Envirotek Tidal Demo Project in Singapore

Singapore Tidal Energy Demonstration Project
Ocean/Marine Renewable Energy: An Emerging Option

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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.

- **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

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**Partners & Collaborators**

- **aquatera**
  - Environmental services and products

- **Nanyang Technological University**
  - Energy Research Institute @ NTU

- **VOS**
  - DHI

- **ITP**
  - Exceedence
  - Making renewables commercial

- **seacore**
  - Southeast Asian collaboration for ocean renewable energy
Ocean Renewable Energy

5 Resources of Ocean Renewable Energy

- **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.
>1,000 Sites
200MW each
**Orkney’s renewable energy resources**

Total = > 5,000 MW deliverable capacity

<table>
<thead>
<tr>
<th>Key</th>
<th>Capacity</th>
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<tbody>
<tr>
<td>Onshore wind</td>
<td>40 MW existing/planned</td>
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<tr>
<td>New onshore wind</td>
<td>100-200 MW</td>
</tr>
<tr>
<td>Wave</td>
<td>500-1000 MW</td>
</tr>
<tr>
<td>Tidal</td>
<td>500-2,500 MW</td>
</tr>
<tr>
<td>Offshore wind</td>
<td>1000 MW</td>
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<tr>
<td>Wave leases</td>
<td>550 MW</td>
</tr>
<tr>
<td>Tidal leases</td>
<td>500 MW</td>
</tr>
<tr>
<td>Micco &amp; other</td>
<td>2.5 MW</td>
</tr>
<tr>
<td>Gas &amp; other</td>
<td>20 MW</td>
</tr>
<tr>
<td>EMEC sites</td>
<td>5 + 7 MW</td>
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</tbody>
</table>

**Orkney Islands, North Scotland, UK**

**107%**

of electrical demand in Orkney met by renewables in 2014
Developing Countries’ Initiatives

- Myanmar: Tidal Barrage
- Indonesia: Tidal Current Test
- Malaysia: OWC Test
- Vietnam: Tidal Turbine Drive Train
- Brunei: Offshore Wind
- Philippines: Tidal Barrage
- Singapore: Tidal Turbine Testing
- Europe, N. America, Australia

Tow Tanks (eg UTM, MMU, NTU)

Source: SEAcORE 2013
Ocean/Marine Renewable Energy Resource in SEA

ORE Potential: Indonesia

<table>
<thead>
<tr>
<th>Potential</th>
<th>Tidal Current</th>
<th>Ocean Wave</th>
<th>Ocean Thermal</th>
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<tbody>
<tr>
<td>Theoretical</td>
<td>180 GW</td>
<td>810 GW</td>
<td>87 GW</td>
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<tr>
<td>Practical</td>
<td>4.8 GW</td>
<td>1.2 GW</td>
<td>43 GW</td>
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</table>

Tidal Current Energy Reserves
Wave Energy Reserves
Contour showing water depth having > 20°C Temp. Gradient

Singapore Tidal In-Stream Energy

- Sentosa/St. John’s/Sisters
- Semakau
- Military

Monthly Energy Density (MegaWatt-hours / sq. m)

Total Resource³
- Technically² Extractable Energy Resource
  - ~900 - 1,200 GWh/yr
- Practically³ Extractable Energy Resource
  - ~300-600 GWh/yr

<table>
<thead>
<tr>
<th>SITE</th>
<th>Peak Power (MW)</th>
<th>Annual Energy Yield (GWh/yr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>102</td>
<td>115.96 - 276</td>
</tr>
<tr>
<td>B</td>
<td>65</td>
<td>71.78 - 170</td>
</tr>
<tr>
<td>C</td>
<td>15</td>
<td>16.57 - 39.4</td>
</tr>
<tr>
<td>D</td>
<td>20</td>
<td>22.09 - 52.55</td>
</tr>
<tr>
<td>E</td>
<td>3</td>
<td>3.31 - 7.88</td>
</tr>
<tr>
<td>F</td>
<td>12</td>
<td>13.25 - 31.53</td>
</tr>
<tr>
<td>G</td>
<td>5</td>
<td>5.52 - 13.14</td>
</tr>
<tr>
<td>H</td>
<td>15</td>
<td>16.57 - 39.42</td>
</tr>
<tr>
<td>I</td>
<td>5</td>
<td>5.52 - 13.14</td>
</tr>
<tr>
<td>J</td>
<td>2</td>
<td>2.21 - 5.25</td>
</tr>
<tr>
<td>K</td>
<td>3</td>
<td>3.33 - 7.88</td>
</tr>
</tbody>
</table>

TOTAL 250 MW ~300 to 600 GWh/yr ~0.6% to 1.5% of Singapore’s Electricity Demand

Others in SEA: Malaysia, Vietnam, Brunei
- Malaysia
- Straits of Malacca (Tidal Current)
- Sabah (OTEC)

OTEC Potential Sites

Wave Energy for year 2007
Marine Renewable Energy towards the Tropics

Sentosa

WaveRider

ERI@N

RD&D

Singapore

Acoustic Doppler Current Profiler

Potential TISE Sites/Locations

15MWp (~40GWh/yr)

170MWp (~450GWh/yr)

SEA + Global ASEAN Center for Energy

Device Assessment

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/Anchoragae, Defence, Protected Areas

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

Waves
80,000 TWh/yr

Thermal Gradient (OTEC)
10,000 TWh/yr

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
Floating Solar

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

The World’s Largest Floating Solar Plant Is Finally Online
Ocean Thermal Energy

**Ocean Thermal (OTEC) Resource**

Color palette 15°C to 25°C

**Theoretical Resource:** World Ocean Atlas (WOA) Annual Average $\Delta T$ ($T_{20m} - T_{1000m}$)

**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

Medium Energy
Medium Risk
Array Approach

Hs > 1m

Huge Waves
High Energy
High Risk
Offshore Challenges

Hs > 0.5m

Hs < 0.5m

Multi-function Device
‘Low Wave’ Resource Capture

‘Dry Setup’
Low Risk
Easier Maintenance

OceanPixel
Wave Energy for the Philippines?

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*
Wave Energy: Albatern’s WaveNet Technology
Energy Harvesting with Existing Infrastructure
* Field Data: WEC and Pontoon

WEC Power Output

3 Day Period

Pontoon Displacement

3 Day Period

WEC Power VS Pontoon Displacement

Power = $\sim 333W_0$
@ 265mm Displacement
(Wave Conditions: $H_s = 0.257m$, $T_p = 3.2s$)
Techno-Economics of Pontoon Rollers

Shibata Rollers (8 per Pontoon)
- Product Cost: $8k x 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 x 8 = $40k
- Installation Cost ($8k)
- Annual Maintenance ($5k)
  - Rubber + Parts Replacements
- Energy Output
  - 54 MWh / year
- 10-year Lifespan
  - LCOE: ~$0.15/kWh
- Payback = ~6 - 8 years
  - Assumed Tariff: $0.15/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)

OceanPixel
ORE Potential: Philippines (170 GW)

(a) Tidal Current  (b) Ocean Thermal  (c) Wave

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
The BUMWI Micro-Grid
Industrial Island Energy Use

Graph showing energy use over time, with peaks at certain times for each day of the week.
Summary of Energy Statistics

- **Diesel Cost (Aug)**
  - $18,800 * $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

Energy Distribution for August 2015

(Total = 33.34368 MWh)

- Wood Chipper 1: 15%
- Wood Chipper 2: 15%
- Wood Chipper 3: 15%
- Conveyor Belts: 0%
- Residential: 33%
- Others: 22%

- Workshop
- Bulldozer
- Shiploading
Tidal Turbine Utility Pole
Tidal power in West Papua, Indonesia

Initiated by: PT. Bintuni Utama Murni Wood Industries (BUMWI)

Supported by: OceanPixel, Schottel, aquatera, Energy Research Institute @ NTU
The BUMWI facility is located on the southern side of Bintuni Bay, West Papua, Indonesia.

The BUMWI facility is now set to be reduced by harnessing power from nearby tidal currents.

Initiated by: PT. Bintuni Utama Murni Wood Industries (BUMWI)

Supported by: OceanPixel
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 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% | 0.50

DIESEL Generators Only
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: -
Wave and tidal

Marine energy markets:

**LONG TERM**
Grid electricity

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

**SHORT TERM**
Remote diesel replacement

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Sources:
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

<table>
<thead>
<tr>
<th>FIT (PhP/kWh)</th>
<th>100 MW</th>
<th>200 MW</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>~USD 378M</td>
<td>~USD 753.5M</td>
</tr>
<tr>
<td>CapEx = $ 233.2M</td>
<td>OpEx = $6.63M/yr</td>
<td>CapEx = $ 465.3M</td>
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<tr>
<td>ROI = 95%</td>
<td>IRR = 14%</td>
<td>ROI = 35%</td>
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<tr>
<td>Profit = ~USD 358M</td>
<td>Payback = ~6.5 yrs</td>
<td>Profit = ~USD 718M</td>
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<tr>
<td>13.5</td>
<td>ROI = 163%</td>
<td>IRR = 21%</td>
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<tr>
<td>Profit = ~USD 616M</td>
<td>Payback = ~5 yrs</td>
<td>Profit = ~USD 869M</td>
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<tr>
<td>17</td>
<td>ROI = 232%</td>
<td>IRR = 28%</td>
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<td>Payback = ~3.5 yrs</td>
<td>Profit = ~USD 691M</td>
</tr>
<tr>
<td></td>
<td>~USD 560M</td>
<td>~USD 1,117.3M</td>
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<tr>
<td>CapEx = $ 406.5M</td>
<td>OpEx = $6.63M/yr</td>
<td>CapEx = $ 811.8M</td>
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<tr>
<td>ROI = 32%</td>
<td>IRR = 6%</td>
<td>ROI = 35%</td>
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<tr>
<td>Profit = ~USD 177M</td>
<td>Payback = ~11 yrs</td>
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<td>13.5</td>
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<td>IRR = 11%</td>
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<td>Payback = ~7.6 yrs</td>
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<td>~USD 1,966.3M</td>
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<td>OpEx = $6.63M/yr</td>
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<td>IRR = 3%</td>
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<td>Payback = ~12 yrs</td>
<td>Profit = ~USD 535M</td>
</tr>
</tbody>
</table>

**Total Project (20-Years)**

- **100 MW**
  - ~USD 378M
  - ~USD 560M
  - ~USD 984M

- **200 MW**
  - ~USD 753.5M
  - ~USD 1,117.3M
  - ~USD 1,966.3M

**Average LCOE (USD/kWh):**
- 100 MW: USD 0.17
- 200 MW: USD 0.17
Hybridized Marine RE Pathway in SEA

- Off-Grid / Co-App Market
- Grid-Connected Project Dev’t (Progressive Dev’t)
- Large Scale Commercial Grid-Tied Projects

Philippines Off-Grid Projects
- Philippines Pilot (Off-Grid) [1-2 years]
- Increase Pilot Capacity (Progressive Dev’t) [2-3 years]
- Philippines Grid-Connected Projects (Feed-in-Tariff: USD ~0.35-0.42/kWh)

Indonesia Off-Grid Projects
- Indonesia Pilot (Off-Grid) [1-2 years]
- Increase Pilot Capacity (Progressive Dev’t) [3-5 years]
- Indonesia Grid-Connected Projects (No FIT yet...)

Floating Platform Demo (Singapore – Low Risk) [6-18 months]

Deployments/Installations

Scoping
Strategic Planning
Scouting

[1-2 years]
[2-3 years]
[3-5 years]
Raffles’ Lighthouse, Singapore
Tidal energy solutions; available as turnkey integrated systems and standalone products

- **SIT 250**
  - 4m / 6.3m
- **Electrical & Control Systems**
- **Platforms**
- **Moorings & Anchors**

- **SCHOTTEL Instream Turbine**
  - Max power output 62kW
  - 4m or 6.3m rotor
- **Solutions for combining electrical output from multiple turbines**
- **Submerged (offshore)**
- **High performance, low cost, anchors to replace gravity systems**
- **Floating (Inshore)**
- **Designed for ease of installation and maintenance access**
- **Solutions for rock and soft seabeds**

sustainablemarine.com
PLAT-I (Inshore)

- PLAT-I – SITs deployed
- PLAT-I – Birds eye view
- PLAT-I – SITs in transit mode
- PLAT-I – Mooring spread

sustainablemarine.com
PLAT-I - SCHEMATIC

Legend:-
STR – Structure
MEC – Mechanical
SIT – SCHOTTEL Instream Turbines
PCI – Power Control and Instrumentation
MOR – Mooring arrangement

~270kW Tidal Power (rated)

Platform and Turbine operating modules- PCI
Hulls - STR
Mooring - MOR
SDM (SIT DEPLOYMENT MODULE) - MEC
SIT (SCHOTTEL INSTREAM TURBINE) - SIT
Building the Global Future of Ocean/Marine RE in SEA

- Seed stage
- Marine RE Hub Stage
- Enriched Regional Ecosystem

>$300B Market
Global Competitiveness
New Products & Services

>$150M in the next 5 years
Inward Investment

>$15M in the last 5 years
Various Efforts

Synergy
Alignment
Capability Dev't
Coordination

Marine RE Hub Stage

Growing a Vibrant National Innovation System
Strong Research Manpower Base
Spurring Academic Excellence

Urban Solutions and Sustainability
Advanced Manufacturing and Engineering

Offshore Marine
Maritime Logistics
Clean Tech
Energy Intelligence

Various Efforts: Agencies, ERI@N, OP, SMEs, Industries

Ocean Pixel
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 in/for the Philippines**
  - Floating Solar, Offshore Wind (can be feasible)
  - Waves and Currents, maybe OTEC
  - 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 Philippines
  - 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! ☺

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