demand
2045	20000	14	
2050	40000	14	

Malaysia: Projected Electricity Generation by Energy Source (GWh) 2012-2050

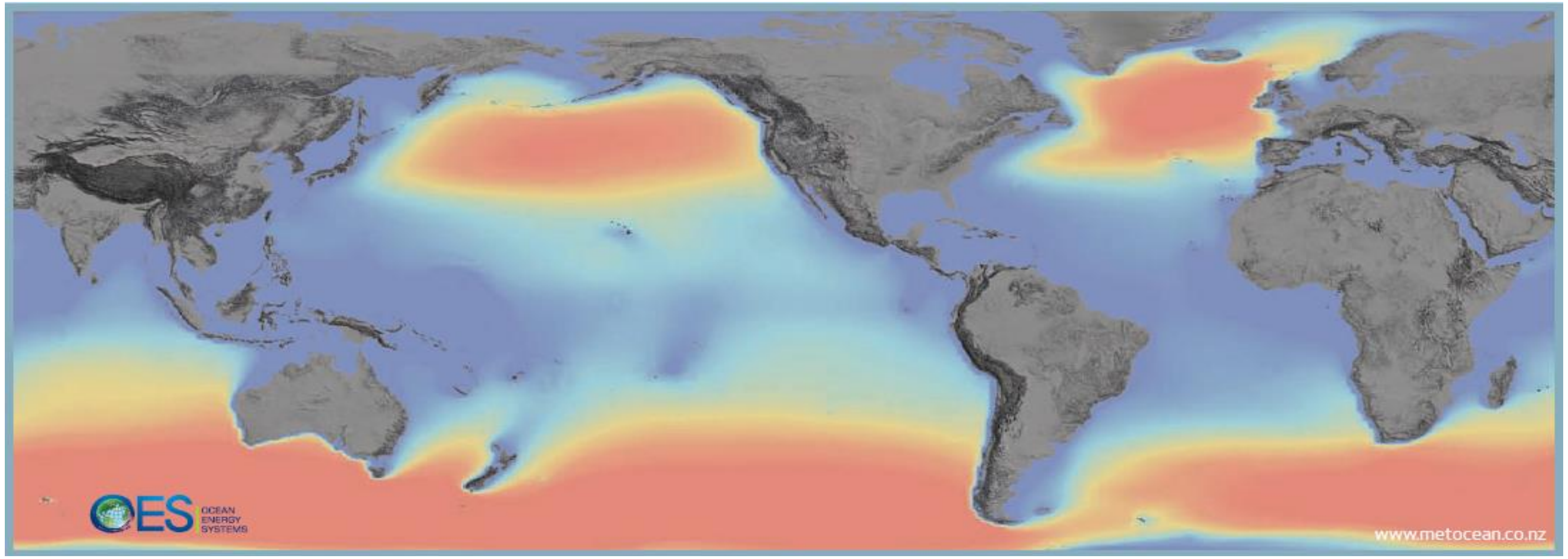


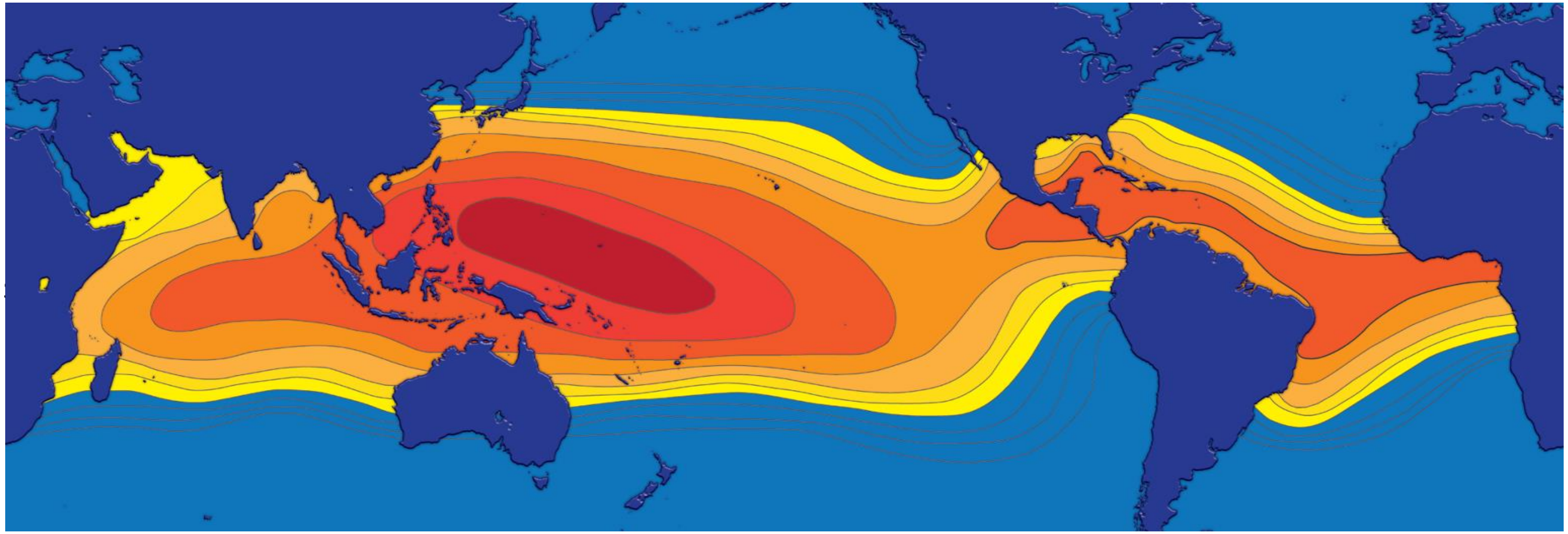
	2012	2015	2020	2025	2030	2035	2040	2045	2050
OTEC	0	0	134	2,848	7,884	15,768	27,594	47,304	59,129
Fuel Cell	0	0	16	354	1,665	4,054	11,603	27,782	53,194
Bioenergy	809	1,455	1,567	4,088	7,553	12,535	14,832	17,823	21,049
Wind Energy	0	0	547	1,095	2,601	5,913	10,052	14,520	18,922
Solar PV	7	437	790	1,579	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

Source: ASM Task Force on Carbon Free Energy (2015)

Region			
Temperate	OTEC	SOLAR WAVE	TIDAL WIND
Sub-Tropic	TIDAL	SOLAR OTEC WAVE	WIND
Tropic	WAVE WIND	SOLAR TIDAL	OTEC
	LOW	MEDIUM	HIGH

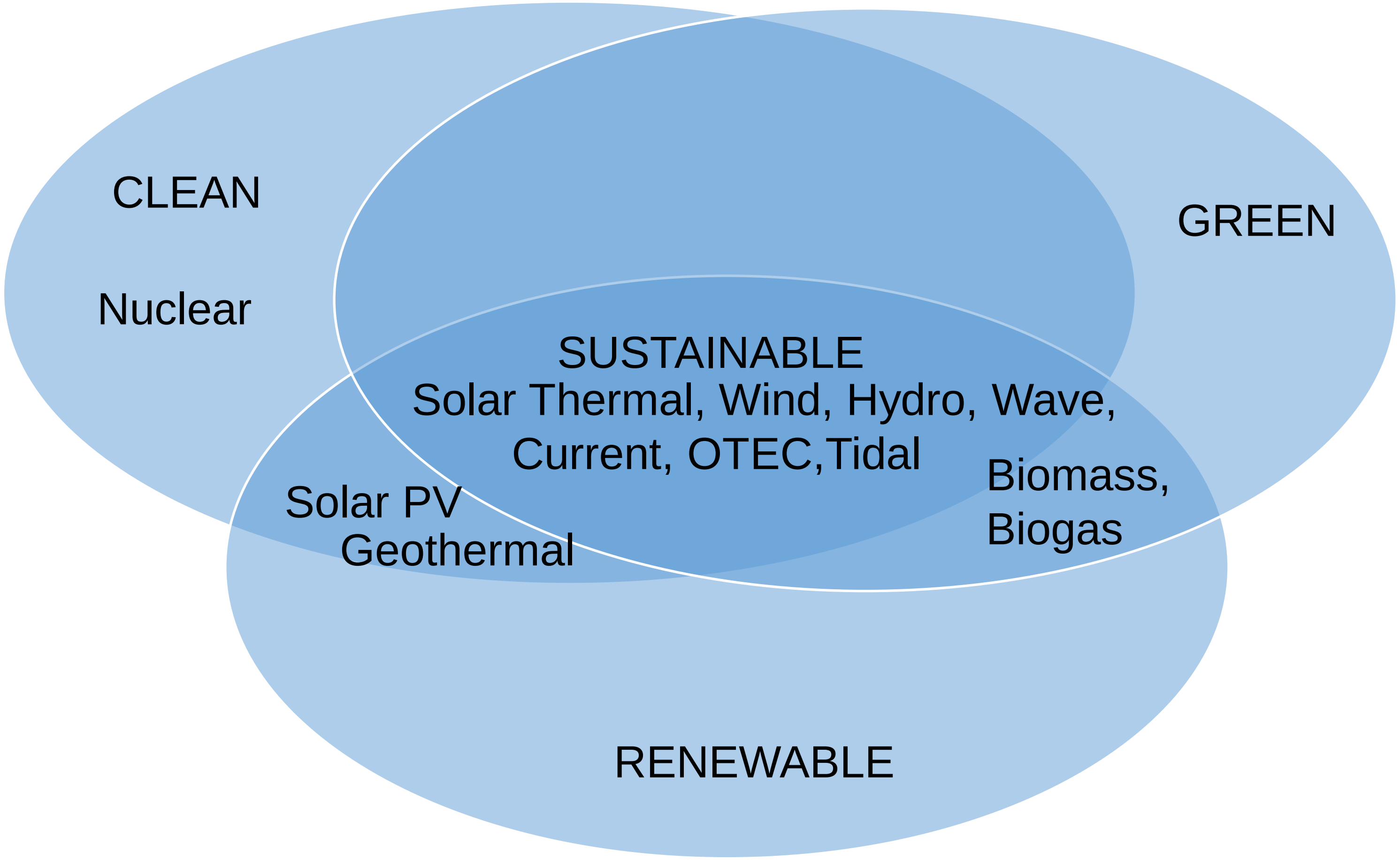
Wave Power Potential in Temperate Regions





OTEC Potential in the Tropics & Subtropics

FORMS OF ENERGY & CLASSIFICATION



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COMPARATIVE COSTS & INVESTMENT BY TYPE OF OCEAN ENERGY

[USD/kWh]

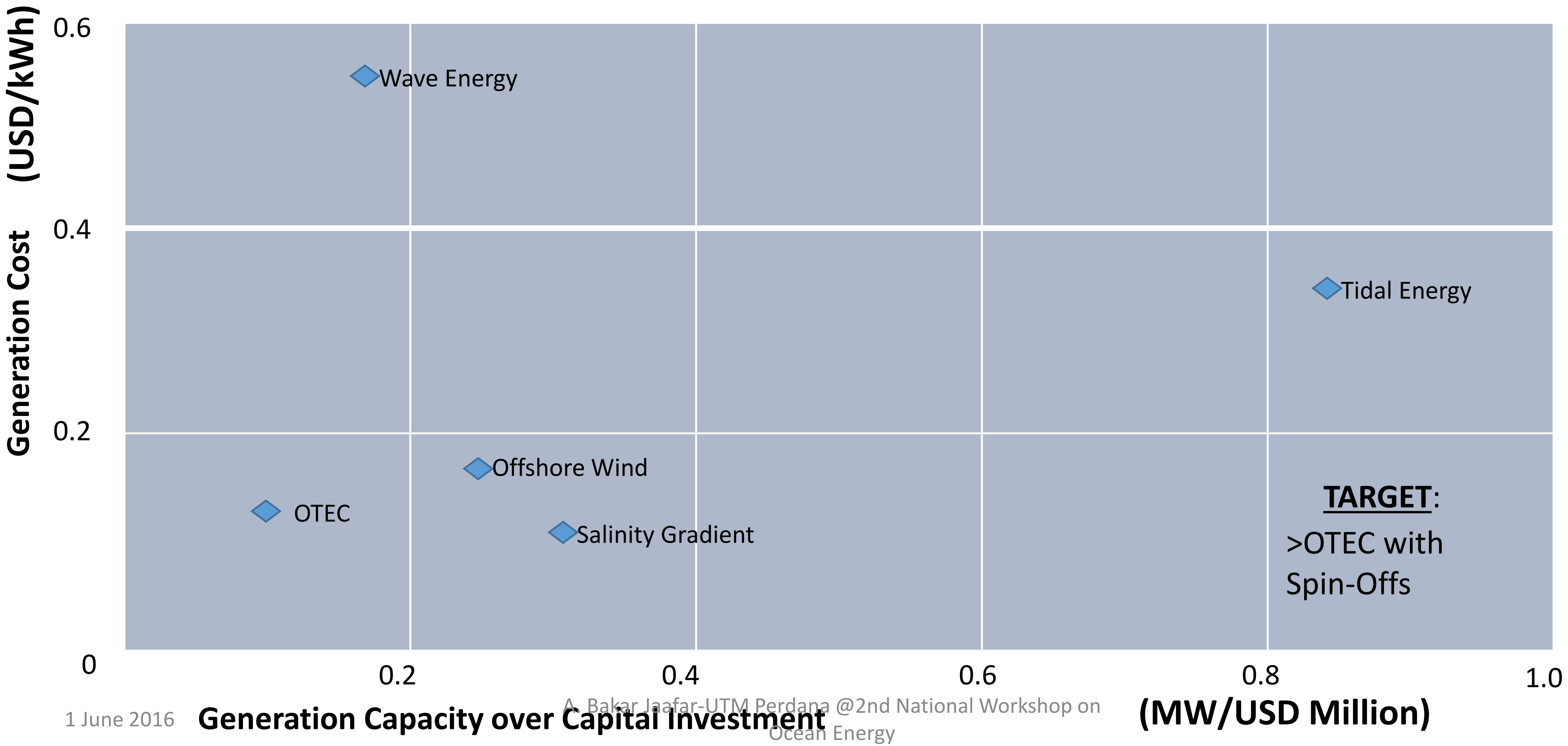
Cost of Generation

WAVE		
	TIDAL CURRENT OCEANIC CURRENT OFFSHORE WIND	
		SALINITY GRADIENT OTEC

Generation Capacity/Capital Input

[MW/USD million]

Ocean Energy Production Cost & Generation Capacity over Capital Investment



Ocean Energy	Input			Output Cost of Ocean Energy (USD/KWh)
	Generation Capacity (MW)	Capital Investment (Million USD)	MW/Million USD	
Wave Energy	10	62.75	**0.16**	**0.561**
Tidal Energy	254	298	**0.85**	**0.28**
Offshore wind	10	40	**0.25**	**0.165**
OTEC	53	451	**0.12**	**0.13**
Salinity gradient	200	600	**0.33**	**0.09**

kWh = kilowatt-hour, MW =megawatt
Source: Asian Development Bank Report & IRENA Technology Brief

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Thank You Merci Gracias спасибо 谢谢 شكر
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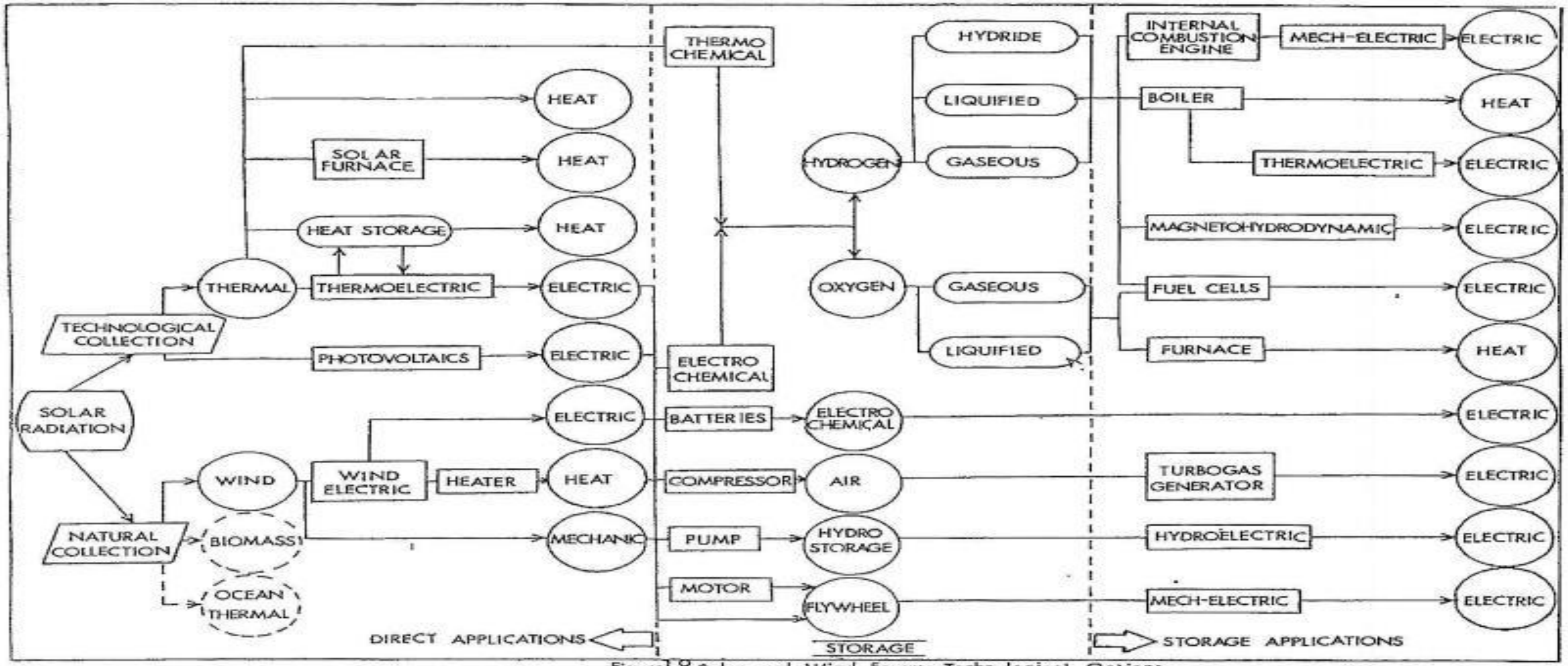

Figure 18 Solar and Wind Energy Technological Options

[Ref: Abu Bakar Jaafar (1976). "Applicability of Solar Energy Technology for Industrial Pollution Control and Production: The Case of the Primary Copper Smelting Industry". An Internship Report. Submitted to the Faculty of Miami University in par tial fulfillment of the requirements for the degree of Master of Environmental Science Institute of Environmental Sciences. Oxford, Ohio. P.82]

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