Envirotek Tidal Demo Project in Singapore

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

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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.

- **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
- Nanyang Technological University
- VOS
- DHI
- ITP
- Exceedence
- Open Ocean
- Seacore

southeast asian collaboration for ocean renewable energy
Ocean Renewable Energy

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

**Total = > 5,000 MW deliverable capacity**

<table>
<thead>
<tr>
<th>Key</th>
<th>Capacity Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Onshore wind</td>
<td>40 MW existing/planned</td>
</tr>
<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>
</tr>
<tr>
<td>Wave leases</td>
<td>550 MW</td>
</tr>
<tr>
<td>Tidal leases</td>
<td>500 MW</td>
</tr>
<tr>
<td>Micro &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>
</tr>
</tbody>
</table>

Orkney Islands, North Scotland, UK

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

Orkney’s renewable energy resources deliverable capacity of electrical demand in Orkney met by renewables in 2014

Total = > 5,000 MW deliverable capacity
Developing Countries’ Initiatives

Simulation Studies

Tow Tanks (eg UTM, MMU, NTU)

Brunei
Offshore Wind

Myanmar
Tidal barrage

Vietnam
Tidal Turbine Drive Train

Philippines
Tidal barrage

Indonesia
Tidal Current Test

Malaysia
OWC Test

Singapore
Tidal Turbine Testing

Europe, N. America, Australia

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>
</tr>
</thead>
<tbody>
<tr>
<td>Theoretical</td>
<td>180 GW</td>
<td>510 GW</td>
<td>87 GW</td>
</tr>
<tr>
<td>Practical</td>
<td>4.8 GW</td>
<td>1.2 GW</td>
<td>43 GW</td>
</tr>
</tbody>
</table>

**ORE Potential: Philippines (170 GW)**

**Others in SEA: Malaysia, Vietnam, Brunei**
- Malaysia: 660 GW Wave
- Brunei: 660 GW OTEC
  - OTEC Potential Sites:
    - Straits of Malacca (Tidal Current)
    - Sabah (OTEC)

**Singapore Tidal In-Stream Energy**

- Total Resource:
  - Technically $^2$ Extractable Energy Resource: ~900 - 1,200 GWh/yr
  - Practically $^3$ Extractable Energy Resource: ~300 - 600 GWh/yr

**Total Resource $^3$**

- Peak Power (MW)
- Annual Energy Yield (GWh/yr)

<table>
<thead>
<tr>
<th>SITE</th>
<th>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 - 30.4</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 - 51.53</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>
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<tr>
<td>J</td>
<td>2</td>
<td>2.21 - 5.25</td>
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<tr>
<td>K</td>
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**TOTAL**

- 250 MW
- ~500 to 600 GWh/yr
- ~0.6% to 1.3% of Singapore's Electricity Demand
Marine Renewable Energy towards the Tropics

Sentosa

15MWp (~40GWh/yr)

170MWp (~450GWh/yr)

Potential TISE Sites/Locations

Acoustic Doppler Current Profiler

SEA + Global
ASEAN Center for Energy

Singapore

WaveRider

ERI@N
RD&D

Device Assessment

Test Bedding Sites

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
Marine-related RE Options

Floating Solar, Offshore Wind

Very High Chance of Feasibility
Up to a certain depth

Tidal / Marine Current
Resource: H
TRL*: High
800+ TWh/yr

Waves
Resource: H
TRL: Med
80,000 TWh/yr

Thermal Gradient (OTEC)
Resource: H
TRL: Med
10,000 TWh/yr

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

Salinity Gradient
Resource: H
2,000 TWh/yr

Present Technologies need >4m to be economically viable
- Good for Energy Recovery for Desalination Plants
- Still Too Expensive w/o co-application

*TRL = Technology Readiness Level
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

- **Multipurpose Device**
  - ‘Low Wave’ Resource Capture
  - Hs < 0.5m

- **‘Dry Setup’**
  - Low Risk
  - Easier Maintenance

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

OceanPixel
Energy Harvesting with Existing Infrastructure

OceanPixel
Field Data: WEC and Pontoon

Power = ~333Wp @ 265mm Displacement
(Wave Conditions: Hs = 0.257m Tp=3.2s)

WEC Power Output

Pontoon Position (z-axis motion)

WEC Power VS Pontoon Displacement

3 Day Period
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

Confidential
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)
ORE Potential: Philippines (170 GW)

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

Tidal In-Stream Energy Potential Sites
Wave Energy Potential Sites
OTEQ 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

The charts illustrate the energy use over a week, with the x-axis representing time from 6am to 6pm, and the y-axis representing the energy consumption. The graphs show the energy consumption for different days of the week, with specific times highlighted for comparison. The data is categorized by different series, as indicated by the legend on the chart.
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

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### 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%

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

Initiated by:

Supported by:
Tidal power in West Papua, Indonesia

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

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

Supported by:
OceanPixel
Schütte
aquatera
Nanyang Technological University
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

### Power System Config.

<table>
<thead>
<tr>
<th>RE Fraction</th>
<th>Excess Electricity</th>
<th>LCOE (USD/kWh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diesel GenSets (910, 100 kVA) + Batt (576kWh) + Solar (300kWp) + Tidal (200kWp)</td>
<td>31.6%</td>
<td>12.6%</td>
</tr>
<tr>
<td>Diesel GenSets (910kVA, 100 kVA) + Batt (720kWh) + Solar (600kWp)</td>
<td>38.6%</td>
<td>20.1%</td>
</tr>
<tr>
<td>Diesel GenSets (910kVA, 100 kVA)+Batt.(1440kWh)</td>
<td>0.0 %</td>
<td>2.47%</td>
</tr>
<tr>
<td>Diesel GenSets (2x 910, 500, 100 kVA)</td>
<td>0.0 %</td>
<td>14.5%</td>
</tr>
</tbody>
</table>

### Simulation Results

- **System Architecture:**
  - 910 kW Gen 1 (50kW A)
  - 728 kW Gen 2 (55kW A)
  - 200 kW Gen 3 (15kW A)

- **Cost Summary:**
  - Initial Cost: $1,400,000
  - O&M Cost: $190,000

- **Cash Flow:**
  - 8kW: $100k
  - 9kW: $110k
  - 10kW: $120k

- **Production:**
  - Diesel GenSets (910 kW)
  - Batt (576 kWh)
  - Solar (300 kWp)
  - Tidal (200 kWp)

- **Consumption:**
  - AC prime load: 1,760,520 kWh
  - Total: 1,760,520 kWh

- **Excess Electricity:**
  - 12.6%

- **LCOE (USD/kWh):**
  - 0.368

### DIESEL Generators Only

- **Power System Production:**
  - Diesel GenSets (910 kW)
  - Batt (720 kWh)
  - Solar (600 kWp)
  - Tidal (200 kWp)

- **Excess Electricity:**
  - 20.1%

- **LCOE (USD/kWh):**
  - 0.386
**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: ¹Carbon Trust; ²CNE; ³World Bank/Bloomberg; ⁴Chilean Ministry of Energy
Some Costs in South East Asia

- **Sinkers**: $500 to $1k / ton $\rightarrow$ $100/ton
- **Surveys** (ADCP Transect + Seabed-mounted): $100k $\rightarrow$ $30k-$50k
- **Barge-Based Floating Support System**: $250k $\rightarrow$ $50k$ to $100k
- **Tug boats / Survey Vessels**: ~$10k/day $\rightarrow$ $1k - $5k/day
- **Feasibility Studies**: $500k-600k/site $\rightarrow$ $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

<table>
<thead>
<tr>
<th>FIT (PhP/kWh)</th>
<th>~USD 378M</th>
<th>~USD 560M</th>
<th>~USD 984M</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>CapEx = $233.2M, OpEx = $6.63M/yr</td>
<td>CapEx = $406.5M, OpEx = $6.63M/yr</td>
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<td>95%</td>
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<td>13.5</td>
<td>~USD 616M</td>
<td>163%</td>
<td>21%</td>
</tr>
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<td>17</td>
<td>~USD 873M</td>
<td>232%</td>
<td>28%</td>
</tr>
<tr>
<td>20</td>
<td>~USD 1,748M</td>
<td>250%</td>
<td>32%</td>
</tr>
</tbody>
</table>

### 200 MW

<table>
<thead>
<tr>
<th>FIT (PhP/kWh)</th>
<th>~USD 753.5M</th>
<th>~USD 1,117.3M</th>
<th>~USD 1,966.3M</th>
</tr>
</thead>
<tbody>
<tr>
<td>17</td>
<td>CapEx = $1,620.3 M, OpEx = $13.25M/yr</td>
<td>CapEx = $1,966.3 M, OpEx = $13.25M/yr</td>
<td>CapEx = $1,966.3 M, OpEx = $13.25M/yr</td>
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### Total Project Cost (20-Years)

<table>
<thead>
<tr>
<th>100 MW</th>
<th>~USD 378M</th>
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<tr>
<td>10</td>
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<td>13.5</td>
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<td>17</td>
<td>Profit = ~USD 873M, Payback = ~3.5 yrs</td>
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<td>13.5</td>
<td>Profit = ~USD 1,233M, Payback = ~4.5 yrs</td>
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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

Scoping
Strategic Planning
Scouting

Philippines Pilot (Off-Grid) → Increase Pilot Capacity (Progressive Dev’t) → Philippines Grid-Connected Projects (Feed-in-Tariff: USD ~0.35-0.42/kWh)

[1-2 years]

Indonesia Pilot (Off-Grid) → Increase Pilot Capacity (Progressive Dev’t) → Indonesia Grid-Connected Projects (No FIT yet...)

[3-5 years]

Floating Platform Demo (Singapore – Low Risk) → Indonesia Off-Grid Projects

[6-18 months]

Deployments/Installations

OceanPixel
Raffles’ Lighthouse, Singapore
Tidal energy solutions; available as turnkey integrated systems and standalone products

**SIT 250 4m / 6.3m**
- SCHOTTEL Instream Turbine
- Max power output 62kW
- 4m or 6.3m rotor

**Electrical & Control Systems**
- Solutions for combining electrical output from multiple turbines
- Control and data acquisition for SITs and platforms

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

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

sustainablemarine.com
PLAT-I (Inshore)

PLAT-I – SITs deployed

PLAT-I – Birds eye view

PLAT-I – SITs deployed

PLAT-I – Mooring spread

PLAT-I – SITs in transit mode
~270kW Tidal Power (rated)

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

Alignment

Coordination

Capability Dev't

Synergy

Marine RE Hub Stage

Growing a Vibrant National Innovation System

Strong Research Manpower Base

Spurring Academic Excellence

Various Efforts

Agencies

ERI@N

OP

SMEs

Industries

Network

~$15M in the last 5 years

Various Efforts

Offshore Marine

Maritime Logistics

Clean Tech

Energy

Intelligence

Urban Solutions and Sustainability

Advanced Manufacturing and Engineering

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**
  - 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!😊

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