

Envirotek Tidal Demo Project in Singapore

Singapore Tidal Energy Demonstration Project



Ocean/Marine Renewable Energy: An Emerging Option

Michael Lochinvar Sim Abundo

Managing Director, OceanPixel Pte Ltd (Singapore)

Mobile: +65 9066 3584

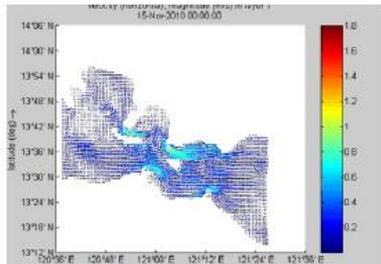
Email: mike@oceanpixel.org

OceanPixel

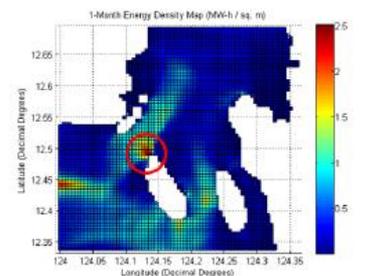
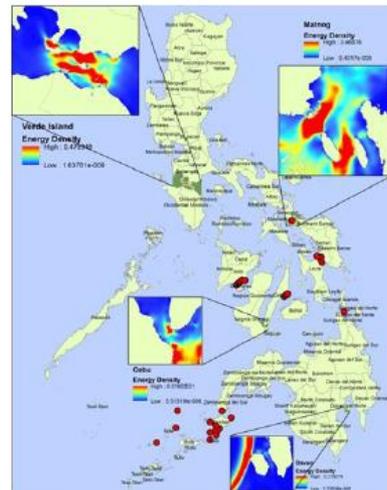
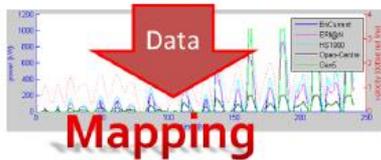
www.oceanpixel.org

OceanPixel is a Singapore start-up company that spun off from the Nanyang Technological University's (NTU) Energy Research Institute. OP is currently engaged in ocean energy projects in Singapore, Indonesia, and the Philippines

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



Turbine Selection	Name	CI	CO	RS	RP	CA	WZM	Cost
<input type="radio"/>	EnCurrent	1.5000	4	3	5	1.1600	0.3100	0.629
<input type="radio"/>	ERIGH	1	4	3	7.5000	1.5000	0.3600	1.561
<input type="radio"/>	HS1000	1.1000	4	2.7000	1000	348	0.2900	103.2
<input type="radio"/>	OpenCe...	0.7000	4	2.5000	200	78	0.3200	368.8
<input type="radio"/>	GenS	1	4	2.5000	160	10	0.3500	13.20



- **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

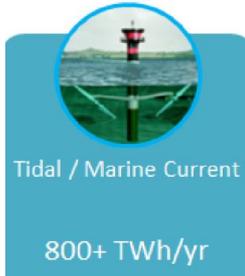
Partners & Collaborators



Energy Research Institute @ NTU



5 Resources of Ocean Renewable



- **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.



- **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.





Global Initiatives



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

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	

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



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

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

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



**>1,000 Sites
200MW each**



Orkney's renewable energy resources

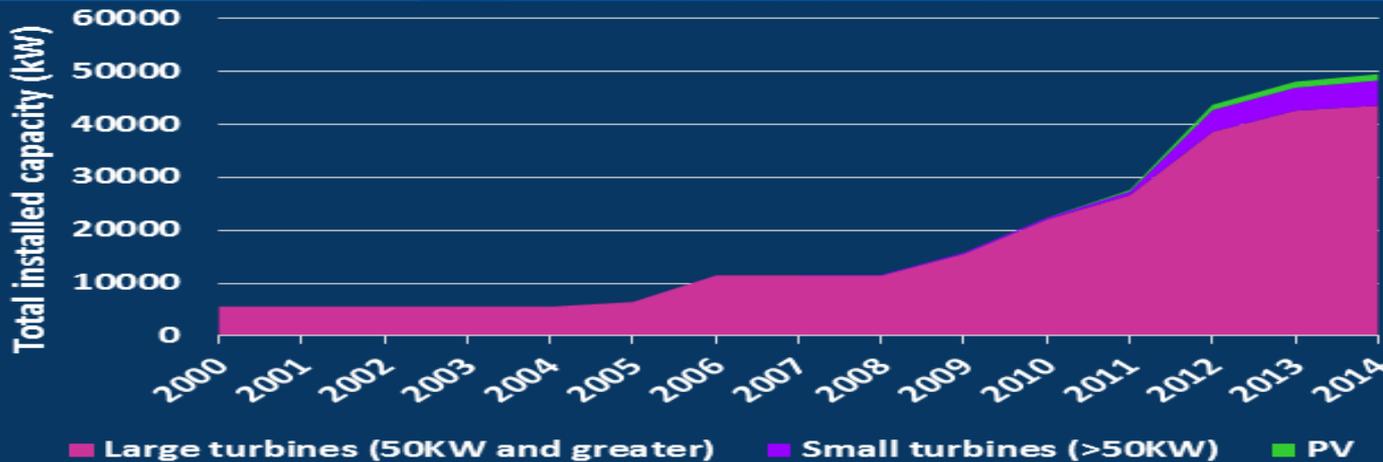
Total = > 5,000 MW deliverable capacity

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	<i>Dispersed</i>
EMEC sites	5 + 7 MW	<i>Dispersed and</i> 



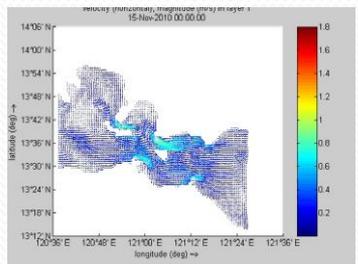
Orkney Islands,
North Scotland, UK

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



Developing Countries' Initiatives

Simulation Studies



Myanmar Tidal Barrage



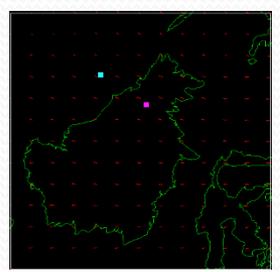
Indonesia Tidal Current Test



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



2003/4 2006/7 2008/9 2009/10 2010/11 2011/12 2013 onwards

Marine Renewable Energy towards the Tropics



SEA + Global

ASEAN Center for Energy

Singapore

Resource

Low Flow (<3m/s), Low Wave, Low Tidal Range

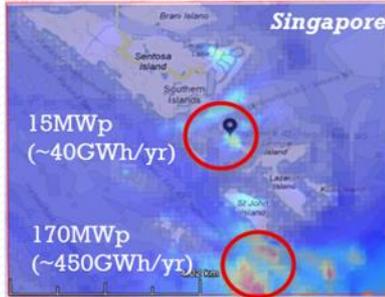
Environment

Shallow Waters, Tropical Biofouling, High Turbidity, Ecology

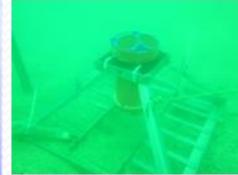
Marine Spatial Planning

Dredging, Reclamation, Shipping Channel/Anchorage, Defence, Protected Areas

Device Assessment



Potential TISE Sites/Locations



Acoustic Doppler Current Profiler



Sentosa

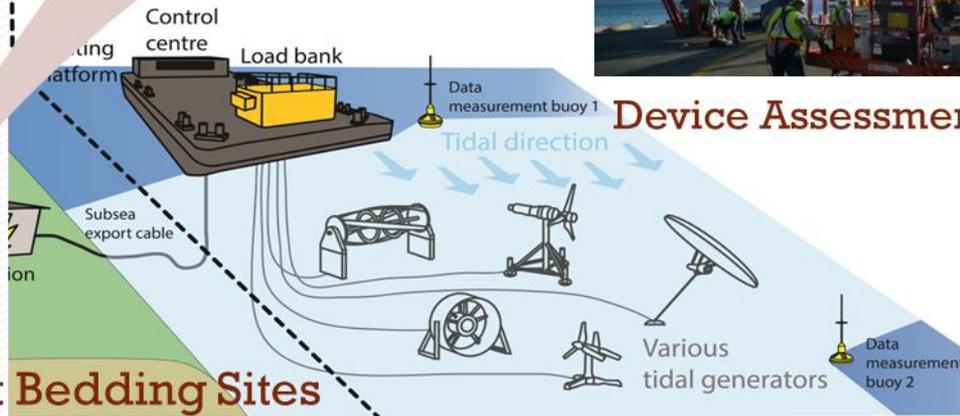


WaveRider



ERI@N

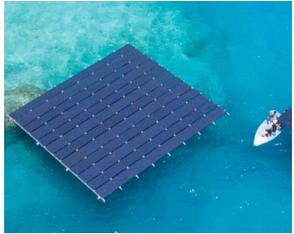
RD&D



Test Bedding Sites

Marine-related RE Options

Floating Solar, Offshore Wind



Very High
Chance of
Feasibility

Up to a
certain
depth



Tidal / Marine Current

800+ TWh/yr

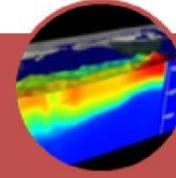
Resource: H
TRL*: High



Waves

80,000 TWh/yr

Resource: H
TRL: Med



Thermal Gradient
(OTEC)

10,000 TWh/yr

Resource: H
TRL: Med

*TRL = Technology Readiness Level



Tides or
Tidal Range (Barrage)
300+ TWh/yr

Present Technologies
need >4m to be
economically viable



Salinity Gradient
2,000 TWh/yr

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

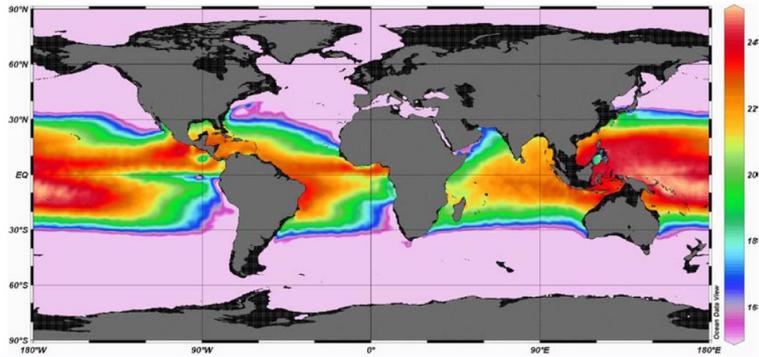
Floating Solar

- In Bodies of water – fresh or salty
- Reservoirs, Lakes, Seas, Bays...
- Use of previously unused or not-so-utilized marine space



Ocean Thermal Energy

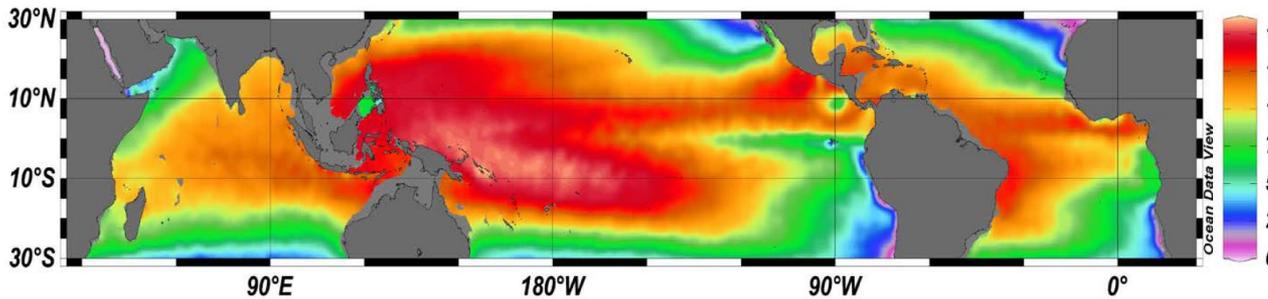
Ocean Thermal (OTEC) Resource



Color palette
15°C to 25°C



Theoretical Resource: World Ocean Atlas (WOA) Annual Average ΔT ($T_{20m} - T_{1000m}$)



Technical Resource: 100 MW OTEC Plant Annual Electricity Generation (GWh)
Baseline: 877 GWh/year @ $\Delta T = 20$ °C



Wave Energy: Various Technology Options

Technology Zones



Hs > 1m



Huge Waves
High Energy
High Risk
Offshore Challenges

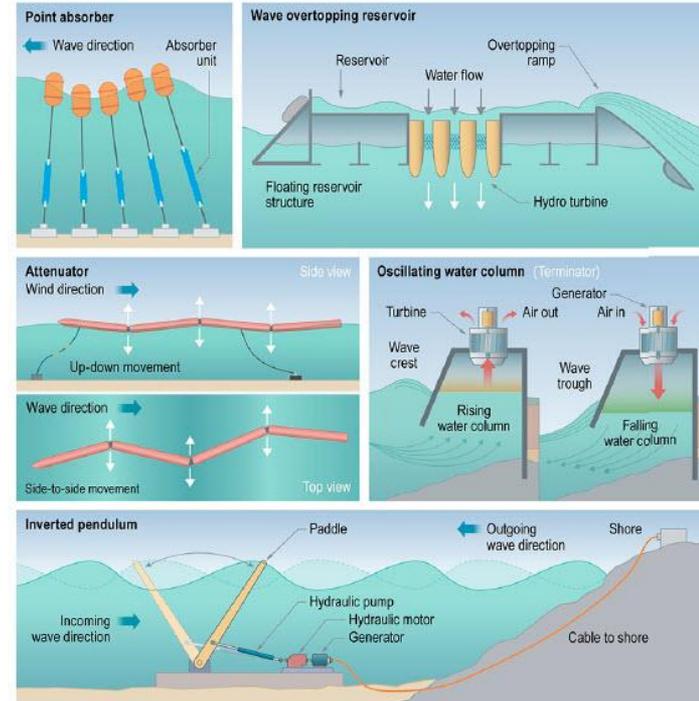
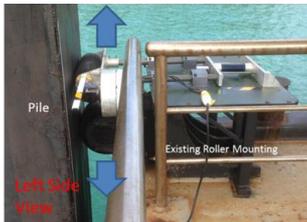
Hs > 0.5m



Hs < 0.5m



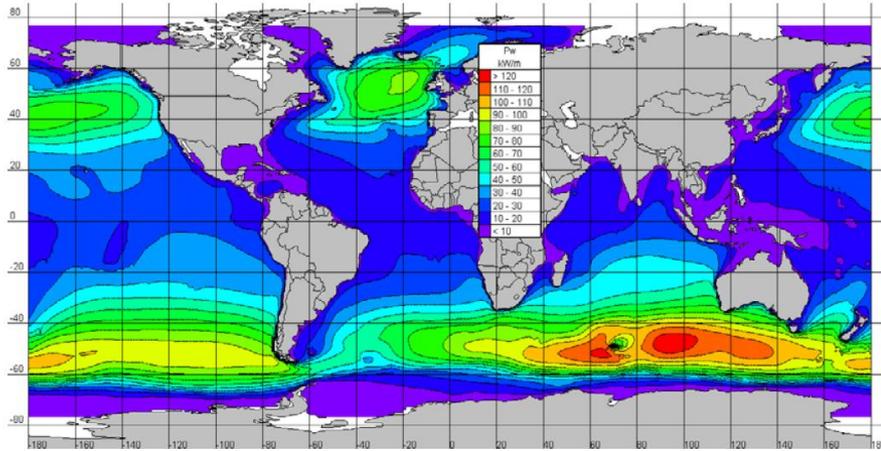
'Dry Setup'
Low Risk
Easier Maintenance



OceanPixel

Confidential

Wave Energy for South East Asia?

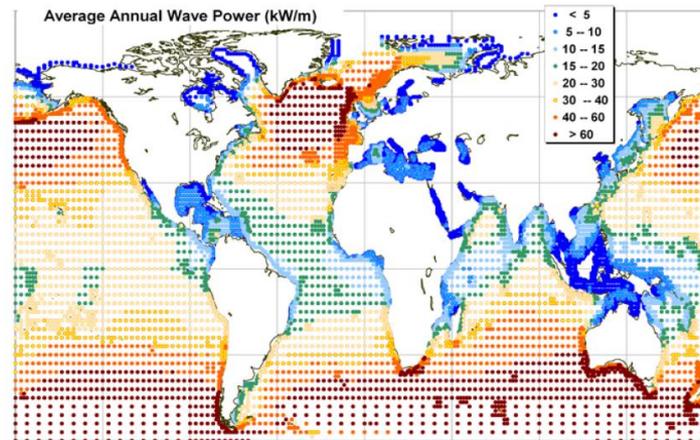


Wave Watch Model

Wave Energy Resource:
5 to 15 kW/m

Theoretical Resource: Deep Water Annual Wave Power Flux (kW/m)

*Input: 1997-2006 Wind Records
Wind-Wave Models calibrated with
satellite altimeter data and buoy data*



WorldWaves Model



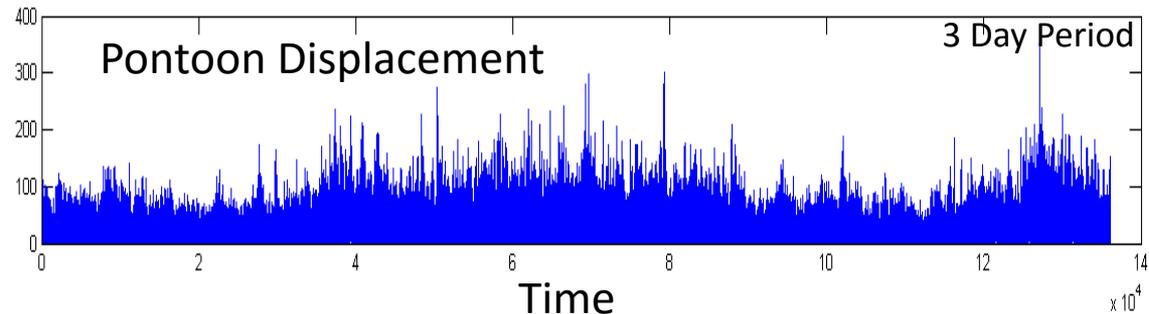
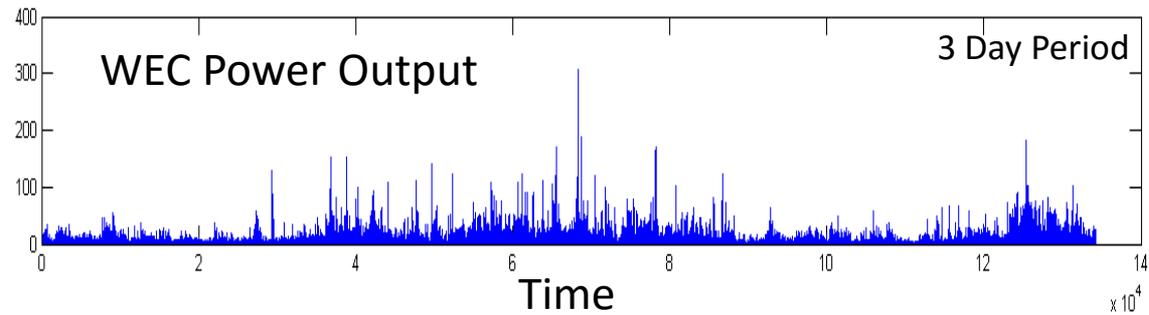
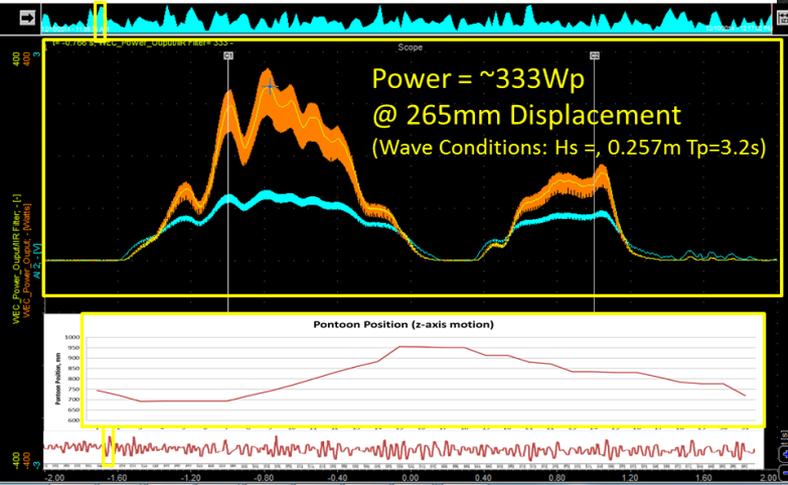
Wave Energy: Albatern's WaveNet Technology



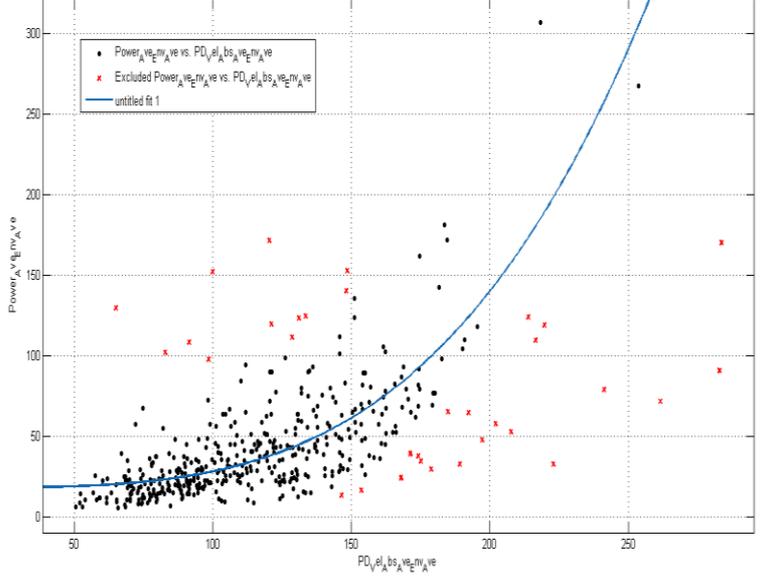
Energy Harvesting with Existing Infrastructure



* Field Data: WEC and Pontoon



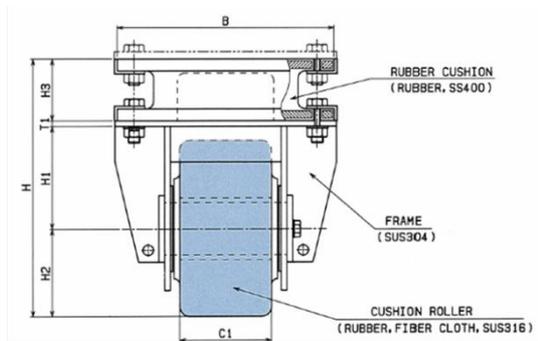
WEC Power VS Pontoon Displacement



Techno-Economics of Pontoon Rollers

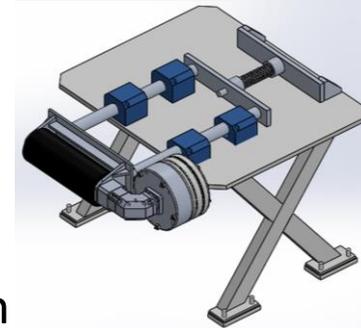
Shibata Rollers (8 per Pontoon)

- Product Cost: $\$8k \times 8 = \$64k$
- Installation Cost ($\$8k$)
- Annual Maintenance ($\$4k$)
 - Rubber Roller Replacement
- Energy Output = 0
- 10-year Lifespan
- Payback: N/A



WEC Pontoon Roller System

- Device Cost: $\$5k \times 8 = \$40k$
- Installation Cost ($\$8k$)
- Annual Maintenance ($\$5k$)
 - Rubber + Parts Replacements
- Energy Output
 - 54 MWh / year
- 10-year Lifespan
 - LCOE: $\sim \$0.15/\text{kWh}$
- Payback = $\sim 6 - 8$ years
 - Assumed Tariff: $\$0.15/\text{kWh}$



Currents – Ocean + Tidal In-Stream Energy

Highly Predictable
(Hourly, and 18.6 year into future)

Relatively More Mature Technology
(availability and support)

Clean and Renewable

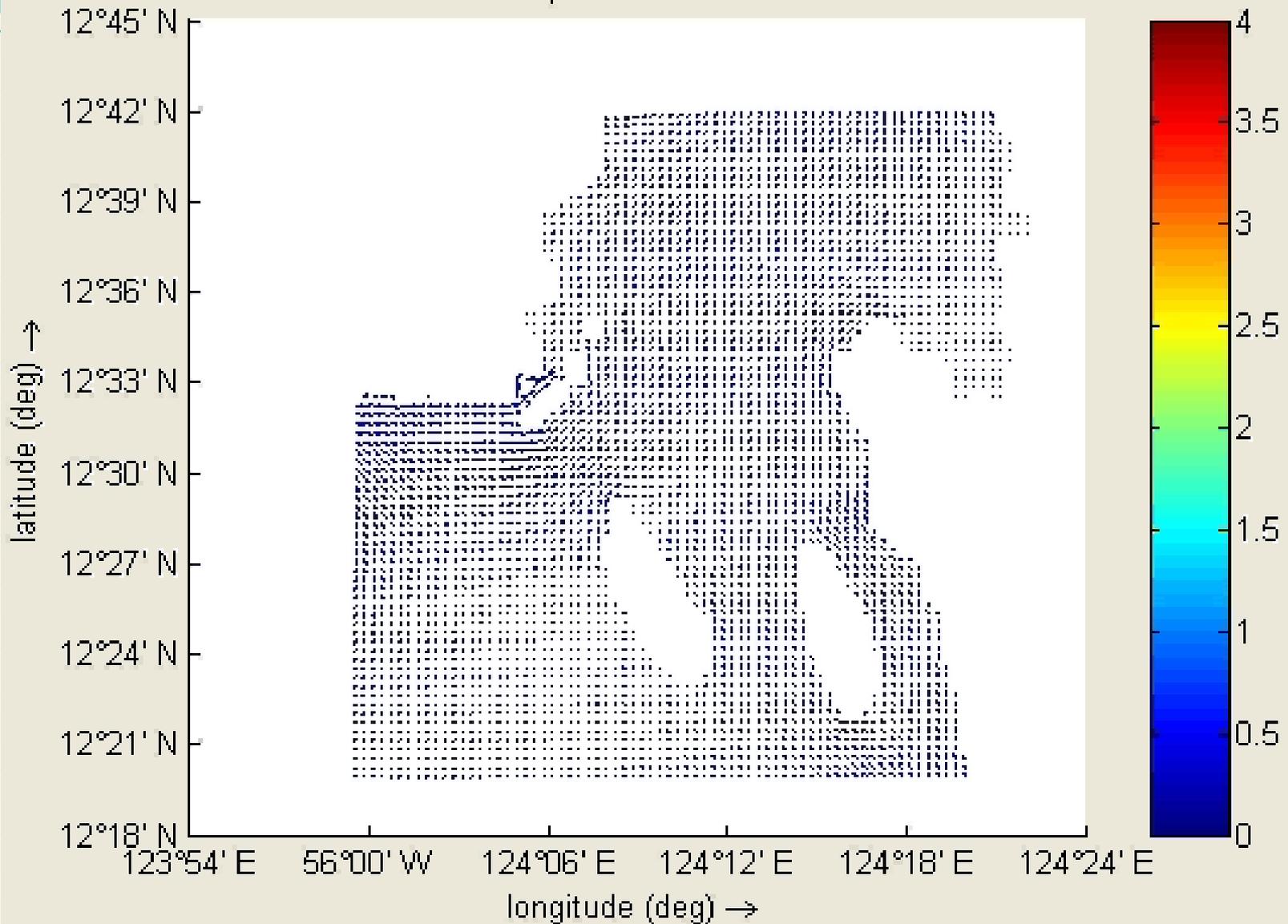
Multiple Commercial Sites
(UK, Europe, Canada)

Applications
(Off-Grid, Diesel Replacement)

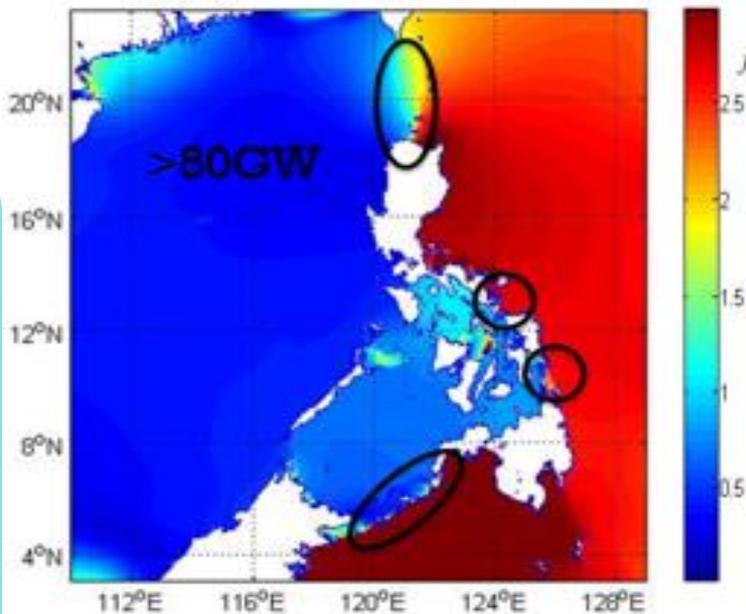
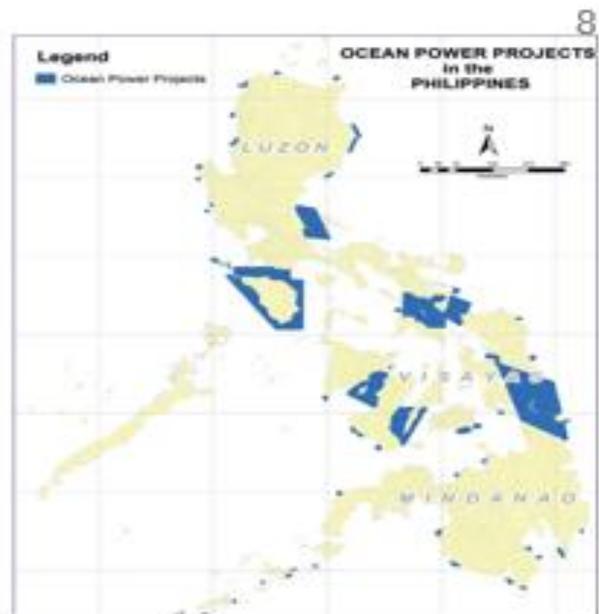
Timeline: 2003/4, 2006/7, 2008/9, 2009/10, 2010/11, 2011/12, 2013 onwards

depth averaged velocity, magnitude (m/s)

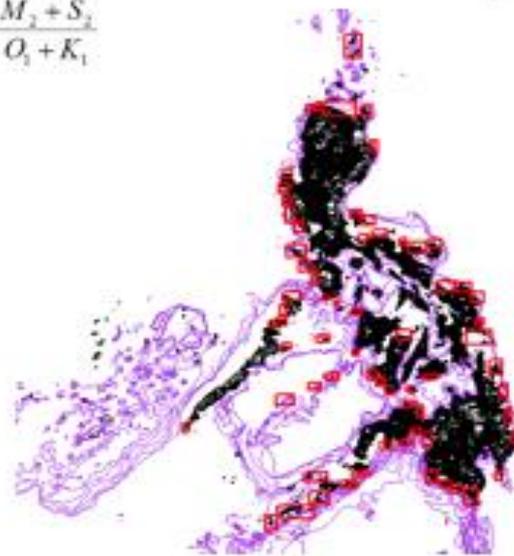
01-Apr-2011 01:00:00



* ORE Potential: Philippines (170 GW)



Tidal In-Stream Energy Potential Sites



Wave Energy Potential Sites



OTEC Route to Grid Parity

Potential Technology Demo/Pilot



Woodchip Plant, Indonesia



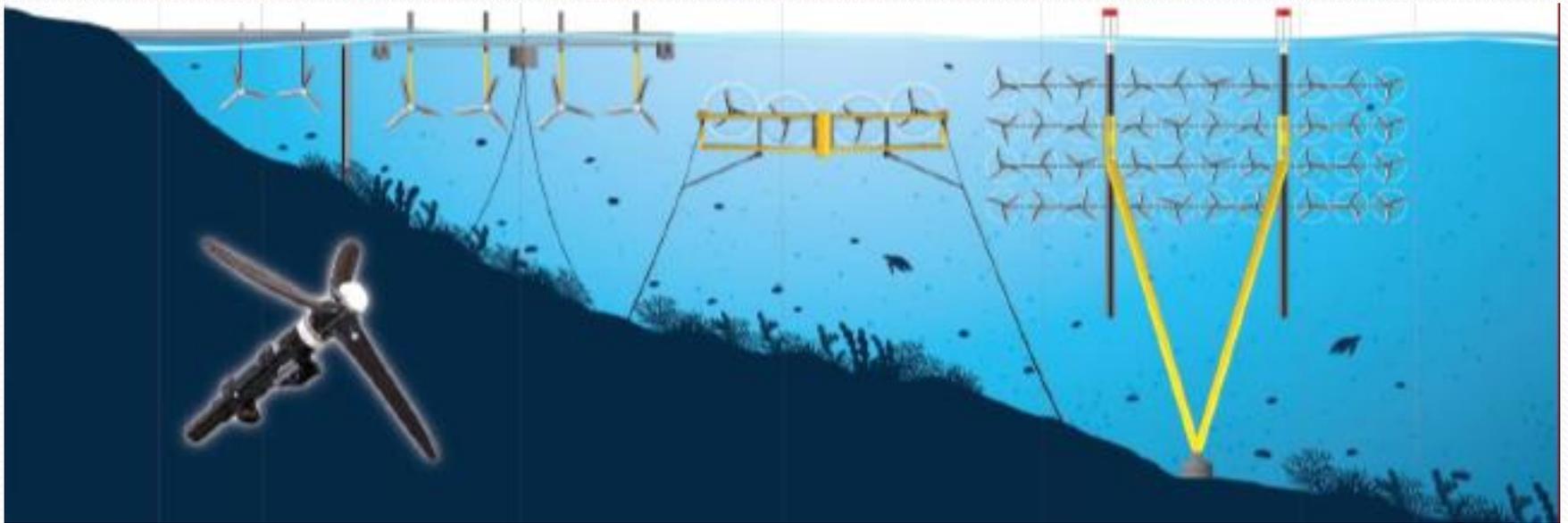
Sentosa, Singapore



Orkney, Scotland



Configuration Options for TISE

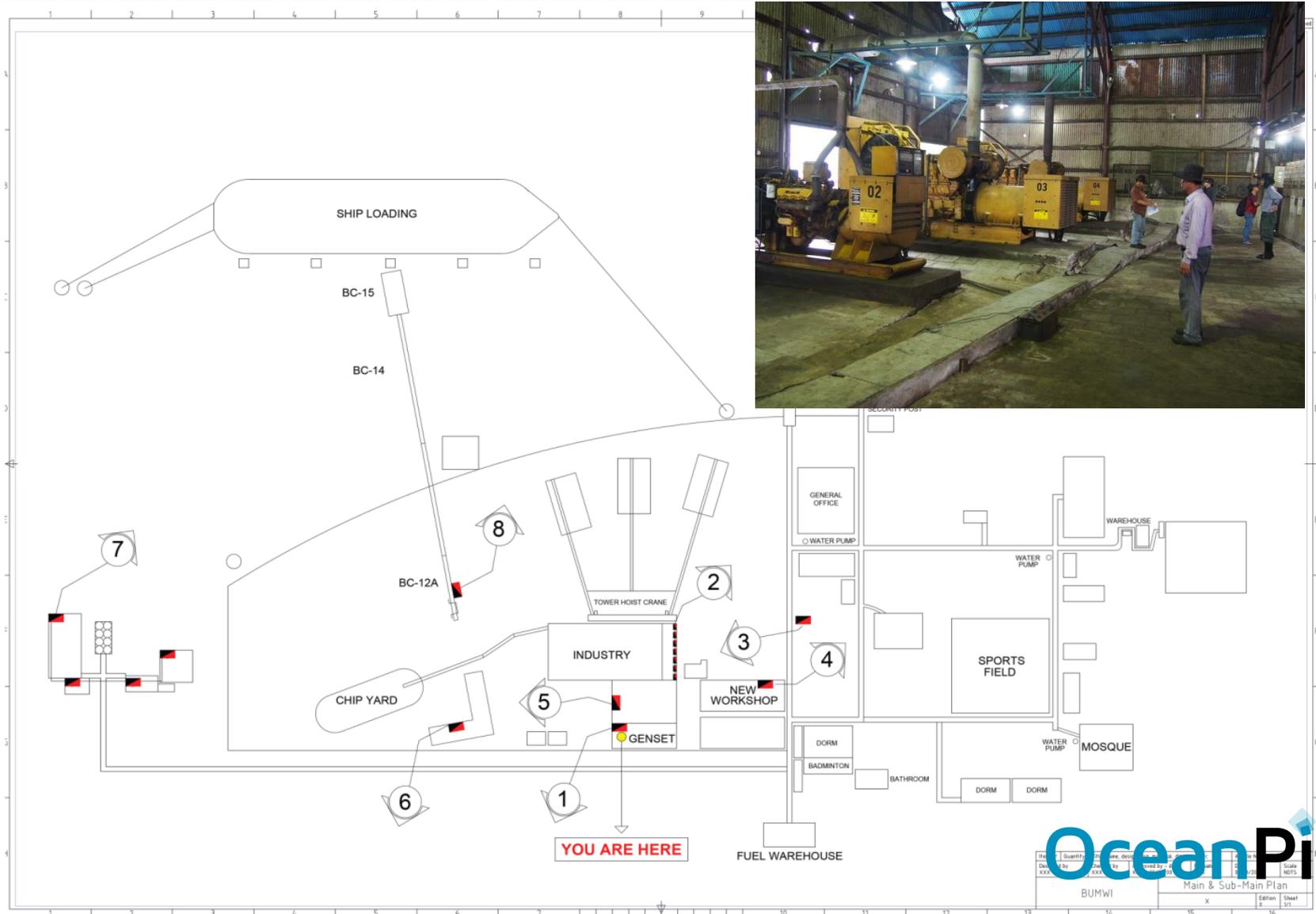


SEA Case Study: Island with Industry

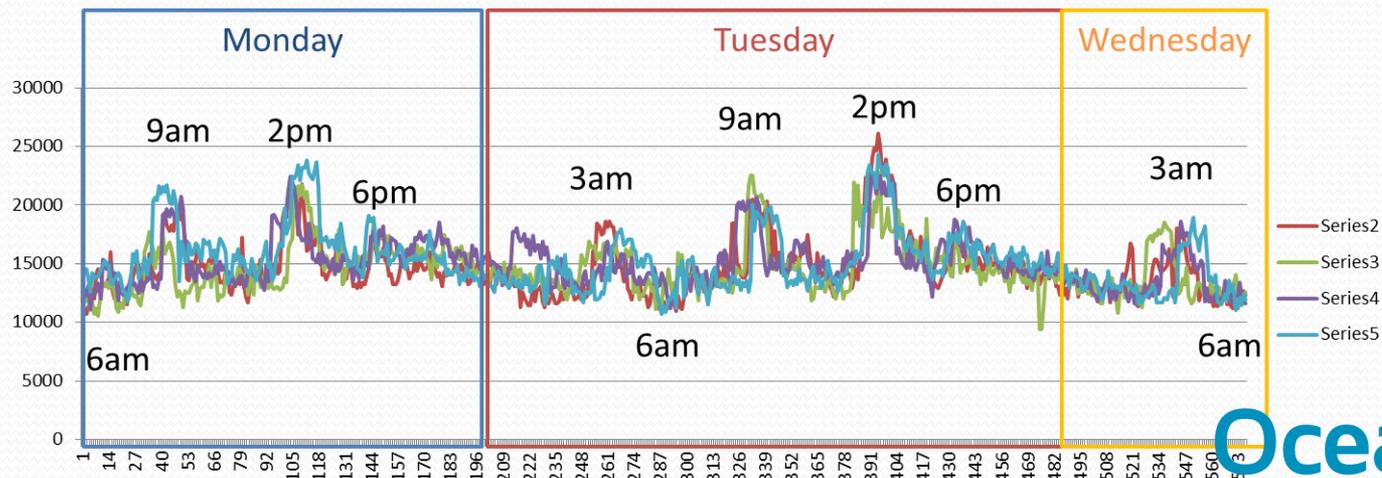
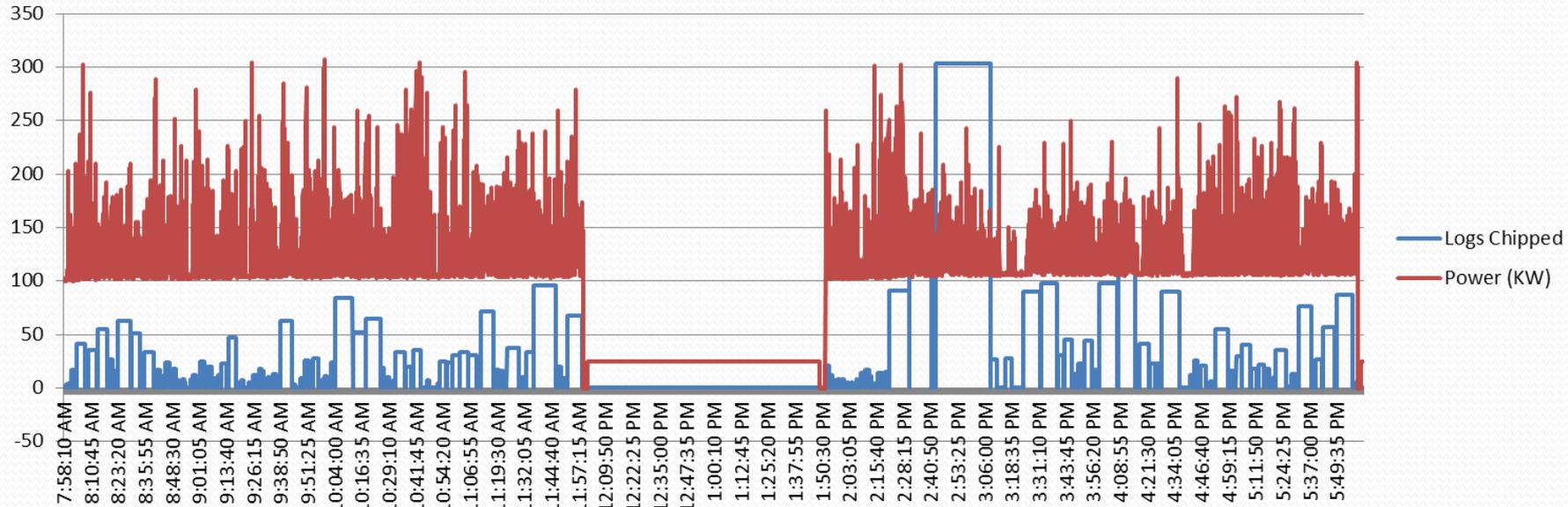


TLC200 PRO 2015/07/17 13:16:20

The BUMWI Micro-Grid

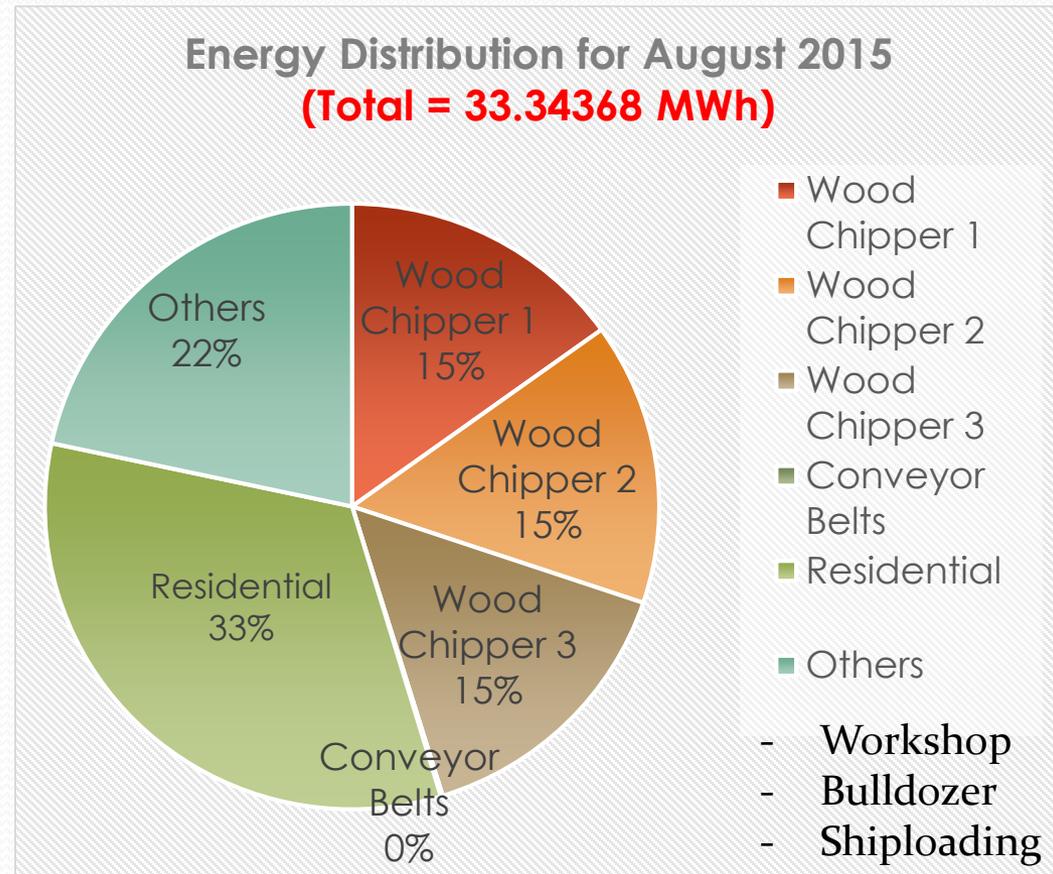


Industrial Island Energy Use



Summary of Energy Statistics

- **Diesel Cost (Aug)**
 - 18,800li x \$0.89/li
 - **\$16,732**
- **Eff. Electricity Rate:**
 - **\$0.5/kWh**
- **Electricity Costs**
 - ~\$7,563 Industry
 - ~\$5,502 Residential
 - ~\$3,667 Others
- **Electricity Cost/Log:**
\$0.045
 - Logs/Month:~165k
 - 21 x 7,870 logs/day





Tidal Turbine Utility Pole



Tidal power in West Papua, Indonesia



Initiated by:



GREEN FOREST
PRODUCT &
TECHNOLOGY

**PT. Bintuni Utama
Murni Wood Industries
(BUMWI)**

Supported by:

OceanPixel



aquatera
environmental services and products



Energy Research Institute @ NTU



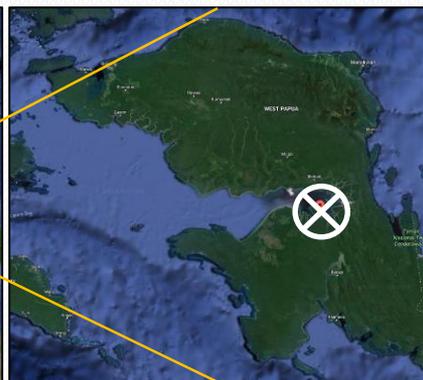
BUMWI's mangrove chipping operation in West Papua is the first of its kind to receive sustainability certification from the Forestry Stewardship Council (FSC®).



The carbon footprint of the plant is now set to be reduced by harnessing power from nearby tidal currents.



The BUMWI facility is located on the southern side of Bintuni Bay, West Papua, Indonesia



Tidal power in West Papua, Indonesia



Initiated by:  GREEN FOREST PRODUCT & TECHNOLOGY

Supported by:    

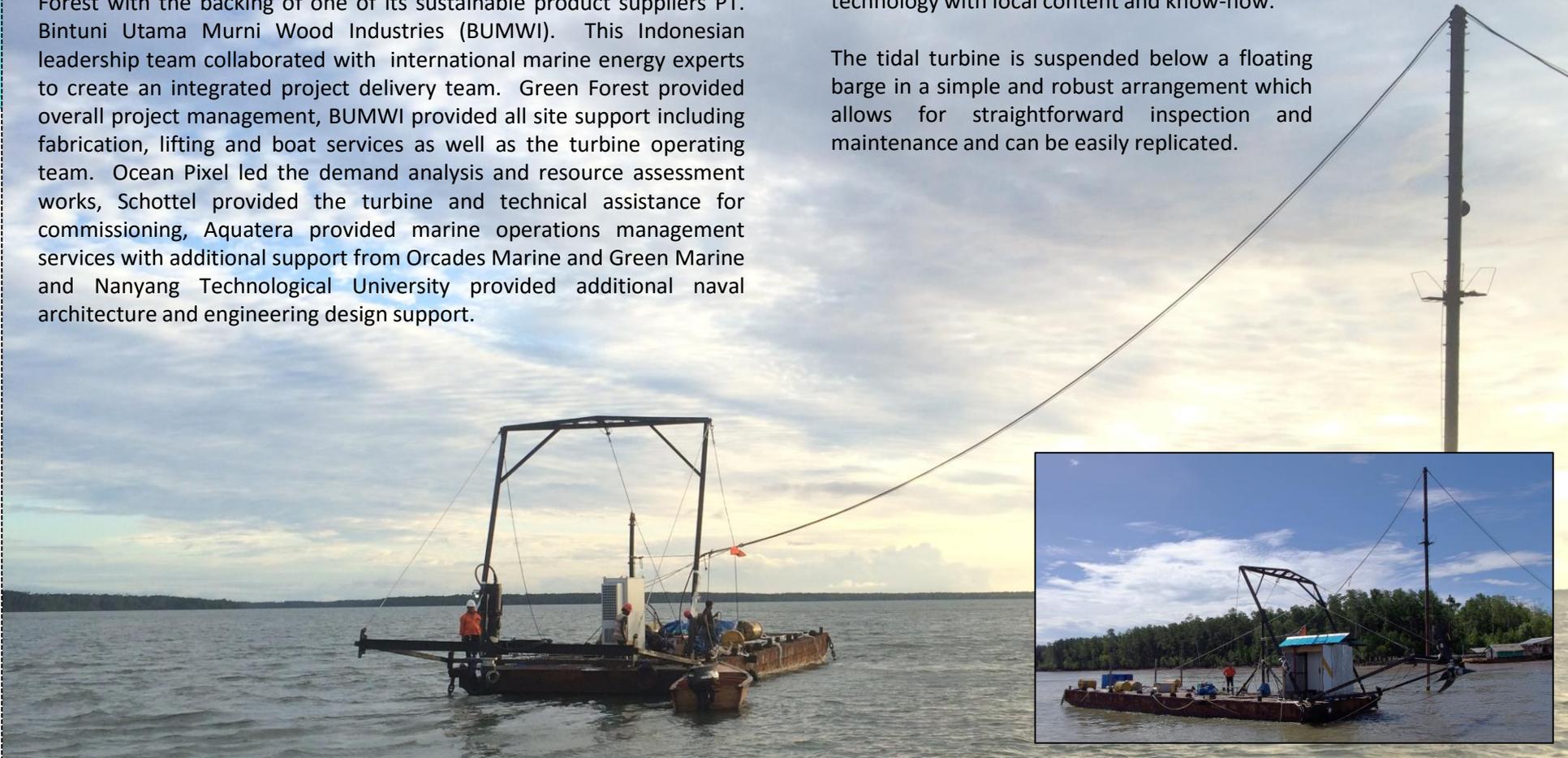
PT. Bintuni Utama Murni Wood Industries (BUMWI)

Energy Research Institute @ NTU

The project was initiated by international wood product trader Green Forest with the backing of one of its sustainable product suppliers PT. Bintuni Utama Murni Wood Industries (BUMWI). This Indonesian leadership team collaborated with international marine energy experts to create an integrated project delivery team. Green Forest provided overall project management, BUMWI provided all site support including fabrication, lifting and boat services as well as the turbine operating team. Ocean Pixel led the demand analysis and resource assessment works, Schottel provided the turbine and technical assistance for commissioning, Aquatera provided marine operations management services with additional support from Orcades Marine and Green Marine and Nanyang Technological University provided additional naval architecture and engineering design support.

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

Simulation Results

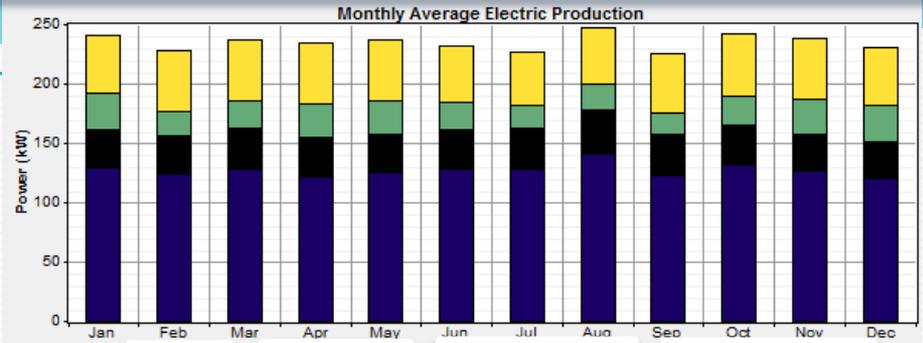
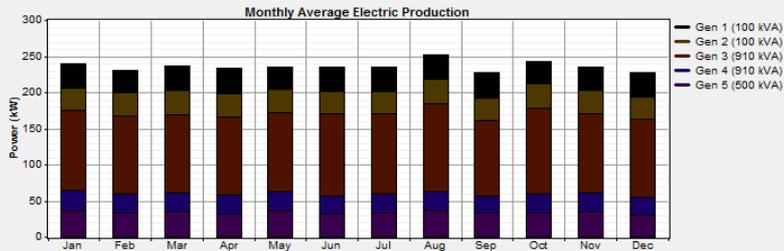
System Architecture: 80 kW Gen 1 (100 kVA) 728 kW Gen 4 (910 kVA)
 80 kW Gen 2 (100 kVA) 400 kW Gen 5 (500 kVA)
 728 kW Gen 3 (910 kVA)

Total NPC: \$ 9,034,855
 Levelized COE: \$ 0.399/kWh
 Operating Cost: \$ 699,805/yr

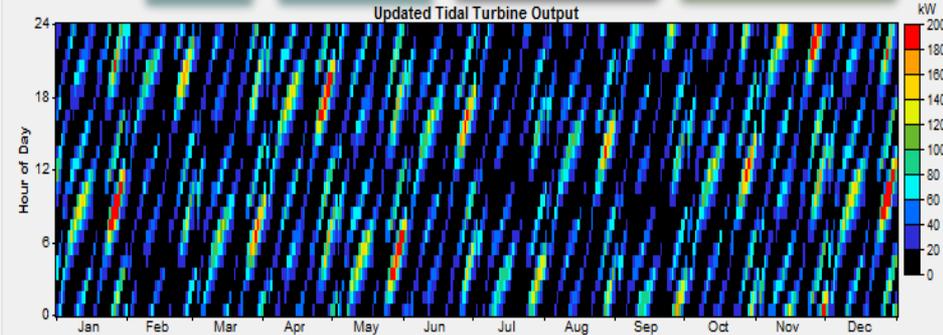
Cost Summary | Cash Flow | **Electrical** | 80kW | 80kW | 728kW | 728kW | 400kW | Emissions | Hourly Data

Production	kWh/yr	%	Consumption	kWh/yr	%	Quantity	kWh/yr	%
Gen 1 (100 kVA)	290,872	14	AC primary load	1,769,520	100	Excess electricity	299,510	14.5
Gen 2 (100 kVA)	279,858	14	Total	1,769,520	100	Unmet electric load	0.00409	0.0
Gen 3 (910 kVA)	969,919	47				Capacity shortage	0.00	0.0
Gen 4 (910 kVA)	228,012	11						
Gen 5 (500 kVA)	300,357	15				Quantity	Value	
Total	2,069,018	100				Renewable fraction	0.00	

DIESEL Generators Only



PV Tidal DG-100 DG-910



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%

0.50

Envirotek Tidal Demo Project in Singapore

Singapore Tidal Energy Demonstration Project

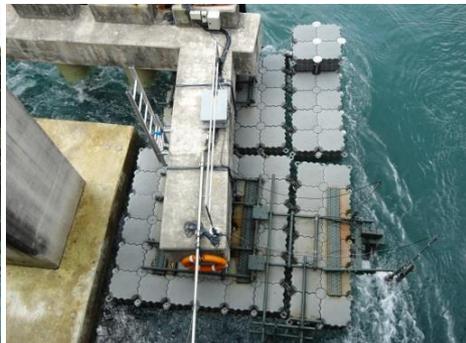


Title: TIDAL IN-STREAM ENERGY DEMONSTRATION IN SG (50kW)

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

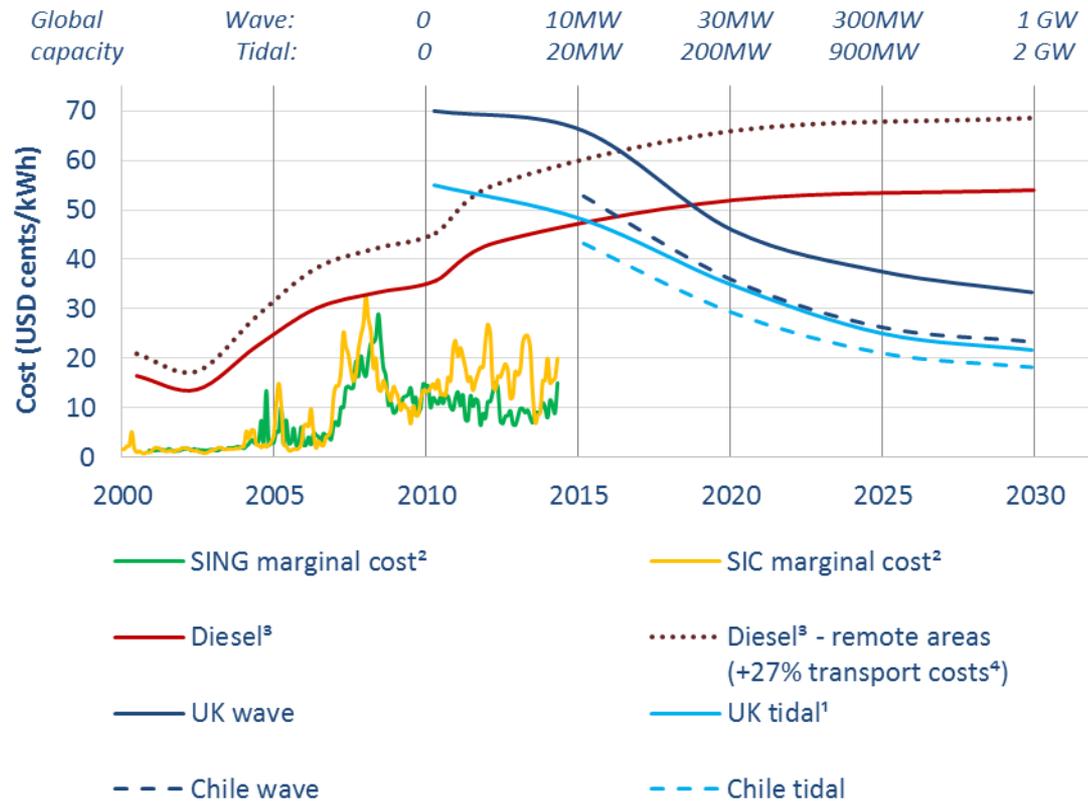
Start: November 2015 Deployment: February 2017 End: -

OceanPixel





Wave and tidal



Marine energy markets:



LONG TERM
Grid electricity



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



SHORT TERM
Remote diesel replacement

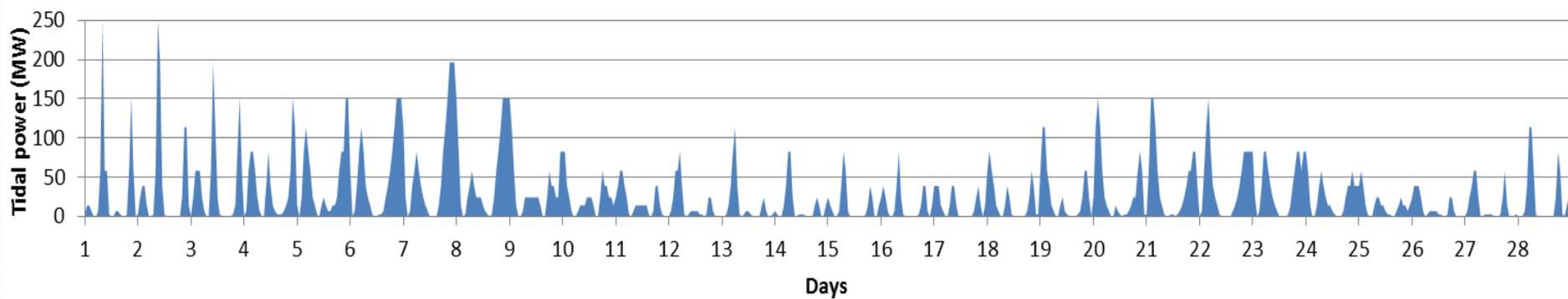
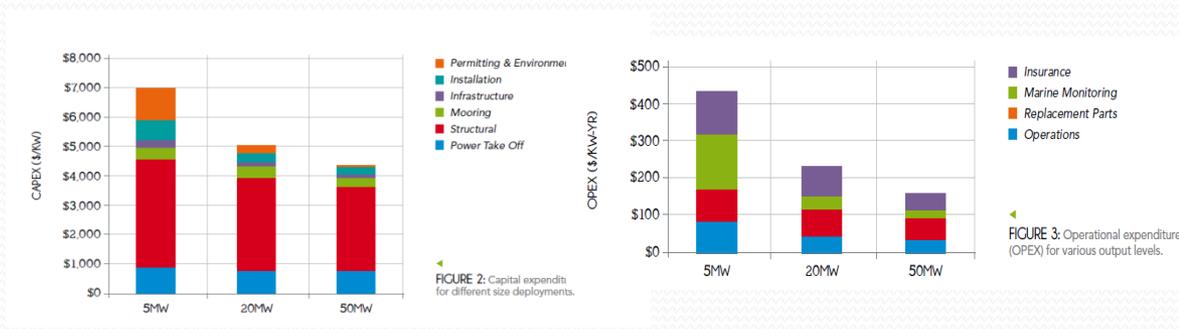
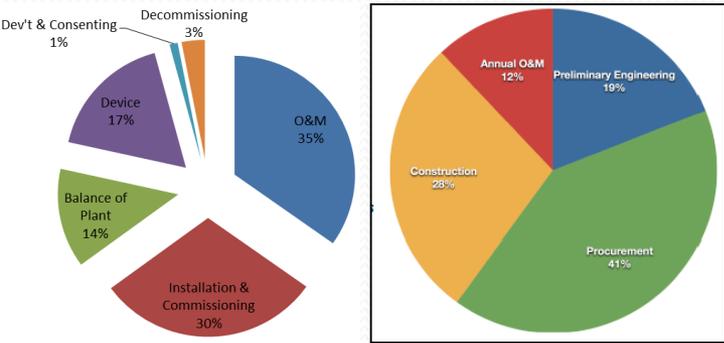
Sources: ¹Carbon Trust; ²CNE; ³World Bank/Bloomberg; ⁴Chilean Ministry of Energy

Some Costs in South East Asia

- Sinkers: \$500 to \$1k / ton → \$100/ton
- Surveys (ADCP Transect + Seabed-mounted): \$100k → \$30k-\$50k
- Barge-Based Floating Support System: \$250k → \$50k to \$100k
- Tug boats / Survey Vessels: ~\$10k/day → \$1k - \$5k/day
- Feasibility Studies: \$500k-600k/site → \$150k - \$300k/site
 - Environment Compliance Certificate (5MW to <100MW): \$50k-\$100k
- Deployed 2m Diameter Tidal Turbine
 - Support Structure(Floating)+Mooring+Installation = \$60k
- Piling, Crane Barges, Cabling...

Techno-Economics

- Levelized Cost of Energy (LCOE) = \$\$\$/kWh

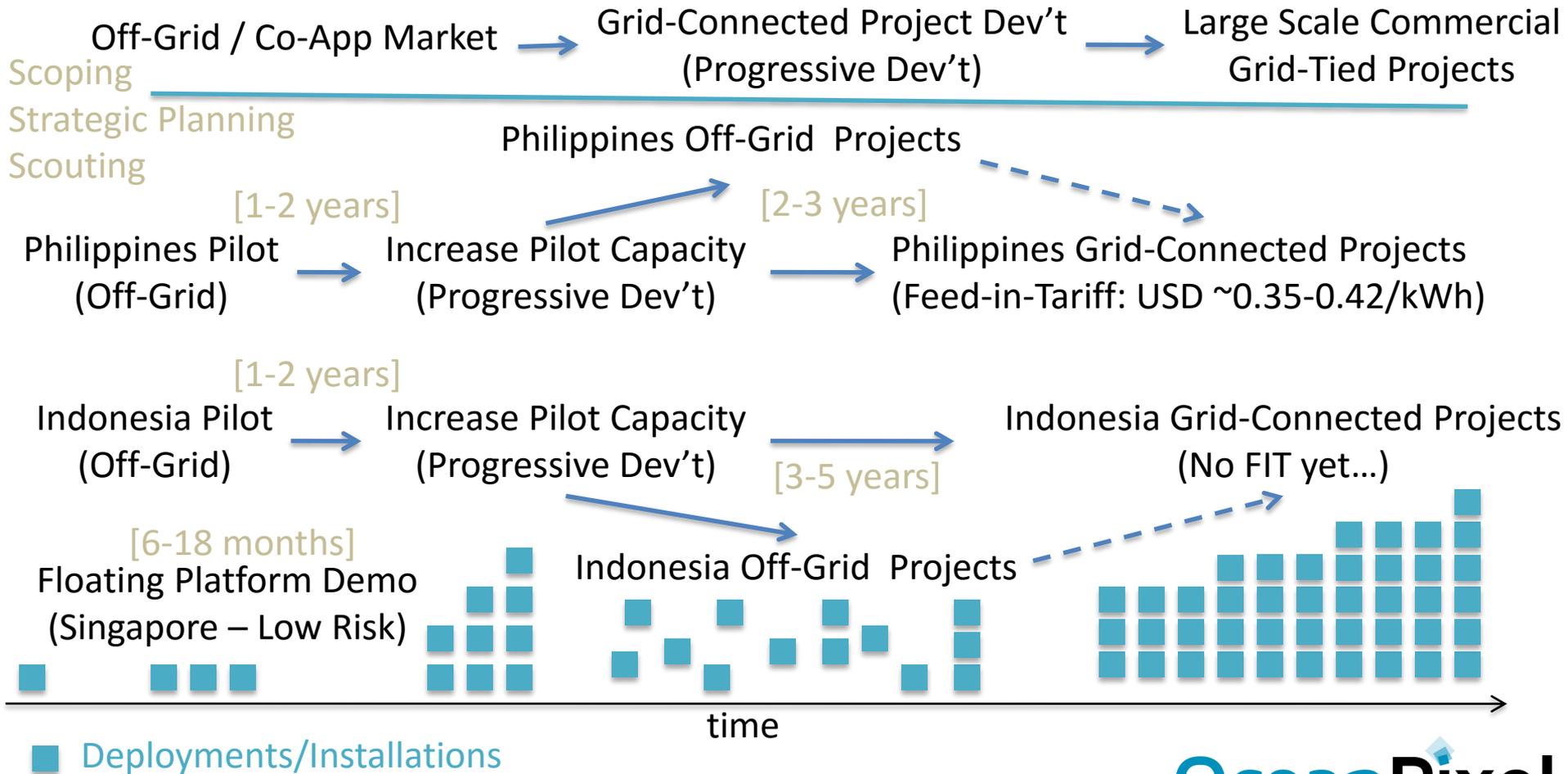


LCOE, IRR, Feed-in-Tariff

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%	IRR = 14%	ROI = 32%	IRR = 6%		
	Profit = ~USD 358M	Payback = ~6.5 yrs	Profit = ~USD 177M	Payback = ~11 yrs		
13.5	ROI = 163%	IRR = 21%	ROI = 78%	IRR = 11%	ROI = 1%	IRR = 3%
	Profit = ~USD 616M	Payback = ~5 yrs	Profit = ~USD 434M	Payback = ~7.6 yrs	Profit = ~USD 9M	Payback = ~16.2 yrs
17	ROI = 232%	IRR = 28%	ROI = 124%	IRR = 15%	ROI = 27%	IRR = 5%
	Profit = ~USD 873M	Payback = ~3.5 yrs	Profit = ~USD 691M	Payback = ~6.3 yrs	Profit = ~USD 267M	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%	IRR = 14%	ROI = 35%	IRR = 6%		
	Profit = ~USD 718M	Payback = ~6.5 yrs	Profit = ~USD 354M	Payback = ~11 yrs		
13.5	ROI = 164%	IRR = 21%	ROI = 78%	IRR = 11%	ROI = 1%	IRR = 3%
	Profit = ~USD 1,233M	Payback = ~4.5 yrs	Profit = ~USD 869M	Payback = ~7.6 yrs	Profit = ~USD 20M	Payback = ~16.2 yrs
17	ROI = 232%	IRR = 28%	ROI = 124%	IRR = 15%	ROI = 27%	IRR = 5%
	Profit = ~USD 1,748M	Payback = ~3.5 yrs	Profit = ~USD 1,384M	Payback = ~6.3 yrs	Profit = ~USD 535M	Payback = ~12 yrs

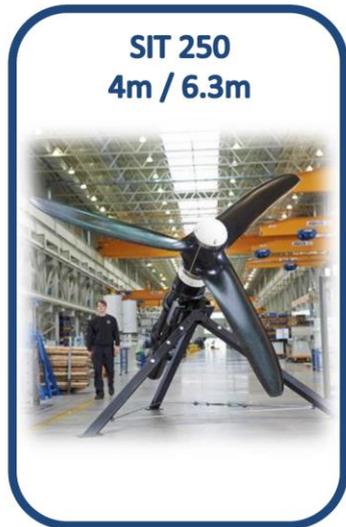
Hybridized Marine RE Pathway in SEA





Raffles' Lighthouse, Singapore

Tidal energy solutions; available as turnkey integrated systems and standalone products



- SCHOTTEL Instream Turbine
- Max power output 62kW
- 4m or 6.3m rotor



- Solutions for combining electrical output from multiple turbines
- Control and data acquisition for SITs and platforms



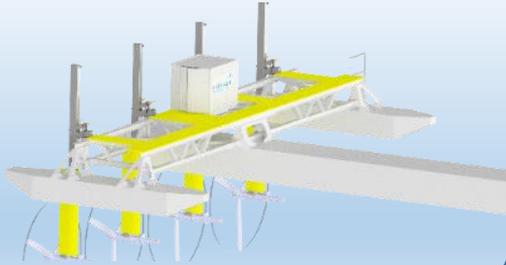
- Submerged (offshore)
- Floating (Inshore)
- Designed for ease of installation and maintenance access



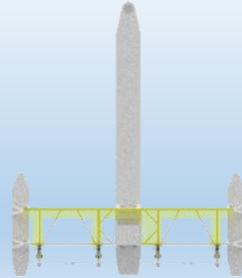
- High performance, low cost, anchors to replace gravity systems
- Solutions for rock and soft seabeds

PLAT-I (Inshore)

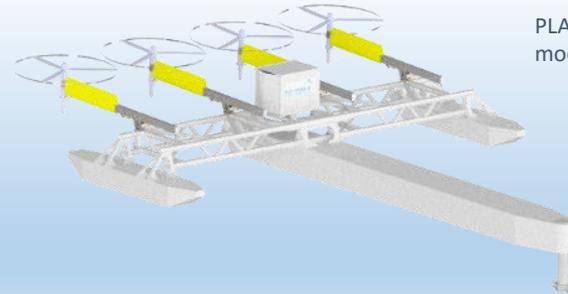
PLAT-I – SITs deployed



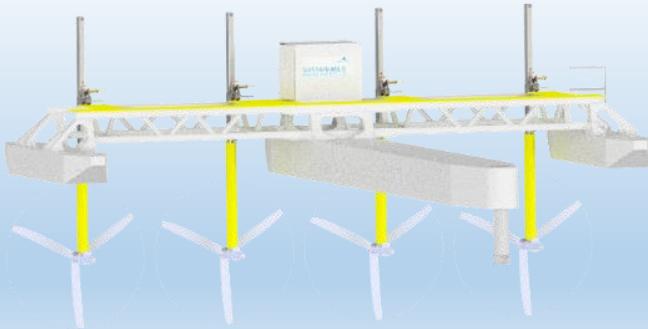
PLAT-I – Birds eye view



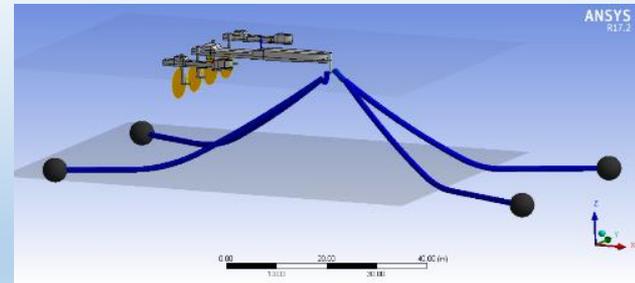
PLAT-I – SITs in transit mode



PLAT-I – SITs deployed

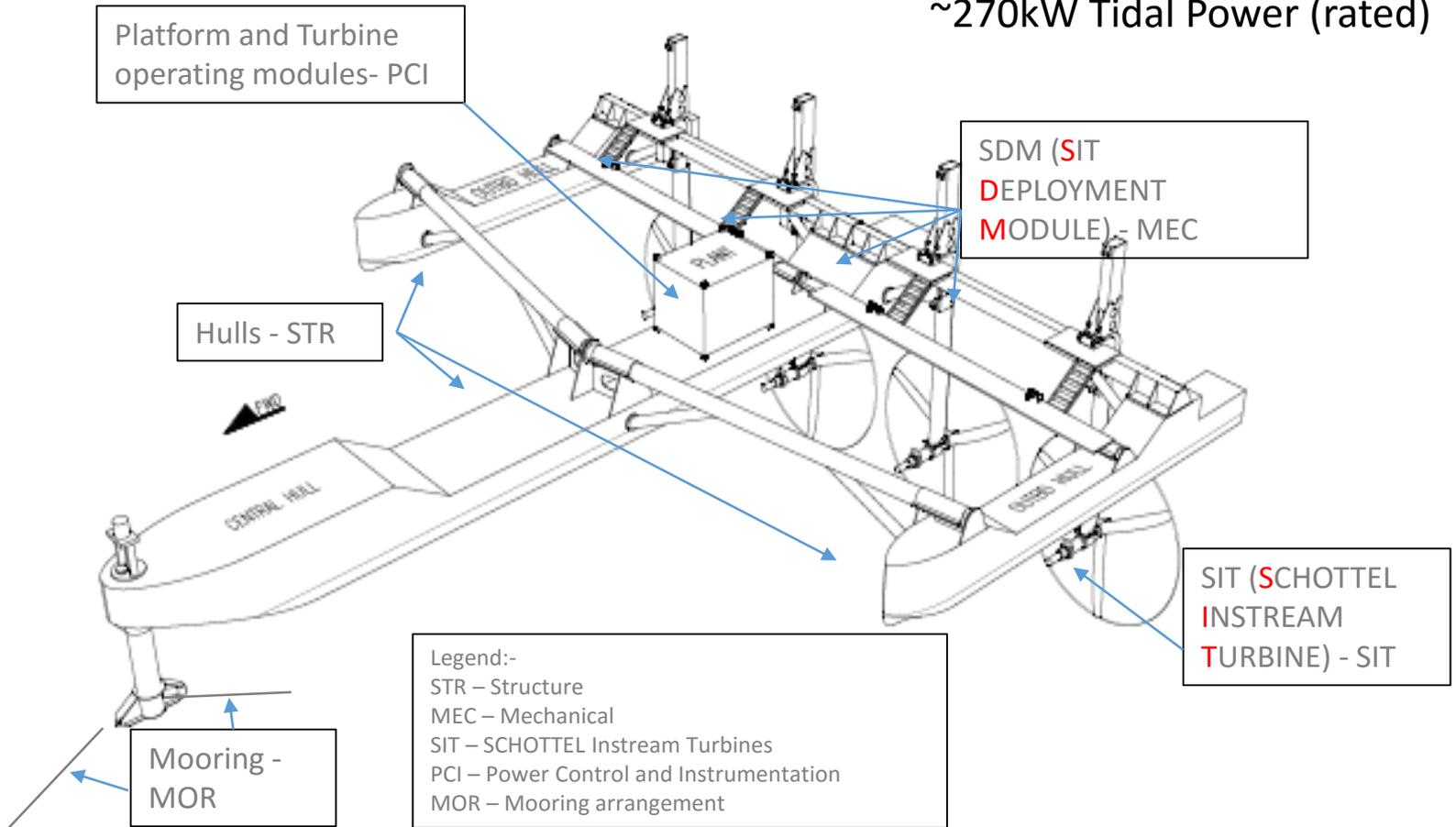


PLAT-I – Mooring spread



PLAT-I - SCHEMATIC

~270kW Tidal Power (rated)



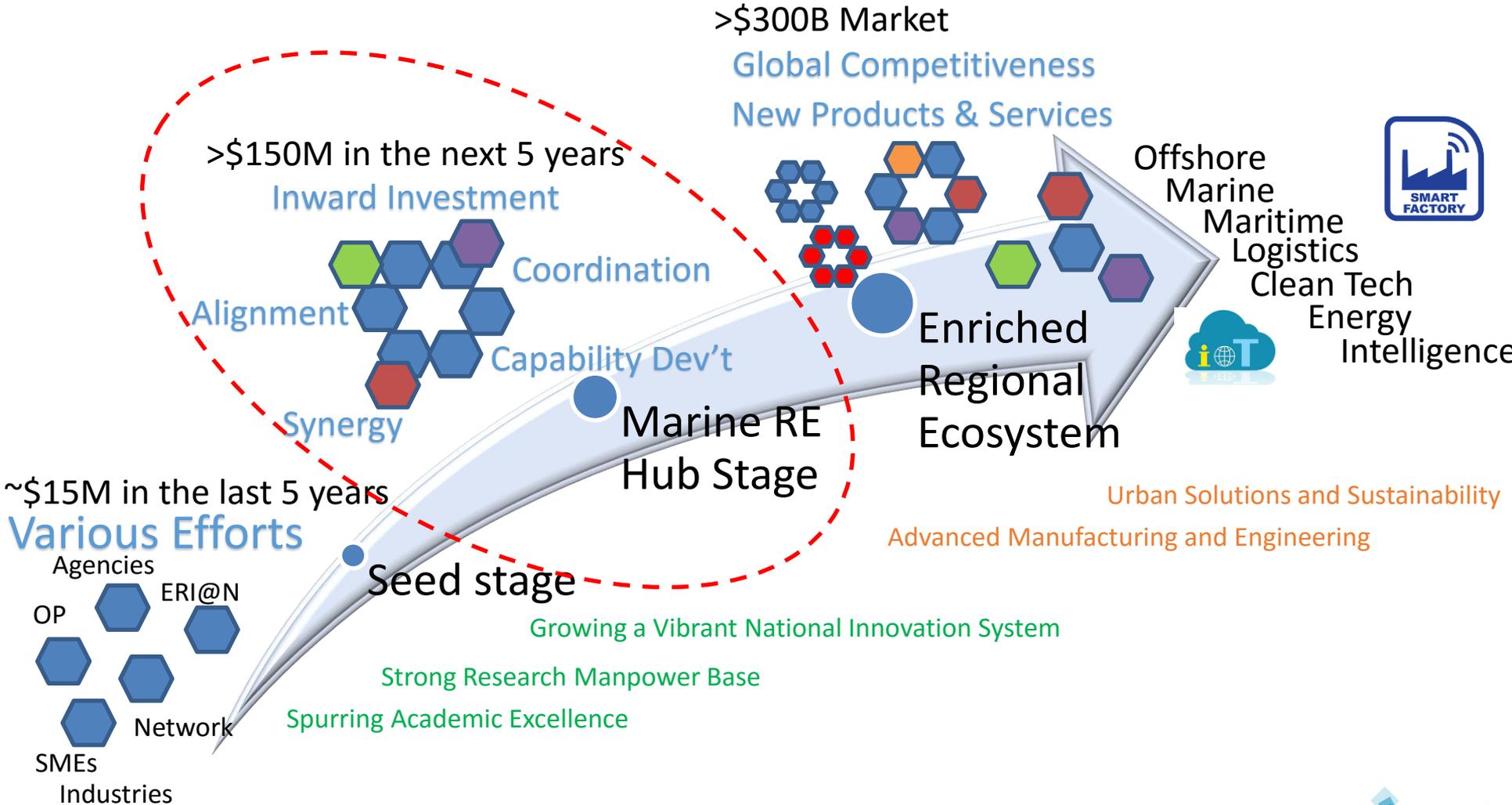


Renewable Energy Integration Demonstrator - Singapore



REIDS Renewable Energy Integration Demonstrator Singapore

Building the Global Future of Ocean/Marine RE in SEA



The NEED for a Marine Renewable Energy Hub

Need for Ecosystem Alignment, Coordination, Steering

RD&D

Education and Training

Capability Dev't

Networking (Business Dev't and Market Dev't)

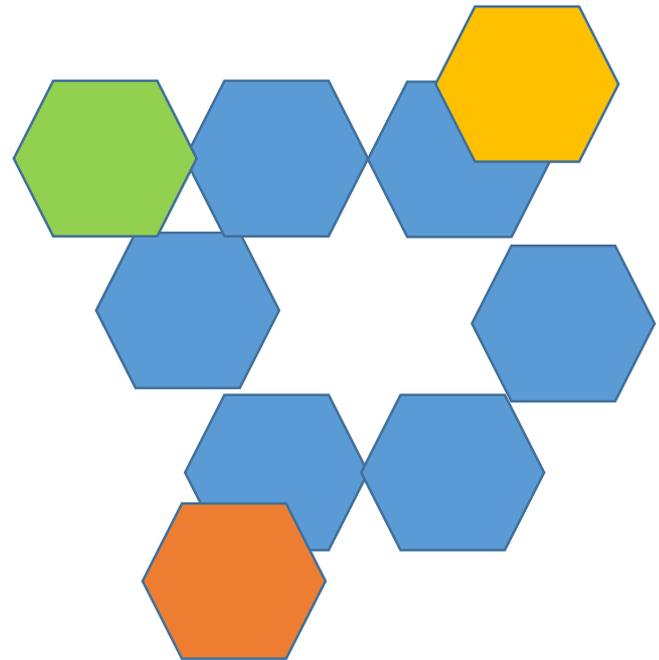
Advisory, Matching, Mentoring

Project Delivery Teams

Financing and Investment

Impact, Socio-Economic, Politico-Legal, Governance

Others



Summary / Conclusions / Recommendations

- ▶ **Ocean/Marine-based Renewable Energy Options Exist**
 - ▶ Waves and Currents, maybe OTEC
 - ▶ Floating Solar, Offshore Wind
 - ▶ Stakeholders must recognize these options and be open to them
- ▶ **Need for a Proper Resource Inventory and Suitability Studies**
 - ▶ Assessment of Marine RE Resources, Sites, Constraints, etc. driven at a National Level with Support from Local Stakeholders
 - ▶ Data Collation, Access, and Management will enable RE uptake
- ▶ **Progressive Development Approach**
 - ▶ Leverage the Marine/Maritime Ecosystem of the Region
 - ▶ 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
 - ▶ Island Micro-grids may very well be Early Adopters

Thank you! 😊

Michael Lochinvar Sim Abundo (Dr)

Managing Director, OceanPixel Pte Ltd (Singapore)

Mobile: +65 9066 3584

Email: mike@oceanpixel.org

OceanPixel
www.oceanpixel.org