Webinar

Friday 14 May 2pm (Manila Time)

Harnessing Marine Renewable Energy

By Dr Michael Abundo

Marine Renewable Energy (MRE) is a necessary step towards decarbonization and the growth of the Blue Economy. Mike will share his insights into the economics of various MRE technologies, resources available, choosing sites, and the drivers for MRE industry development.

Dr Michael Abundo is Managing Director of OceanPixel Pte Ltd, Singapore. He has extensive experience in marine energy applications and R&D in IoT, Drones, all forms of MRE and the Blue Economy.

If you are unable to attend, a recording of the Webinar will be available at https://events.development.asia/learning-events/mining-offshore-renewable-energy

MARES Webinar Series

Harnessing Marine Renewable Energy

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OceanPixel

Enabling Sustainability through Data Intelligence

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Supporting Sustainable Transformations

OceanPixel

Supporting Sustainable Transformations

Enabling Sustainability through Data Intelligence

fluid . energy . intelligence

NANYANG TECHNOLOGICAL UNIVERSITY

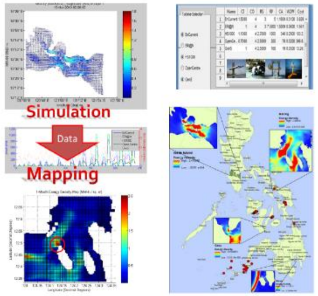
Energy Research Institute @ NTU

OceanPixel is a Singapore start-up that was incorporated in 2014, having spun-off from the Energy Research Institute at NTU.

The core team has combined expertise in sustainable energy research, development, demonstration, project development and experience in the relevant industry ecosystem, business, finance, policy and education.

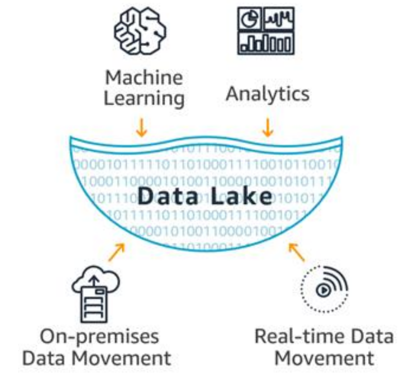
OceanPixel believes in the development of **Sustainable Ecosystems**, and supports these efforts by offering **Data Management** technologies and services coupled with **Suitability Analytics**, data catalogues, report products and technical services. OceanPixel has various global involvements, but is currently focused in South East Asia, handling projects in Singapore, Philippines and Indonesia.

With OceanPixel's capabilities, we provide *Multi-Site, Multi-Device, Multi-Criteria GIS Decision Approach* to project development.



- **Resource Data**
  - Integration
  - Processing
  - Analysis
- **Device Database**
  - Mechanical Specs
  - Electrical Specs
  - Cost
- **Installation**
  - Distance to Port
  - Distance to Shore (Grid)
- **Constraints**
  - Navigation & Shipping
  - Marine Protected Areas
  - Depth Constraints
- **Suitability Scoring**
  - "Best Site" Nomination
  - "Best Technology"
  - "Best Device"
  - Least Cost Analysis

BLUE ECONOMY



- 'Oceans' of Data.
- Multiple 'Ecosystems'.
- Visualized and Understood.

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Marine Renewable Energy (MRE)

*"Renewable energy production which makes use of marine resources or marine space."**

*European Science Foundation

- Offshore Wind
- Floating Solar
- Marine biomass

(micro- and macro-algae)

Ocean Renewable Energy (ORE)

- Currents (Ocean Current, Tidal Currents/In-Stream)
- Tides (Tidal Range)
- Waves
- Salinity / Osmotic Gradient
- Thermal Gradient

MRE ≠ ORE

ORE is a subset of MRE.

Ocean Renewable Energy

5 Ocean Renewable Energy Resources*


Tidal / Marine Current

800+ TWh/yr


Waves

80,000 TWh/yr


Salinity Gradient

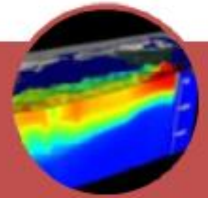
2,000 TWh/yr

- **Ocean Current / Tidal In-Stream** energy is harvested by Current/Hydrokinetic turbines placed underwater where fast-flowing currents turn the generator blades similar to what wind does with wind turbines.
- **Tides (Tidal Range)** Tidal Barrages utilize the potential energy from the difference in height between high and low tides.
- **Wave** energy is produced from the surface motion of ocean waves or from pressure fluctuations below the surface.
- **Ocean Thermal** energy conversion (OTEC) uses the temperature difference between the surface seawaters (warm) and the deep seawaters (cool) to drive a heat engine to produce electricity.
- **Salinity Gradient** power is the available energy (or chemical potential) from the differences in salt concentration between the fresh water and seawater.


Tides or

Tidal Range (Barrage)

300+ TWh/yr

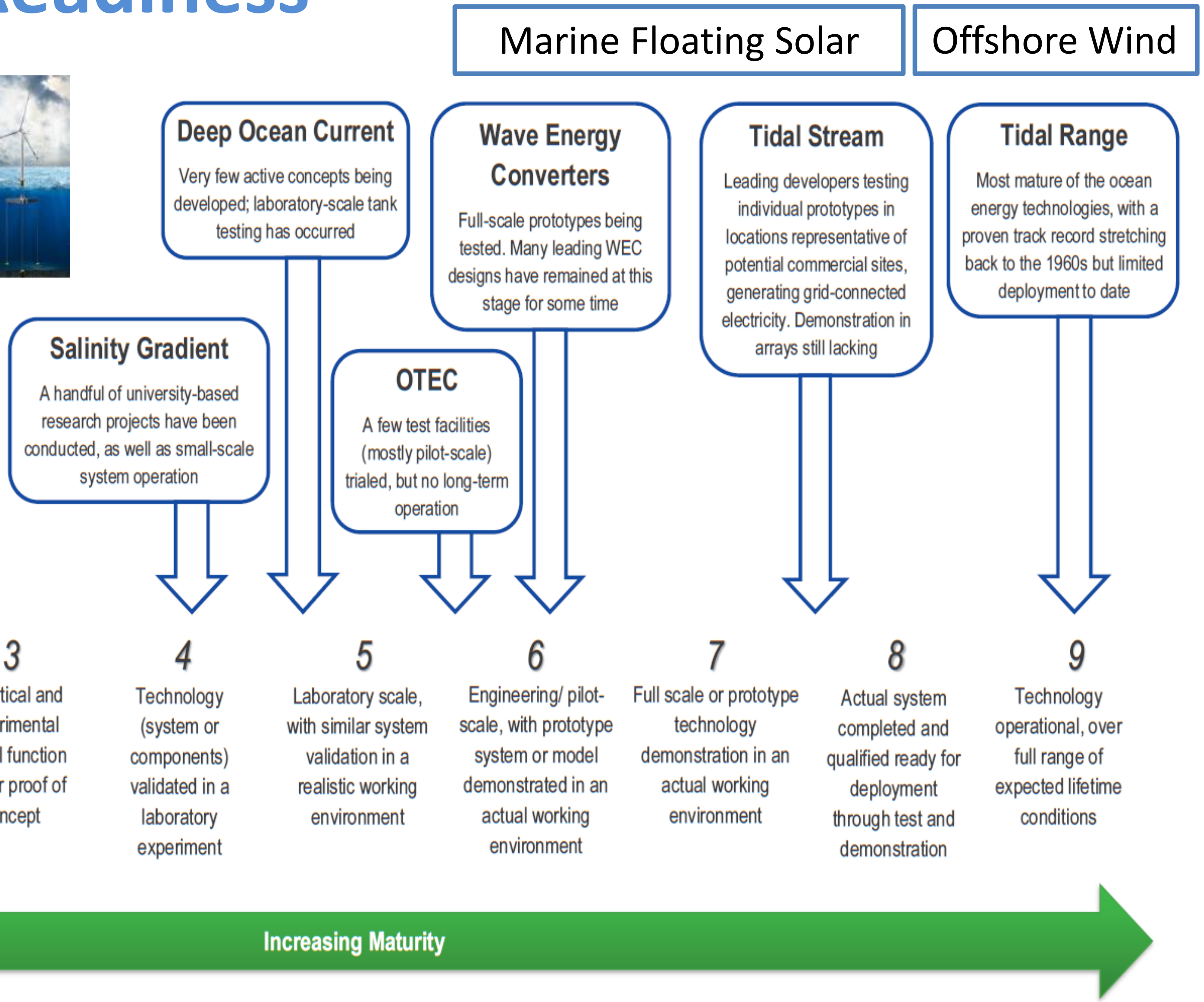

Thermal Gradient

(OTEC)

10,000 TWh/yr

*International Energy Agency -Ocean Energy Systems (IEA-OES)

Marine Renewable Energy:
Technology Readiness



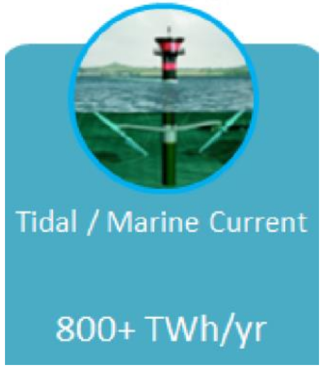
Source: IRENA

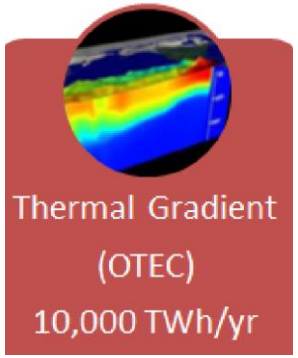
Marine-related RE Options

Floating – Solar, Wind

Very High Chance of Feasibility

Up to a certain depth





Resource: H
TRL*: High

Resource: H
TRL: Med

Resource: H
TRL: Med

*TRL = Technology Readiness Level

Present Technologies need >4m to be economically viable

- Good for Energy Recovery for Desalination Plants
- Still Too Expensive w/o co-application

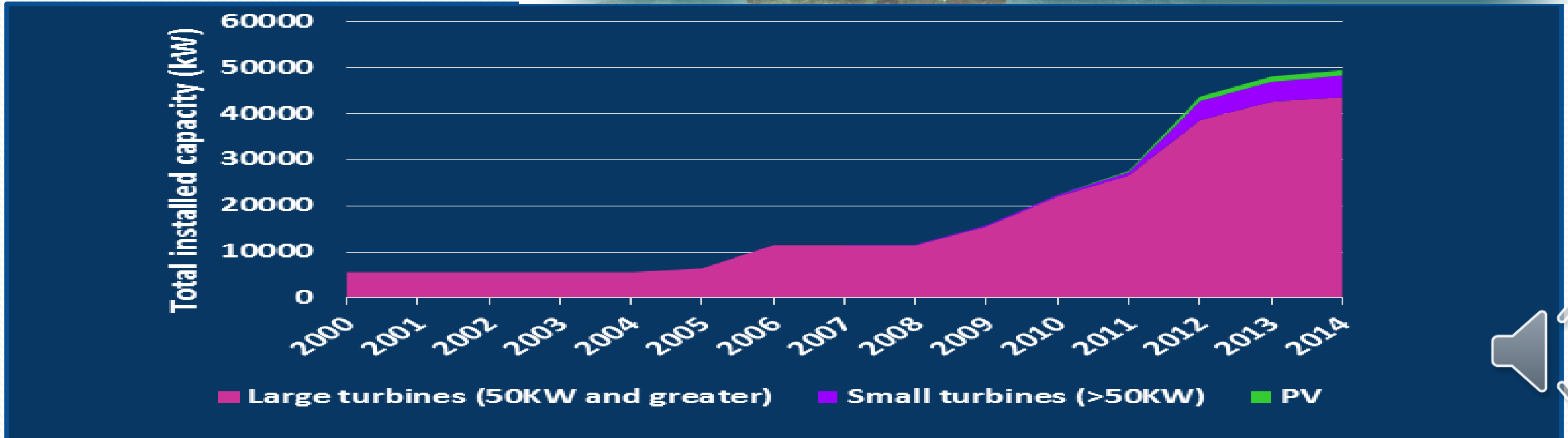
Sustainable Energy – Islands Example

Total = > 5,000 MW deliverable capacity

Key

Onshore wind	40 MW existing/planned	
New onshore wind	100-200 MW	
Wave	500-1000 MW	
Tidal	500-2,500 MW	
Offshore wind	1000 MW	
Wave leases	550 MW	
Tidal leases	500 MW	
Mirco & other	2.5 MW	
Gas & other	20 MW	*Dispersed*
EMEC sites	5 + 7 MW	*Dispersed and*

107% of electrical demand in Orkney met by renewables in 2014



Global Initiatives

EMEC ORKNEY
The European Marine Energy Centre Ltd

FORCE
Fundy Ocean Research Center for Energy

NETHERLANDS

RESOURCE	INSTALLED CAPACITY (kW)	CONSENTED PROJECTS (kW)
Wave Power		
Tidal Currents	130	3000
Salinity Gradient	50	

UK

RESOURCE	INSTALLED CAPACITY (kW)	CONSENTED PROJECTS (kW)
Wave Power	3730	40000
Tidal Currents	5600	96000

CANADA

RESOURCE	INSTALLED CAPACITY (kW)	CONSENTED PROJECTS (kW)
Tidal Currents		20450
Tidal Power	20000	

SWEDEN

RESOURCE	INSTALLED CAPACITY (kW)	CONSENTED PROJECTS (kW)
Wave Power	180	10400-10600
Tidal and Ocean Currents	7.5	

DENMARK

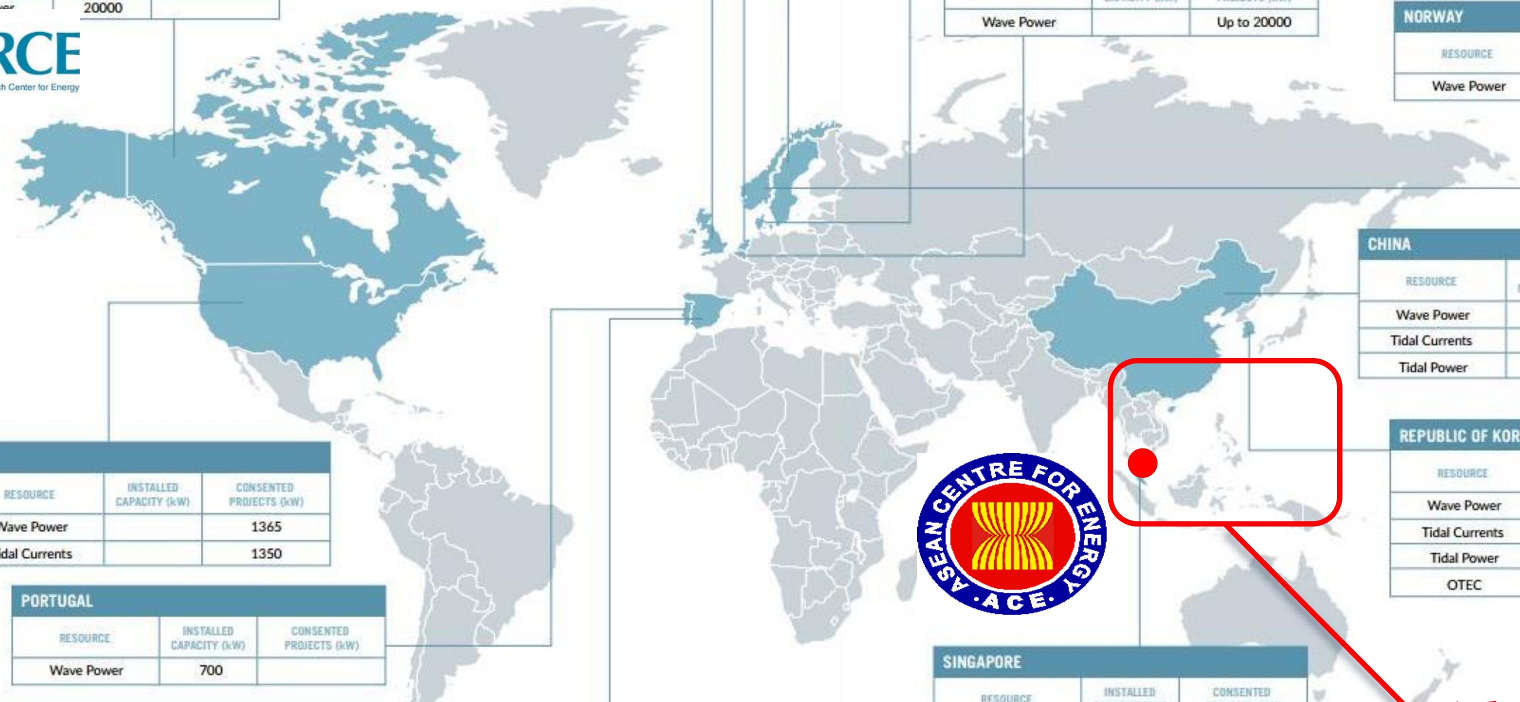
RESOURCE	INSTALLED CAPACITY (kW)	CONSENTED PROJECTS (kW)
Wave Power		115

BELGIUM

RESOURCE	INSTALLED CAPACITY (kW)	CONSENTED PROJECTS (kW)
Wave Power		Up to 20000

NORWAY

RESOURCE	INSTALLED CAPACITY (kW)	CONSENTED PROJECTS (kW)
Wave Power	200	



CHINA

RESOURCE	INSTALLED CAPACITY (kW)	CONSENTED PROJECTS (kW)
Wave Power	350	2860
Tidal Currents	170	4500
Tidal Power	3900	200

REPUBLIC OF KOREA

RESOURCE	INSTALLED CAPACITY (kW)	CONSENTED PROJECTS (kW)
Wave Power	500	300
Tidal Currents	1000	1300
Tidal Power	1000	1300
OTEC	220	1000

USA

RESOURCE	INSTALLED CAPACITY (kW)	CONSENTED PROJECTS (kW)
Wave Power		1365
Tidal Currents		1350

PORTUGAL

RESOURCE	INSTALLED CAPACITY (kW)	CONSENTED PROJECTS (kW)
Wave Power	700	

SPAIN

RESOURCE	INSTALLED CAPACITY (kW)	CONSENTED PROJECTS (kW)
Wave Power	296	300

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SINGAPORE

RESOURCE	INSTALLED CAPACITY (kW)	CONSENTED PROJECTS (kW)
Wave Power	16	
Tidal and Ocean Currents		2.5

>1,000 Sites
200MW each

openhydro a DCNS company

MEYGEN

ATLANTIS RESOURCES

LOCKHEED MARTIN

seacore
southeast asian collaboration for ocean renewable energy

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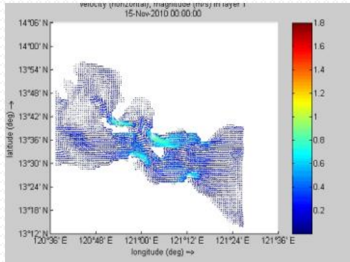
Developing Countries' Initiatives

Simulation Studies

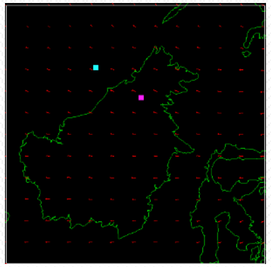


Myanmar
Tidal Barrage

Indonesia
Tidal Current Test

Europe, N. America, Australia

Brunei
Offshore Wind



Vietnam
Tidal Turbine Drive Train

Malaysia
OWC Test

Tow Tanks
(eg UTM, MMU, NTU)

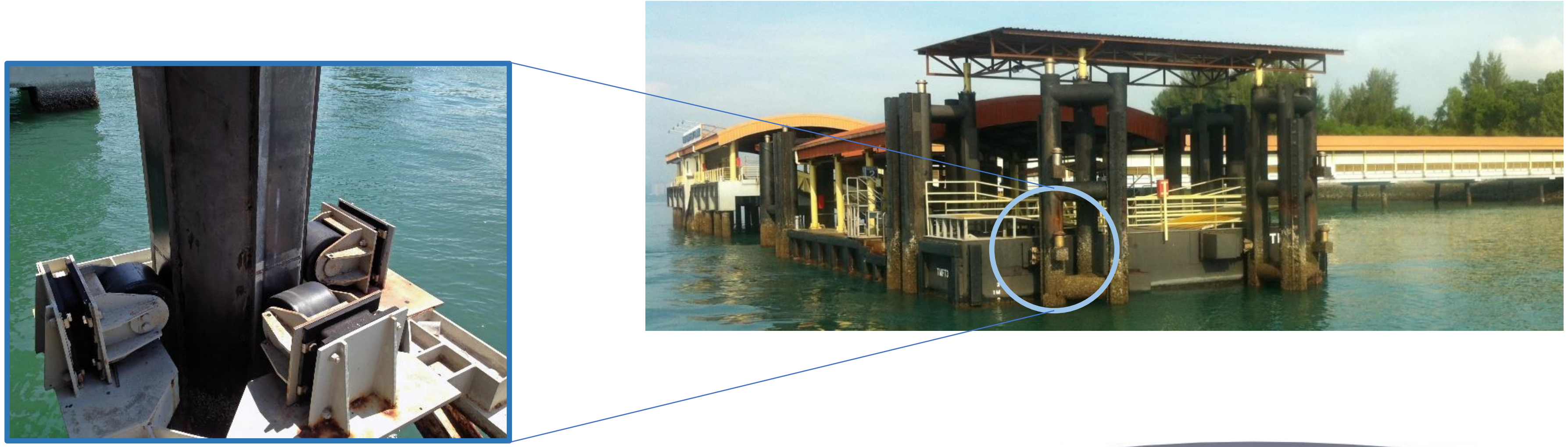
Philippines
Tidal Barrage

Singapore
Tidal Turbine Testing

Source: SEAcORE 2013

What is a Cushion Roller?

Cushion Rollers are components that hold floating platforms in place while absorber impacts that the platforms experience.



Technology Zones

Hs> 1m

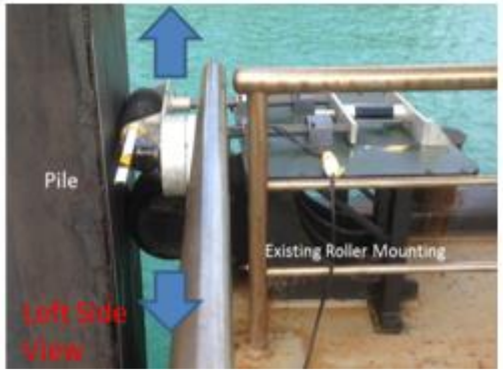
Medium Energy
Medium Risk
Array Approach

Hs> 0.5m

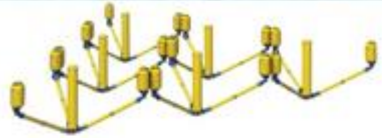
Huge Waves
High Energy
High Risk
Offshore Challenges

Hs < 0.5m

Multi-function Device
'Low Wave' Resource Capture



'Dry Setup'
Low Risk
Easier Maintenance



Technology Innovation – Competitive Edge

<u>As a Cushion Roller</u>

- First cushion roller to be able to produce electricity
  - Translate to cost savings
- Impact absorbing mechanism has potential for extended lifespan

<u>As a Wave Energy Device</u>

- Device is completely above water
  - Translate to reduced corrosion
  - Easier access for installation, maintenance and repair
- Able to generate under small waves conditions
  - Translate to greater range of application

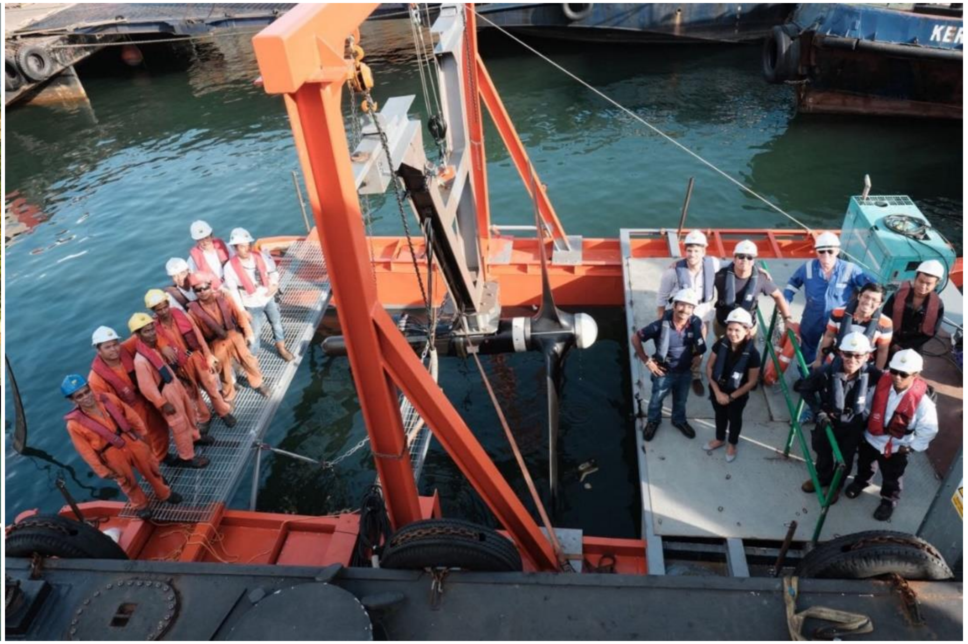
Confidential

Riding Waves Towards Sustainable Maritime Ecosystems

TIDAL IN-STREAM ENERGY DEMONSTRATION IN SG (50kW)

Client: Envirotek Pte Ltd **Collaborators:** Schottel Hydro, OceanPixel, LitaOcean, Sentosa, Aquatera, Orcades Marine, ITP, Braemar Offshore

Start: November 2015 *Deployment: February 2017 End: February 2018*



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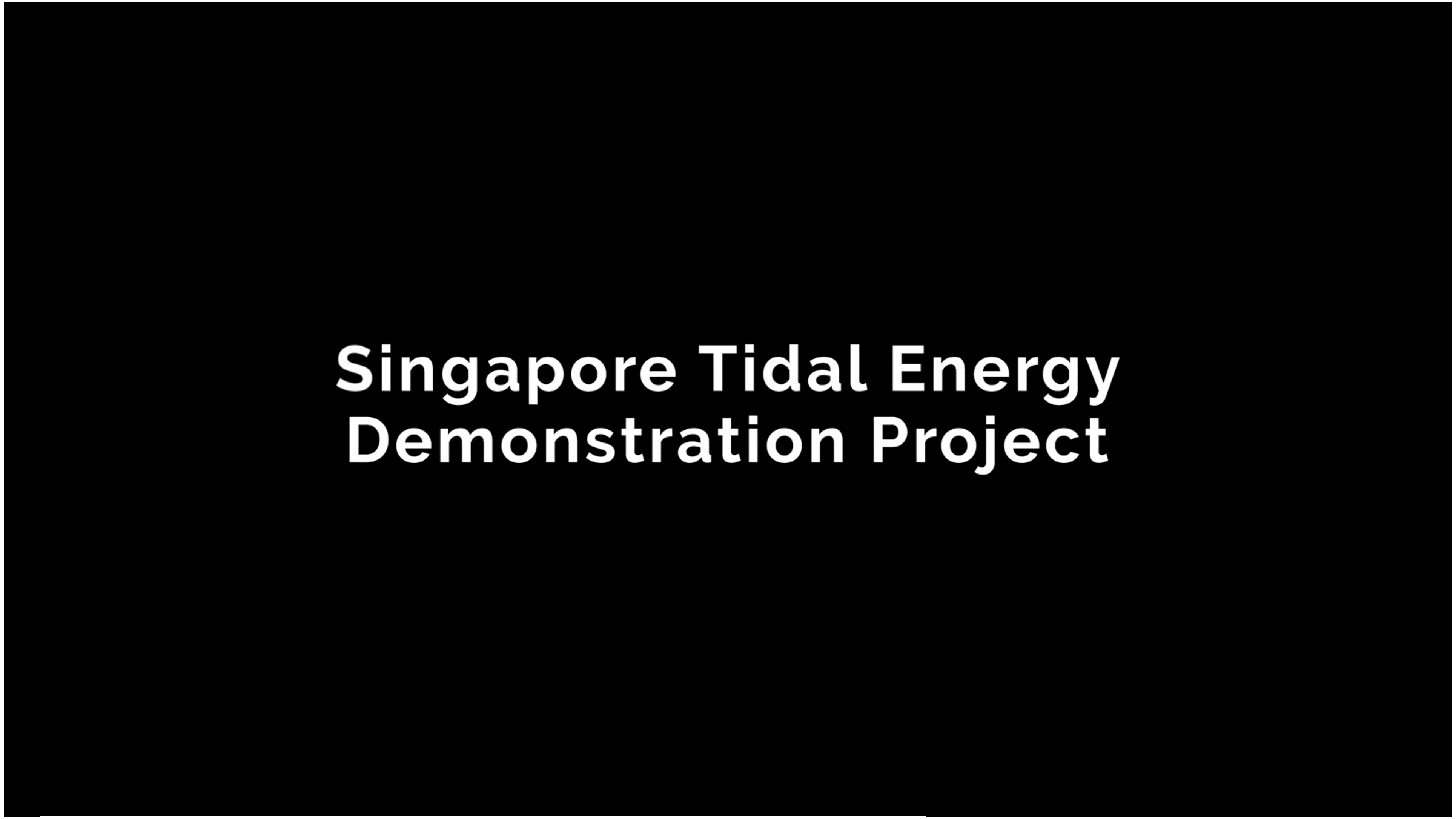
Envirotek Tidal Demo Project in Singapore (~3mins)



ENVIROTEK

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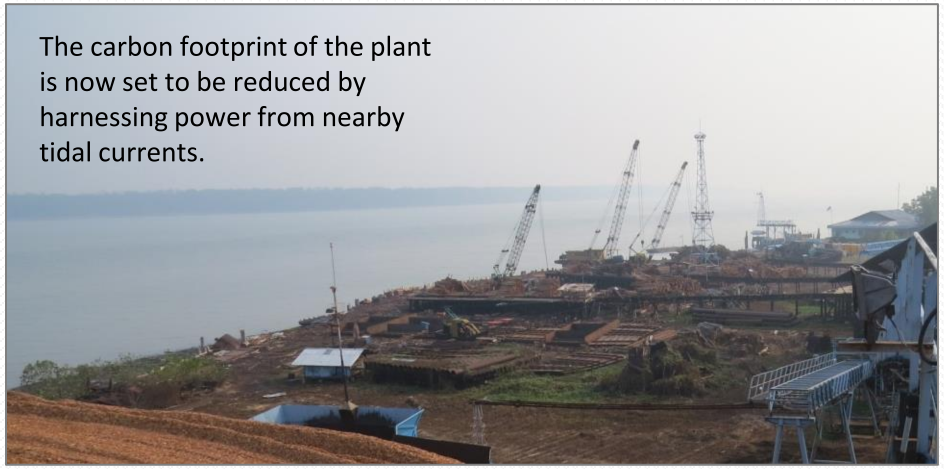
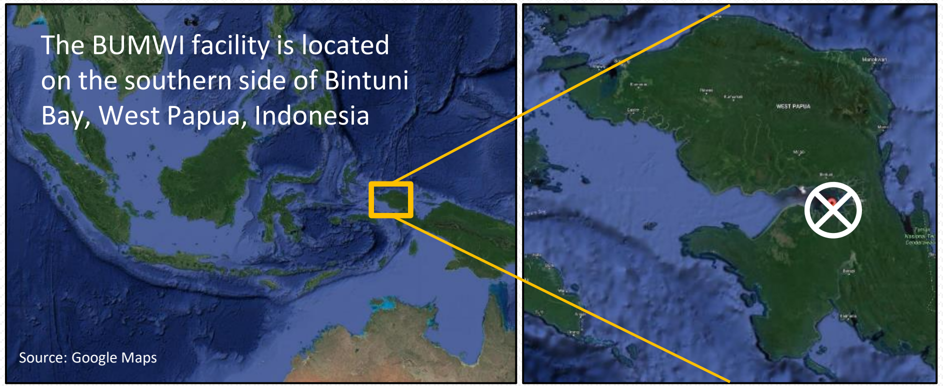
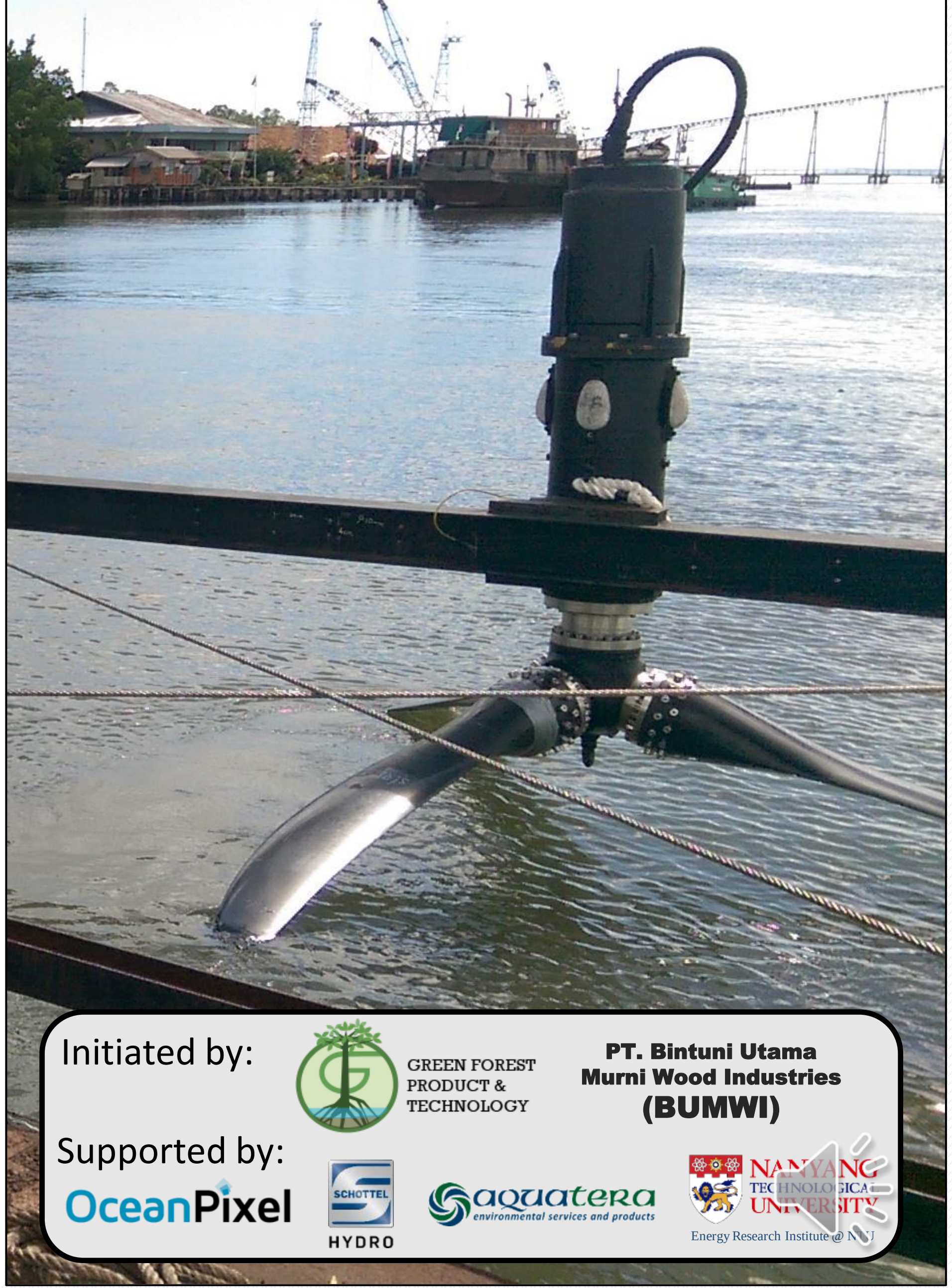
www.litaocean.com

https://vimeo.com/212361278





Tidal power in West Papua, Indonesia



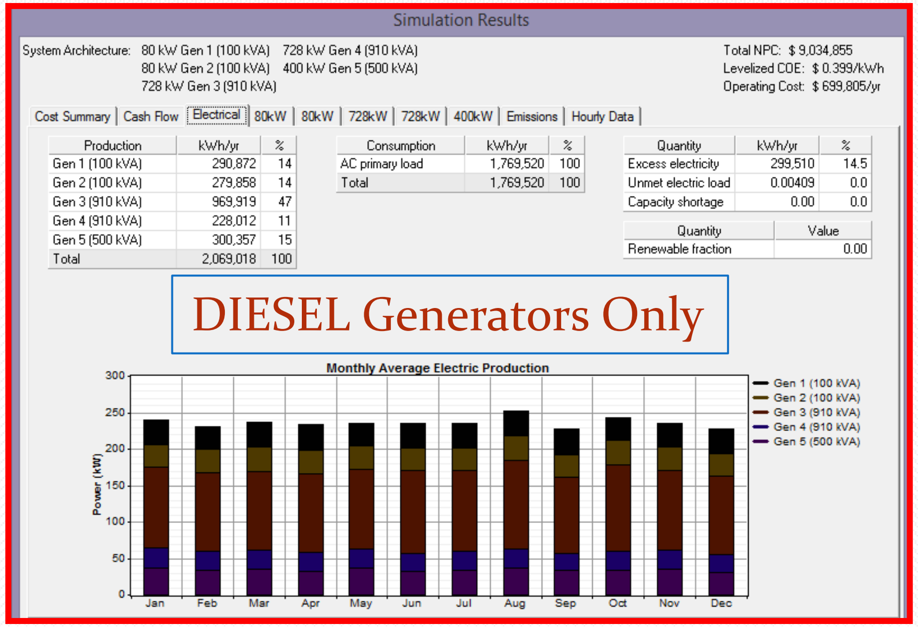
The project approach combines appropriate technology with local content and know-how.

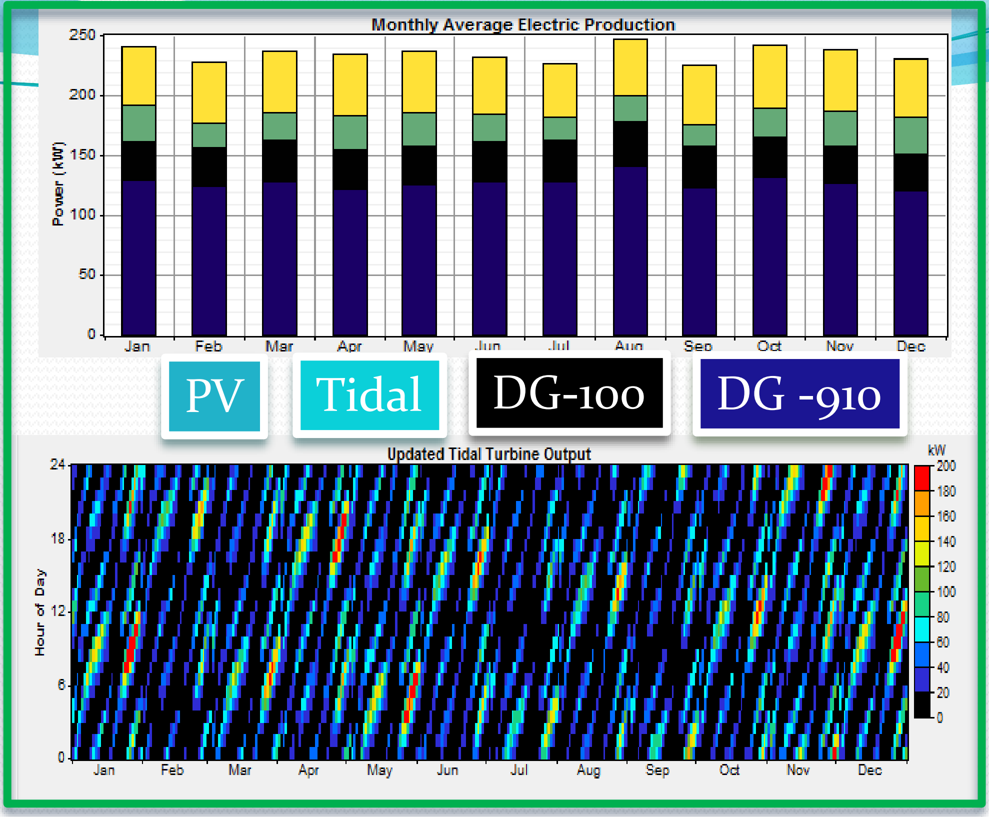
The tidal turbine is suspended below a floating barge in a simple and robust arrangement which allows for straightforward inspection and maintenance and can be easily replicated.

The project has proven the capability of a multi-company team to develop, implement and successfully deploy a tidal turbine in one of the most remote and areas of Indonesia.

The installation of Schottel Hydro’s 50kW turbine in West Papua is a significant step on the journey to use marine renewables to de-carbonise energy supplies across the region.

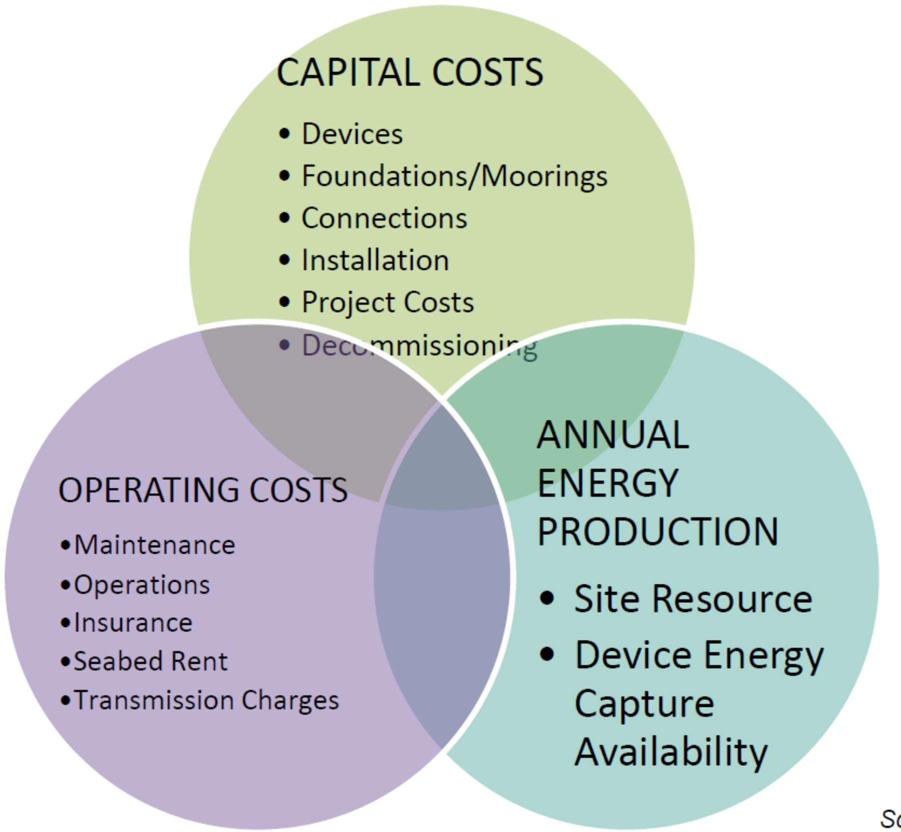
Case Study: Hybrid System for an Island Micro-Grids





Power System Config.	RE Fraction	Excess Electricity	LCOE (USD/kWh)
Diesel GenSets (910, 100 kVA) + Batt (576kWh) + Solar (300kWp) + Tidal (200kWp)	**31.6%**	**12.6%**	**0.368**
Diesel GenSets (910kVA, 100 kVA) + Batt (720kWh) + Solar (600kWp)	38.6%	20.1%	0.386
Diesel GenSets (910kVA, 100 kVA)+Batt.(1440kWh)	0.0 %	2.47%	0.456
Diesel GenSets (2x 910, 500, 100 kVA)	0.0 %	14.5%	0.5

FACTORS AFFECTING LCOE



Source : SI Ocean, Ocean Energy : Cost of Energy and Cost Reduction Opportunities, May 2013

Summary data gathered for each stage of deployment, and each technology type

Deployment Stage	Variable	Unit	Wave		Tidal		OTEC	
			Min	Max	Min	Max	Min	Max
First array/First Project	Project Capacity	MW	1	3	0.3	10	0.1	5
	CAPEX	$/kW	4,000	18,100	5,100	14,600	25,000	45,000
	OPEX	$/kw per year	140	1,500	160	1,160	800	1,440
Second array/Second Project	Project Capacity	MW	1	10	0.5	28	10	20
	CAPEX	$/kW	3,600	15,300	4,300	8,700	15,000	30,000
	OPEX	$/kW per year	100	500	150	530	480	950
	Availability	%	85%	98%	85%	98%	95%	95%
	Capacity Factor	%	30%	35%	35%	42%	97%	97%
	LCOE	$/MWh	210	670	210	470	350	650
First Commercial-scale Project	Project Capacity	MW	2	75	3	90	100	100
	CAPEX	$/kW	2,700	9,100	3,300	5,600	7,000	13,000
	OPEX	$/kW per year	70	380	90	400	340	620
	Availability	%	95%	98%	92%	98%	95%	95%
	Capacity Factor	%	35%	40%	35%	40%	97%	97%
	LCOE	$/MWh	120	470	130	280	150	280

Source :OES, International Levelised Cost of Enery for Ocean Energy Technologies, May 28, 2015

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Project Keys to Success:

Need/Demand/End-Use (Market Existence)

Good Site and Resource

Appropriate Technology

What does this table mean???

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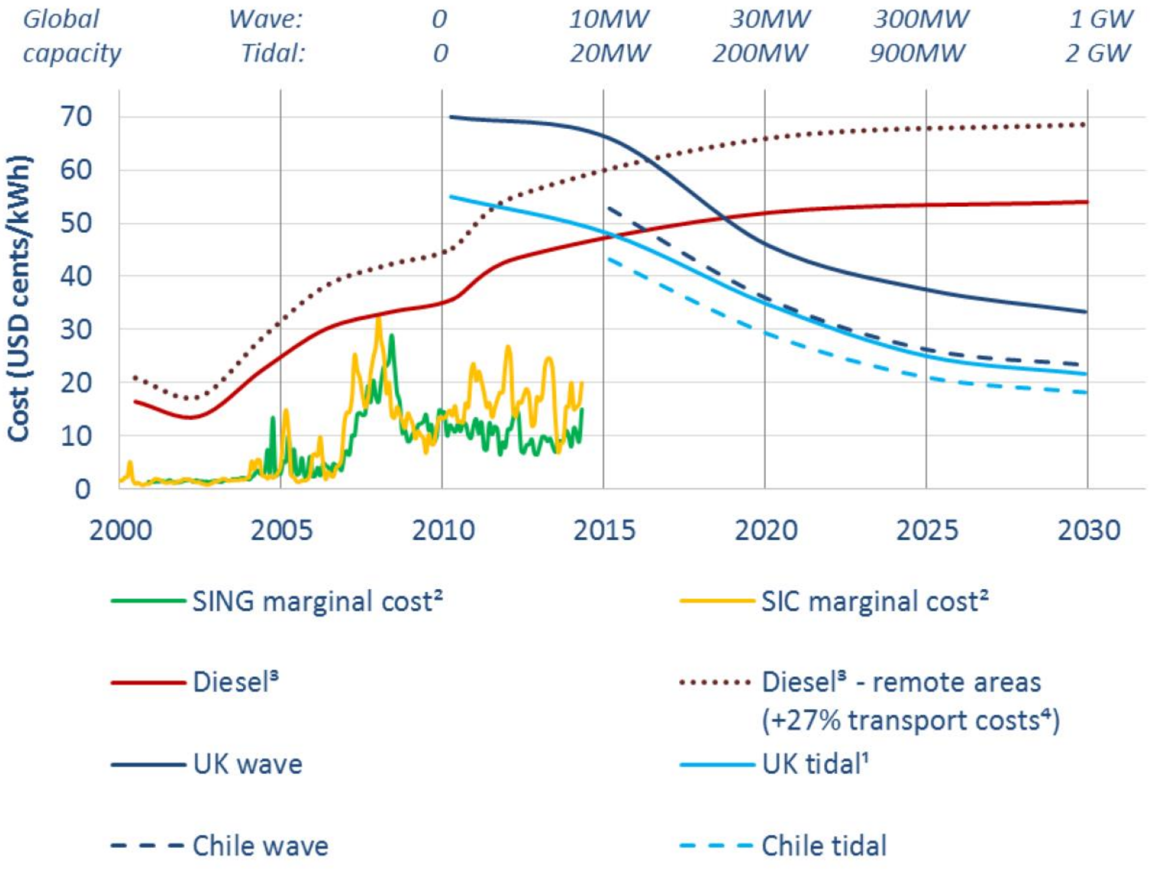
Wave and tidal



Sources: [1]Carbon Trust; [2]CNE; [3]World Bank/Bloomberg; [4]Chilean Ministry of Energy

Marine energy markets:

LONG TERM
Grid electricity

MEDIUM TERM
Diesel replacement; water pumping and desalination (mines)

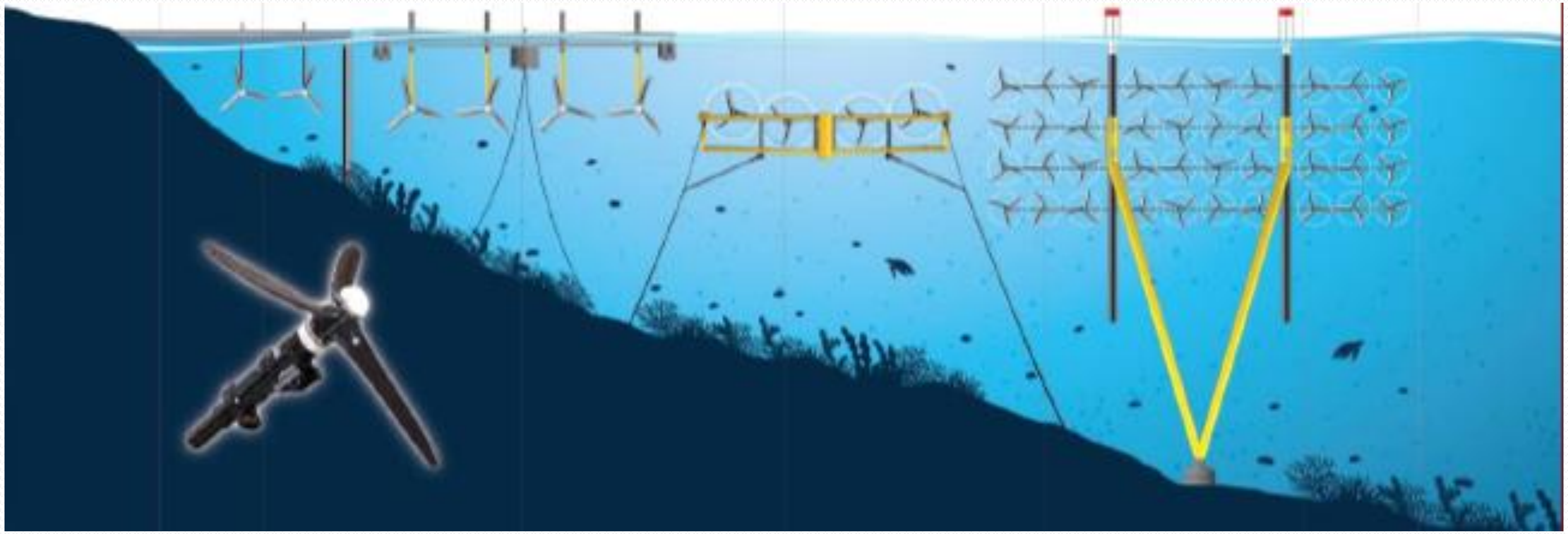
SHORT TERM
Remote diesel replacement

In the HYBRIDShip project of Fiskestrand Holding launched in 2016, a diesel-powered ferry was converted to hydrogen.

"Energy Observer" is currently touring the world to demonstrate the potential of hydrogen as a power source.

Ocean Energy - Configuration Options

(Tidal In-Stream Energy Device example)



- Jetty-based / fixed structure (e.g. bridges)
- Floating
- Submerged (neutrally-buoyant)
- Seabed-mounted
- Others? – Vessel-mounted?

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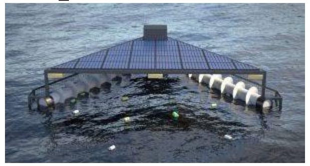
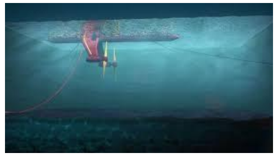
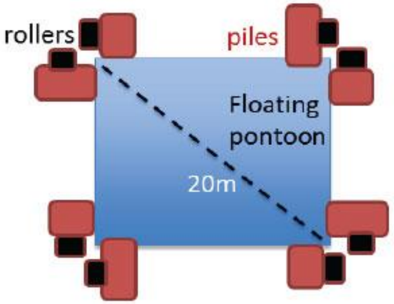
Project Design – Some Deployment+Installation Options





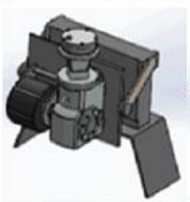
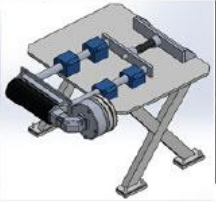




1 pontoon = 8 rollers : ~2kW (ave)

Total Annual Energy: ~17.5MWh/yr



WEC Power Output (Watts)[1]		Wave Period, T (sec)								
		2	3	4	5	6	7	8	9	10
Wave Height, H (m)	0.1	106	46	26	16	11	8	6	4	3
	0.2	429	190	106	67	46	34	26	20	16
	0.3	-	429	241	154	106	78	59	46	37
	0.4	-	765	429	274	190	139	106	84	67
	0.5	-	-	672	429	298	218	167	131	106
	0.6	-	-	-	619	429	315	241	190	154

241W Output @ 0.3m Wave Height, 4s Wave Period

https://www.mpa.gov.sg/assets/rnd/e-bulletins/issue2/html/index4.html

All Renewable Energy Options should be explored if possible:

Solar, Wind, Tidal, Wave, etc

Sizing Combinations are Flexible and Scalable

- **E.g. Tidal Turbines Systems Small to Large: 3.5kW, 5kW, 20kW, 70kW, and more, up to 2MW**

Various Deployment & Installation Options should also be explored:

- **Seabed-mounted**
- **Seaport-attached**
- **Jetty-based**
- **Floating Stand-alone**
- **Floating-Integrated**

  (to offshore structure, or Vessel, etc)
- **Mobile, Floating**
- **Mobile, Underwater**

And more!

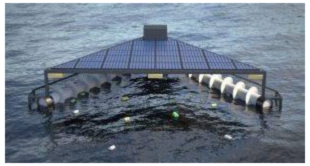
Example for 10kW* Load – Some Technology Options

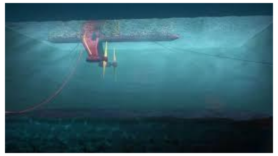
Marine Floating Solar

- Resource Availability: ~ 17% of the time
- Size: ~20 kWp
- Surface Space: ~140 sqm
- Costs**:
- Project Dev't + CapEx ~S$150k to S$200k
- Annual OpEx ~S$10k to S$20k

Tidal Current Turbine/s

- Resource Availability: ~30% to 40% of the time (in a month)
- Size: ~ 40 to 100 kWp
- Surface Space: ~35 to 70 sqm
- Costs**:
- Project Dev't + CapEx ~S$200k to S$350k
- Annual OpEx ~S$10k to S$25k





Hybrid Floating Solar + Tidal

- Size (Solar): ~10 kW
- Size (Tidal): ~20 to 60 kWp
- Surface Space: ~70 sqm
- Costs**:
- Project Dev't + CapEx ~S$175k to S$300k
- Annual OpEx ~S$10k to S$20k

*Electrical Load: 10kW Power with 8 hours per day operation, assumed daily load energy requirement = 80kWh/d

** May include a feasibly-sized energy storage system (e.g. battery)

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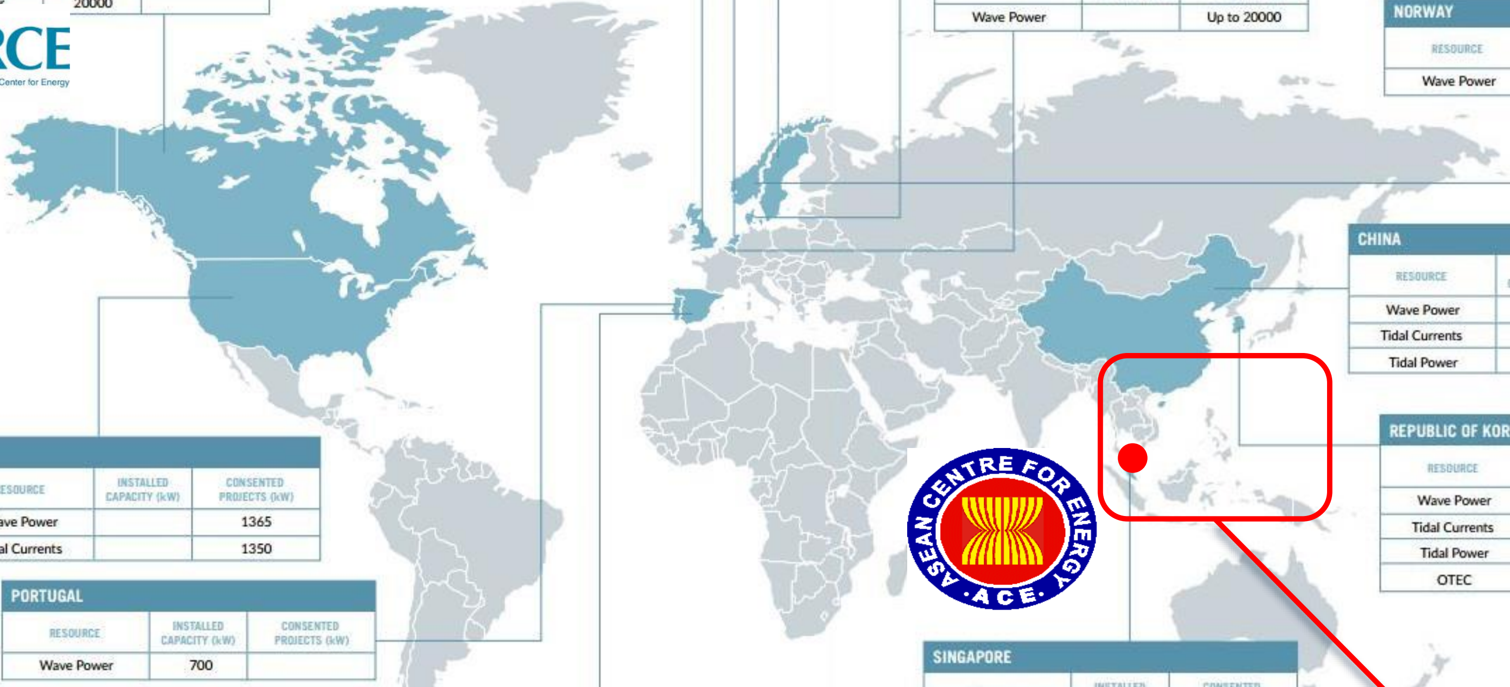
Global Initiatives

EMEC ORKNEY
The European Marine Energy Centre Ltd

FORCE
Fundy Ocean Research Center for Energy



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Tidal Currents		1350

PORTUGAL

RESOURCE	INSTALLED CAPACITY (kW)	CONSENTED PROJECTS (kW)
Wave Power	700	

SPAIN

RESOURCE	INSTALLED CAPACITY (kW)	CONSENTED PROJECTS (kW)
Wave Power	296	300

SWEDEN

RESOURCE	INSTALLED CAPACITY (kW)	CONSENTED PROJECTS (kW)
Wave Power	180	10400-10600
Tidal and Ocean Currents	7.5	

DENMARK

RESOURCE	INSTALLED CAPACITY (kW)	CONSENTED PROJECTS (kW)
Wave Power		115

BELGIUM

RESOURCE	INSTALLED CAPACITY (kW)	CONSENTED PROJECTS (kW)
Wave Power		Up to 20000

NORWAY

RESOURCE	INSTALLED CAPACITY (kW)	CONSENTED PROJECTS (kW)
Wave Power	200	

CHINA

RESOURCE	INSTALLED CAPACITY (kW)	CONSENTED PROJECTS (kW)
Wave Power	350	2860
Tidal Currents	170	4500
Tidal Power	3900	200

REPUBLIC OF KOREA

RESOURCE	INSTALLED CAPACITY (kW)	CONSENTED PROJECTS (kW)
Wave Power	500	300
Tidal Currents	1000	1300
Tidal Power	1000	1300
OTEC	220	1000

SINGAPORE

RESOURCE	INSTALLED CAPACITY (kW)	CONSENTED PROJECTS (kW)
Wave Power	16	
Tidal and Ocean Currents		2.5

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southeast asian collaboration for ocean renewable energy

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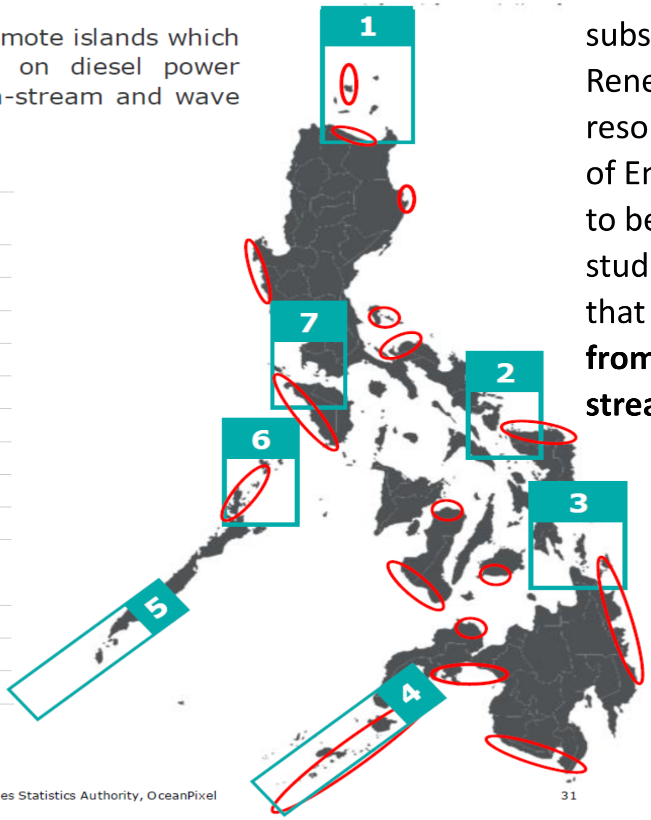
Philippines' Tidal In-Stream (Current) & Wave Energy Potential

Philippines has more than 7 thousand islands, including remote islands which either do not have electricity access or rely heavily on diesel power generation. Some of these areas are suitable for tidal in-stream and wave energy power generation development.

Philippines' tidal in-stream and wave energy potential

No	Province / Region	Electrification rate*	Population (million)
1	Cagayan / II	91.8%	1.20
2	Catanduanes / V	88.7%	0.26
	Sorsogon / V	88.7%	0.79
	Northern Samar / VIII	87.2%	0.63
3	Southern Leyte / VIII	87.2%	0.42
	Surigao del Norte / XIII/Caraga	93.8%	0.49
4	Basilan / ARMM	38.7%	0.35
	Sulu / ARMM	38.7%	0.82
	Tawi-tawi / ARMM	38.7%	0.39
5, 6	Palawan / IV-B	82.2%	0.85
7	Batangas / IV-A	96.3%	2.69
	Occidental Mindoro / IV-B	82.2%	0.49
	Oriental Mindoro / IV-B	82.2%	0.84



identified tidal current energy reserves

identified wave energy reserves

* electrification rate are identified in Region level

Source: Energy Research Institute at Nanyang Technological University, Philippines Department of Energy, Philippines Statistics Authority, OceanPixel

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The Philippines has substantial Ocean Renewable Energy (ORE) resource (the Department of Energy has estimated it to be 170GW, and some studies have estimated that around **80GW+ are from tidal currents / tidal streams**).

Deloitte Consulting and OceanPixel SEA(2017).
Marine Renewable Energy: Unlocking The Hidden Potential Southeast Asia (SEA) Market Assessment, Singapore: OceanPixel.

Tidal In-Stream Energy - Potential Technology for Archipelagic Countries (like the Philippines, Indonesia, etc)

Economics of Tidal In-Stream Energy Grid-Connected Projects (Levelized Cost of Energy, Internal Rate of Return, Return of Investment) with Indicative Estimates for Low, Medium, and High Project CapEx Scenarios

100 MW	Total Project (20-Years)					
	~USD 378M		~USD 560M		~USD 984M	
	CapEx = $ 233.2M	OpEx = $6.63M/yr	CapEx = $ 406.5M	OpEx = $6.63M/yr	CapEx = $ 810.2M	OpEx = $6.63M/yr
FIT (PhP/kWh)	USD 2M/ MW (LCOE = $ 0.11/kWh)		USD 4M/ MW (LCOE = $ 0.17/kWh)		USD 8M/MW (LCOE = $ 0.3/kWh)	
10	ROI = 95% Profit = ~USD 358M	IRR = 14% Payback = ~6.5 yrs	ROI = 32% Profit = ~USD 177M	IRR = 6% Payback = ~11 yrs		
13.5	ROI = 163% Profit = ~USD 616M	IRR = 21% Payback = ~5 yrs	ROI = 78% Profit = ~USD 434M	IRR = 11% Payback = ~7.6 yrs	ROI = 1% Profit = ~USD 9M	IRR = 3% Payback = ~16.2 yrs
17	ROI = 232% Profit = ~USD 873M	IRR = 28% Payback = ~3.5 yrs	ROI = 124% Profit = ~USD 691M	IRR = 15% Payback = ~6.3 yrs	ROI = 27% Profit = ~USD 267M	IRR = 5% Payback = ~12 yrs

200 MW	Total Project Cost (20-Years)					
	~USD 753.5M		~USD 1,117.3M		~USD 1,966.3M	
	CapEx = $ 465.3M	OpEx = $13.25M/yr	CapEx = $ 811.8M	OpEx = $13.25M/yr	CapEx = $ 1,620.3 M	OpEx = $13.25M/yr
FIT (PhP/kWh)	USD 2M/ MW (LCOE = $ 0.11/kWh)		USD 4M/ MW (LCOE = $ 0.17/kWh)		USD 8M/MW (LCOE = $ 0.3/kWh)	
10	ROI = 95% Profit = ~USD 718M	IRR = 14% Payback = ~6.5 yrs	ROI = 35% Profit = ~USD 354M	IRR = 6% Payback = ~11 yrs		
13.5	ROI = 164% Profit = ~USD 1,233M	IRR = 21% Payback = ~4.5 yrs	ROI = 78% Profit = ~USD 869M	IRR = 11% Payback = ~7.6 yrs	ROI = 1% Profit = ~USD 20M	IRR = 3% Payback = ~16.2 yrs
17	ROI = 232% Profit = ~USD 1,748M	IRR = 28% Payback = ~3.5 yrs	ROI = 124% Profit = ~USD 1,384M	IRR = 15% Payback = ~6.3 yrs	ROI = 27% Profit = ~USD 535M	IRR = 5% Payback = ~12 yrs

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BACKGROUND / CONTEXT

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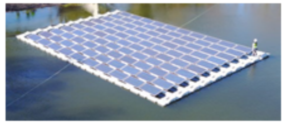
Hybrid Marine Renewable Energy System

Harnessing Energy from Tidal Currents and Solar (on land and at sea)

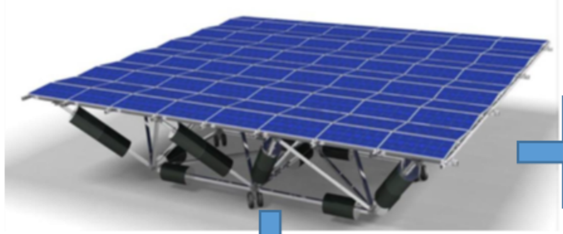
Resource → Energy Converter → Electrical Energy



Solar (Light) → Solar Photovoltaic (PV) Cells/Panels → Electrical Energy

Tidal Currents (water flow from tides) → Hydrokinetic Energy Converters (e.g. Turbines) → Electrical Energy

Solar PV Panels



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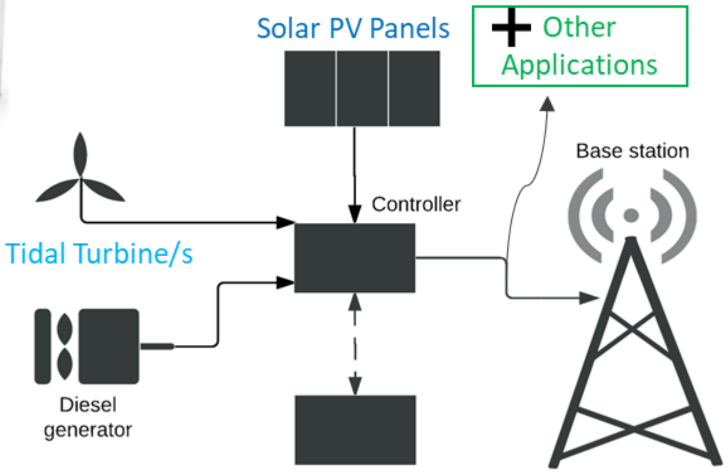
Tidal Turbine/s

+

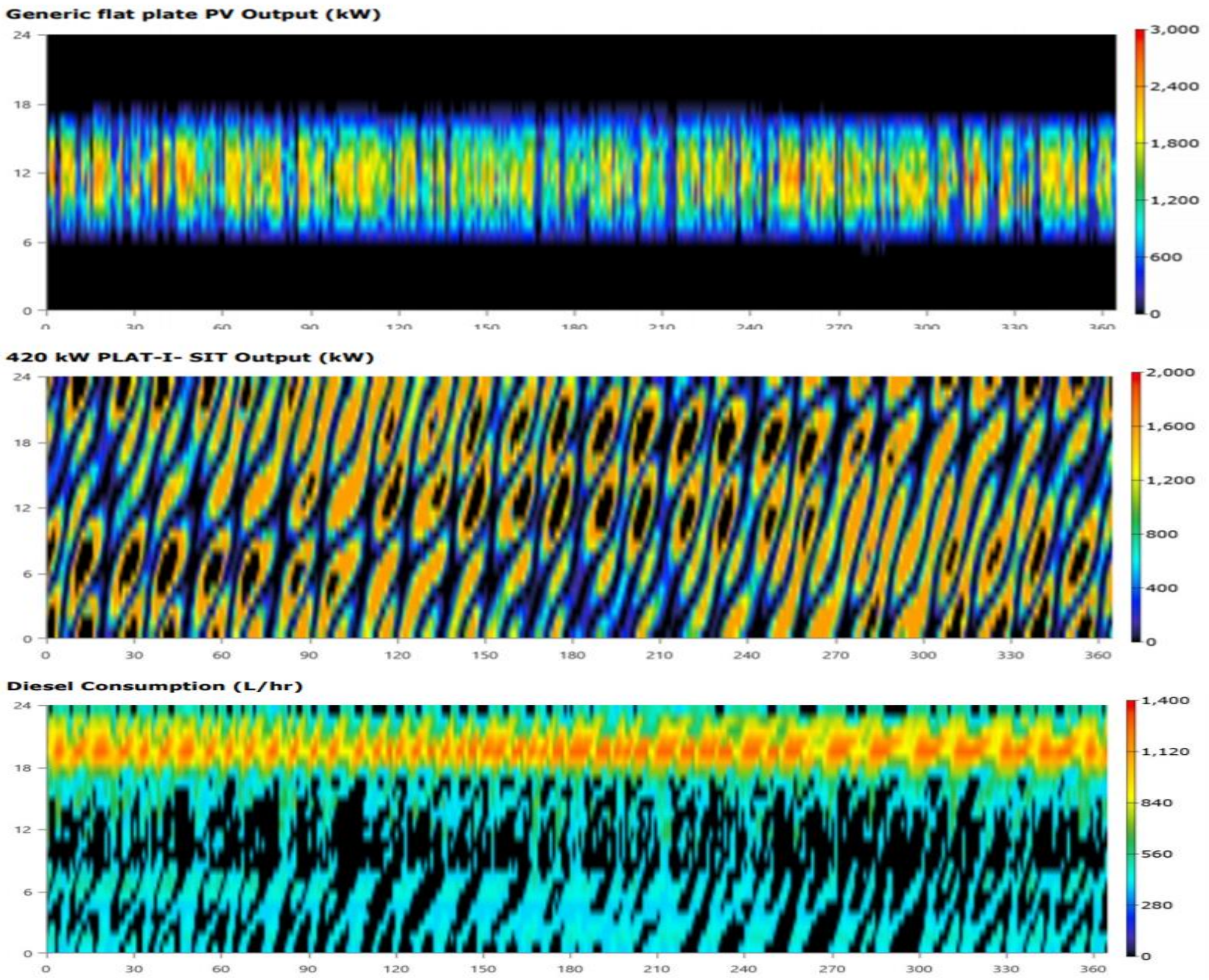
+

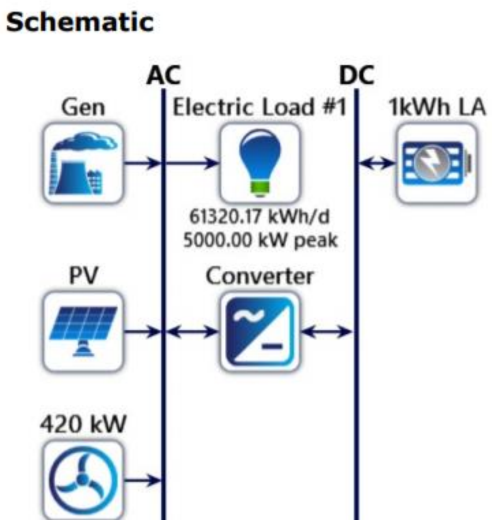
Diesel Generator/s



HYBRIDIZING OFF-GRID ISLAND ENERGY MIX

Techno-Economic Modelling





	Architecture					Cost					System				
	PV (kW)	Gen (kW)	1 kWh LA	420 kW	Converter (kW)	COE (₱)	COE ($)	NPC ($)	Operating Cost ($/yr)	Initial capital ($)	Ren Frac (%)	Total Fuel (L/yr)	Cap Short (%)	Excess Elec (%)	Excess Elec (kWH/yr)
A	2500	5,600		4		14.725	0.288	143,000,000	5,920,000	11,800,000	27.8	4,636,592	0	12.5	3,185,091
B	3000	5,600	9504	4	1062	12.425	0.243	120,000,000	4,820,000	13,800,000	43.1	3,606,766	0	0.916	209,221
C	3000	5,600		4		14.521	0.284	140,000,000	5,800,000	12,300,000	29.6	4,523,624	0	13.5	3,499,373
D	5000	5,600	21417	4	1666	10.635	0.208	103,000,000	3,960,000	15,400,000	53.3	2,928,471	0	1.73	405,556
E	9000	5,600	38082	8	3560	10.226	0.200	99,100,000	3,230,000	27,700,000	81.5	1,131,654	0	15.8	4,522,101
F		5,600				14.930	0.292	145,000,000	6,470,000	1,680,000	0	6,247,966	0	0	-

Philippine Off-Grid Island Case Study: High-level techno-economic model:

- A hybrid solar PV and tidal with battery system and back-up diesel generator set is found to be optimal.
- The optimal sizing for the case study shown is at 5MW solar PV, 1.68MW tidal, 21.4MWh Battery with 2MW guaranteed dependable capacity.
- 53% RE Fraction, ~USD0.2 Blended Rate

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Some Reference Rates and Costs of Tidal In-Stream Energy Projects

Project/s Size and Location	Technology	Feed-in Tariff (FIT) / Power Purchase Agreement (PPA) Rate or LCOE and term	Notes/Remarks
22MW, Canada [2]	Tidal In-Stream	(a) FIT: CAD530/MWh (~PhP19.63/kWh), 15 years (b) FIT: CAD420/MWh (~PhP15.56/kWh), 15 years	FIT rates are developmental rates called “COMFIT” or Community FIT. Lower rate for projects producing >16,640 MWh
9MW, Canada [3]	Tidal In-Stream	CAD530/MWh (~PhP19.63/kWh), 15 years	Project Cost: ~PhP4.34B
~1-2MW, Indonesia (West Papua) [1]	Hybrid Tidal In-Stream, Solar, Diesel	Diesel-only LCOE: USD0.5 to USD 1 / kWh (~PhP24.06 to PhP48.12/kWh) Hybrid (Tidal+Solar+Battery+Diesel) Case Study LCOE: USD 0.25 to USD 0.368 /kWh (~PhP12.03 to PhP 17.71/kWh), 20 years	Phase 1 (Test): Tidal + Diesel – completed in 2017
600kW to 5MW, Philippines	Hybrid Tidal In-Stream, Solar, Diesel	Diesel-Only True Cost of Generation Rate: ~PhP 13.5 to 24.83/kWh Hybrid (Tidal+Solar+Battery+Diesel) LCOE: (~PhP12.03 to PhP 17.71/kWh), 20 years	Various Off-Grid Studies – i.e. Tawi-Tawi, Dinagat, San Antonio (N. Samar) Estimated/Indicative Project Costs: PhP75m-100m (600kW, no OpEx) PhP125m-150m (1.2MW, no Opex) ~PhP500m (5MW, no Opex)

[1] Deloitte Consulting and OceanPixel SEA(2017). *Marine Renewable Energy: Unlocking The Hidden Potential Southeast Asia (SEA) Market Assessment*, Singapore
[2] https://energy.novascotia.ca/renewables/programs-and-projects/tidal-fit
[3] https://www.offshore-energy.biz/canada-awards-c30-million-for-9mw-tidal-energy-scheme/

Hybridized Marine RE Pathway

MARES: Marine Aquaculture, Reefs, Renewable Energy, and Ecotourism for Ecosystem Services

Off-Grid and Co-App Market → Grid-Connected Project Dev't (Progressive Dev't) → Large Scale Commercial Grid-Tied Projects

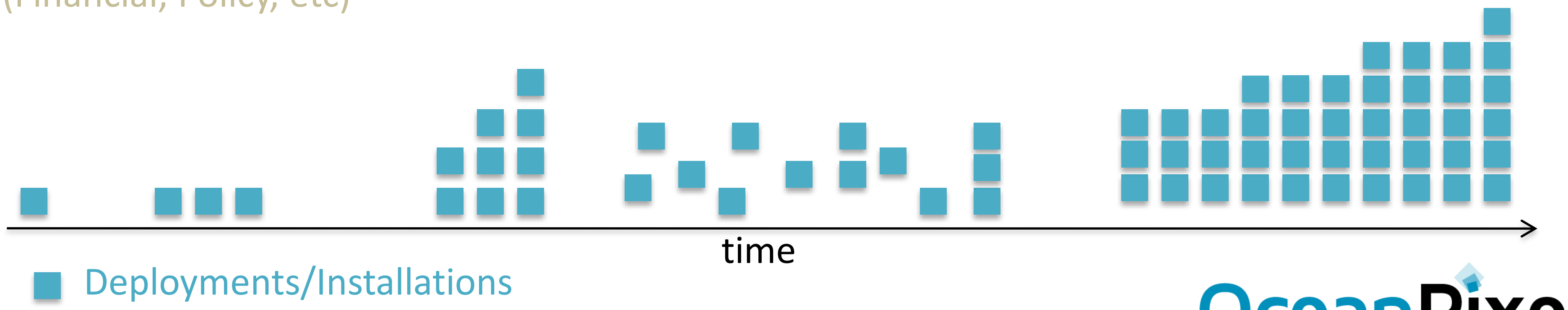
Scoping
Strategic Planning
Scouting

MARES @ VARIOUS SCALES

Small Scale Pilot (Off-Grid and Micro-grid) → [1-3 years] → Increase Pilot Capacity (Progressive Dev't) → [3-5 years] → Large Scale Grid-Connected and Other Islands' Micro-Grid Projects

Increase Pilot Capacity (Progressive Dev't) → Outer Islands' Projects ⇢ Large Scale Grid-Connected and Other Islands' Micro-Grid Projects

Capability Development
Support Mechanisms
(Financial, Policy, etc)



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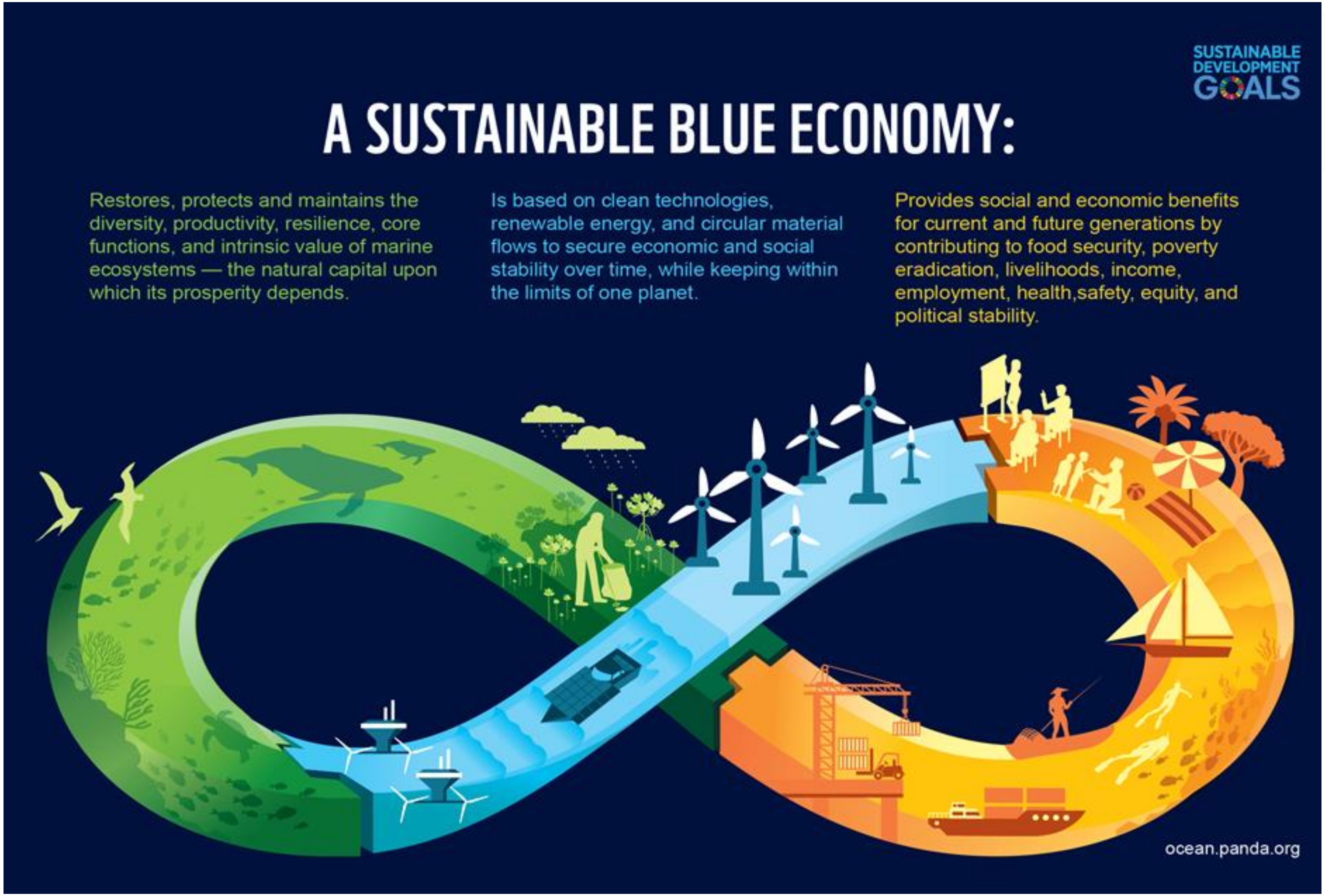
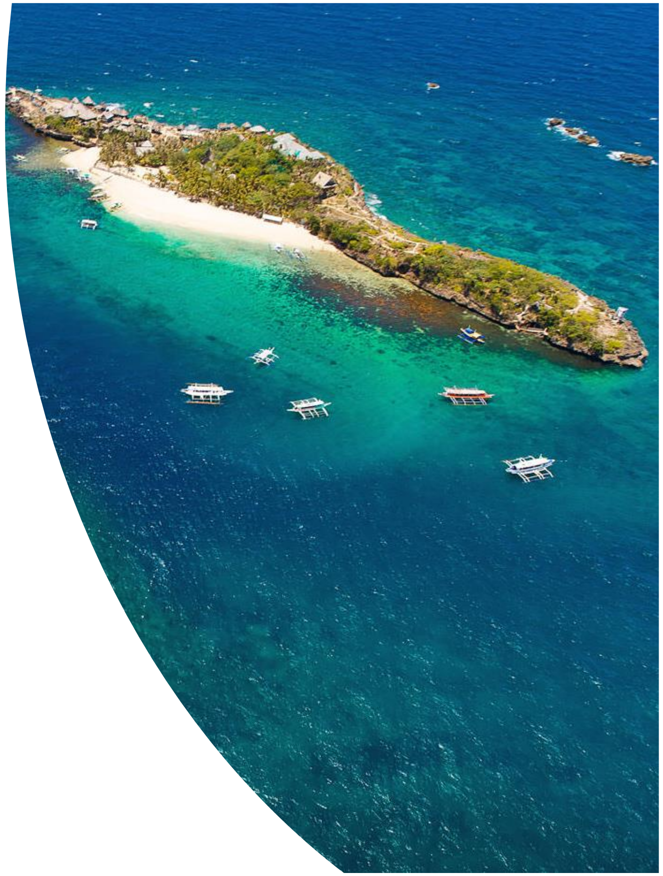


MARES:
Marine Aquaculture, Reefs, Renewable Energy, & Ecotourism for Ecosystem Services



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Electrification: More than just electricity supply

- Electrification of Transportation
- Electrification of Vessels
- Electrification of Ports
- Automation of Processes
- Energy Storage Systems
- Aquaculture Applications
- Water Production (e.g. Desalination)
- Ice Making
- Digitalization
- Others?

Sustainable Integrated Development for Islands & Coasts



Aquaculture & Fisheries

Green Transport – Sea and Land


Green Maritime Ecosystem – Ports, Vessels, Aquaculture, Desalination, Water, Ice/Cooling ++


Renewable Energy + Green Transport
+ Aquaculture + Water Production
+ Freezing/Cooling + Local Content
+ Other Sustainable Initiatives

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Building the Sustainable Future Blue Economy

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Enabling MARES
(Marine Aquaculture, Reefs, Renewable Energy, & Ecotourism for Ecosystem Services)

Long-Term Sustainability
Global Competitiveness
New Products & Services

Regenerative Marine Industries

Hydrogen Economy

Impact-Driven Projects

Inward Investment
Coordination
Alignment
Capability Dev't
Synergy

Offshore
Marine
Maritime
Logistics
Clean Tech
Energy
Intelligence

Enriched Regional Ecosystem

Marine & Maritime Sustainability Hub Stage

Seed stage

Various Efforts
Agencies
R&D
Pilots
Network
SMEs
Industries

Potential Pilot Projects





Ocean/Marine Renewable Energy: Marine Solar, Offshore Wind, Tidal In-Stream, Wave

Systems and Eco-Systems' Integration

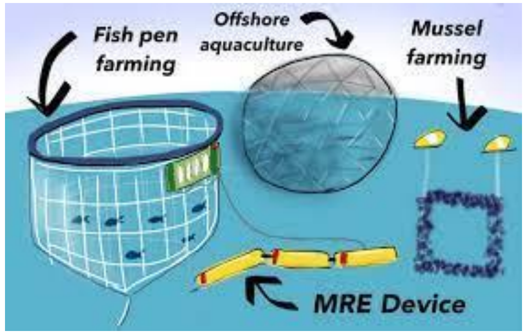
Energy Storage

Testbedding
Other Innovations
Technologies
Business Models
"Learn by Doing"

Transportation

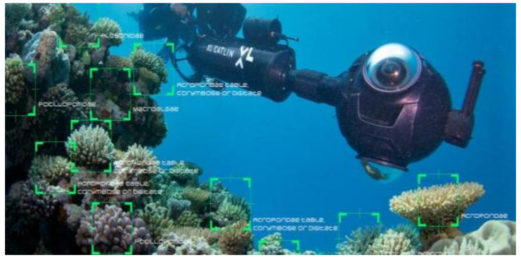
Ice

Aquaculture



Ports/Marinas/Bays

Water Production



Reef Restoration,
Marine Area Monitoring

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Summary / Conclusions / Recommendations

- **Marine Renewable Energy Options Exist**
  - Floating Solar, Offshore Wind (both already commercially viable)
  - Waves and Currents, maybe OTEC and Salinity Gradient
  - Need for a Resource Inventory Review and Suitability Studies for Pilot Projects
- **Green Marine and Maritime Ecosystem**
  - Lower Hanging Fruits – Green Vessels, Green Ports
  - Electrification of a Suite of Applications – Transport, Aquaculture, Water, Ice, Others?
  - Detailed planning of a Sustainable Integrated Development for Islands and Coasts
- **Progressive Development Approach Towards a Blue Economy**
  - Leverage the Marine/Maritime Ecosystem of the Country/Region(s)
  - Capability Development – Local Supply Chain (especially Services)
  - Demonstration and Pilot Projects can accelerate the uptake
  - Hybrid Systems and Co-Application will be key to success

Thank You! ☺

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