Ocean Renewable Energy in South East Asia

Michael Lochinvar Sim Abundo (Dr)
Managing Director, OceanPixel Pte Ltd

OceanPixel Pte Ltd
#02-15 CleanTech One Bldg.,
1 CleanTech Loop, Singapore 637141

Unit 113B, Innovation Centre Block 2
18 Nanyang Drive, Singapore 637723

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
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
EMEC sites 5 + 7 MW

of electrical demand in Orkney met by renewables in 2014

107%
South East Asia RD&D

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
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>810 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>

Note: Theoretical Tidal Current = 180 GW, Practical Tidal Current = 4.8 GW, Ocean Wave = 810 GW, Ocean Thermal = 87 GW.

**Singapore Tidal In-Stream Energy**

Total Resource

- Technically Extractable Energy Resource: \( \sim 900 - 1,200 \text{ GWh/yr} \)
- Practically Extractable Energy Resource: \( \sim 300-600 \text{ GWh/yr} \)

### Monthly Energy Density (Watt-hours / sq. m)

<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>105</td>
<td>115.96</td>
</tr>
<tr>
<td>B</td>
<td>65</td>
<td>75.79</td>
</tr>
<tr>
<td>C</td>
<td>15</td>
<td>101.52</td>
</tr>
<tr>
<td>D</td>
<td>20</td>
<td>22.09</td>
</tr>
<tr>
<td>E</td>
<td>3</td>
<td>3.31</td>
</tr>
<tr>
<td>F</td>
<td>12</td>
<td>3.22</td>
</tr>
<tr>
<td>G</td>
<td>5</td>
<td>15.48</td>
</tr>
<tr>
<td>H</td>
<td>15</td>
<td>5.06</td>
</tr>
<tr>
<td>I</td>
<td>5</td>
<td>15.34</td>
</tr>
<tr>
<td>J</td>
<td>2</td>
<td>7.05</td>
</tr>
<tr>
<td>K</td>
<td>3</td>
<td>1.66</td>
</tr>
<tr>
<td>TOTAL</td>
<td>250 MW</td>
<td>363.36 GWh/yr</td>
</tr>
</tbody>
</table>

Notes:
- \(^1\) Energy Density of \( \sim 1 \text{MWh/m}^2/\text{month} \)
- \(^2\) Water-to-Wire Efficiency: 0.3 to 0.4
- \(^3\) Without detrimental environmental effects, Significant Impact Factor (SIF): 0.1 to 0.2
- Velocity Data from PORL, TMSI, NUS

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

- Tidal In-Stream Energy Potential Sites
- Wave Energy Potential Sites
- OTEC Route to Grid Party

**Others in SEA: Malaysia, Vietnam, Brunei**

- Brunei: 660 GW Wave
  - Malaysia: Straits of Malacca (Tidal Current)
  - Sabah (OTEC)

**OTEC Potential Sites**

Wave Energy Potential 2007

Notes:
- Energy Density of \( \sim 1 \text{MWh/m}^2/\text{month} \)
- Water-to-Wire Efficiency: 0.3 to 0.4
- Without detrimental environmental effects, Significant Impact Factor (SIF): 0.1 to 0.2
- Velocity Data from PORL, TMSI, NUS
Singapore Tidal In-Stream Energy

Total Resource\(^1\)  \~3 TWh/year

Technically\(^2\) Extractable Energy Resource  \~900 – 1,200 GWh/yr

Practically\(^3\) 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>105</td>
<td>115.96</td>
</tr>
<tr>
<td>B</td>
<td>65</td>
<td>71.78</td>
</tr>
<tr>
<td>C</td>
<td>15</td>
<td>101.52</td>
</tr>
<tr>
<td>D</td>
<td>20</td>
<td>22.09</td>
</tr>
<tr>
<td>E</td>
<td>3</td>
<td>3.31</td>
</tr>
<tr>
<td>F</td>
<td>12</td>
<td>3.22</td>
</tr>
<tr>
<td>G</td>
<td>5</td>
<td>15.48</td>
</tr>
<tr>
<td>H</td>
<td>15</td>
<td>5.06</td>
</tr>
<tr>
<td>I</td>
<td>5</td>
<td>15.34</td>
</tr>
<tr>
<td>J</td>
<td>2</td>
<td>7.95</td>
</tr>
<tr>
<td>K</td>
<td>3</td>
<td>1.66</td>
</tr>
<tr>
<td>TOTAL</td>
<td>250 MW</td>
<td>363.36 GWh/yr</td>
</tr>
</tbody>
</table>

Notes:
- \(^1\) Energy Density of \~1MWh/m\(^2\)/month \*5km length (channel width) \*50m ave. depth \*12 months
- \(^2\) Water-to-Wire Efficiency: 0.3 to 0.4
- \(^3\) Without detrimental environmental effects, Significant Impact Factor (SIF): 0.1 to 0.2
- Velocity Data from PORL, TMSI, NUS

Wave and tidal

Global capacity | Wave: | 0 | 10MW | 30MW | 300MW | 1 GW | 2 GW
--- | --- | --- | --- | --- | --- | --- | ---
Tidal: | 0 | 20MW | 200MW | 900MW | 2 GW

Cost (USD cents/kWh)

- SING marginal cost²
- SIC marginal cost²
- Diesel³
- Diesel³ - remote areas (+27% transport costs⁴)
- UK wave
- UK tidal¹
- Chile wave
- Chile tidal

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

Marine energy markets:

**LONG TERM**
Grid electricity

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

**SHORT TERM**
Remote diesel replacement
Marine Renewable Energy towards the Tropics

Sentosa

Singapore

TMFT

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
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...
Technology Zones

Medium Energy
Medium Risk
Array Approach

Hs > 1m

Hs > 0.5m

Hs < 0.5m

Multi-function Device
‘Low Wave’ Resource Capture

‘Dry Setup’, Low Risk, Easier Maintenance

Huge Waves
High Energy
High Risk
Offshore Challenges

Confidential
Tidal Resource Validation

Tidal Current Simulation VS ADCP Data

- Peaks: 90%-95%
- Mid Range: 85% - 90%
- Low Range: 80% - 85%
- Ave Correlation: 87.5%

Flow Speeds in m/s
- 1.5 m/s ≤ x ≤ 14 m/s
- 10.5 m/s ≤ x ≤ 11 m/s
- 9 m/s ≤ x ≤ 9.5 m/s
- 8 m/s ≤ x ≤ 8.5 m/s
- 7 m/s ≤ x ≤ 7.5 m/s

Flow Rose
SEA Case Study: Island with Industry
The BUMWI Micro-Grid
Industrial Island Energy Use
Summary of Energy Statistics

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

---

**Energy Distribution for August 2015**

(Total = 33,34368 MWh)

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

- Workshop
- Bulldozer
- Shiploading
## Case Study: Hybrid System for an Island Micro-Grids

### Power System Config.

<table>
<thead>
<tr>
<th>Configuration</th>
<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>
<td>0.3 – 0.37</td>
</tr>
<tr>
<td>Diesel GenSets (910kVA, 100 kVA) + Batt (720kWh) + Solar (600kWp)</td>
<td>38.6%</td>
<td>20.1%</td>
<td>0.386</td>
</tr>
<tr>
<td>Diesel GenSets (910kVA, 100 kVA) + Batt (1440kWp)</td>
<td>0.0 %</td>
<td>2.47%</td>
<td>0.456</td>
</tr>
<tr>
<td>Diesel GenSets (2x 910, 500, 100 kVA)</td>
<td>0.0 %</td>
<td>14.5%</td>
<td>0.50</td>
</tr>
</tbody>
</table>
Tidal Turbine Utility Pole
Tidal power in West Papua, Indonesia

Initiated by:

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

Initiated by:

Supported by:

Source: Google Maps

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

Tidal power in West Papua, Indonesia

Initiated by:

Supported by:

Source: Google Maps

BUMWI’s mangrove chipping operation in West Papua is the first of its kind to receive sustainability certification from the Forestry Stewardship Council (FSC®).
Floating Hybrid RE Platforms?
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: -
Potential Feasible Installation Areas
(Applied Depth-Mask of <100m)
# LCOE, IRR, Feed-in-Tariff

## 100 MW

<table>
<thead>
<tr>
<th>FIT (PhP/kWh)</th>
<th>Total Project (20-Years)</th>
<th>Total Project Cost (20-Years)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>~USD 378M</td>
<td>~USD 753.5M</td>
</tr>
<tr>
<td></td>
<td>CapEx = $ 233.2M OpEx = $6.63M/yr</td>
<td>CapEx = $ 465.3M OpEx = $13.25M/yr</td>
</tr>
<tr>
<td></td>
<td>ROI = 95% IRR = 14% Profit = ~USD 358M Payback = ~6.5 yrs</td>
<td>ROI = 95% IRR = 14% Profit = ~USD 718M Payback = ~6.5 yrs</td>
</tr>
<tr>
<td>13.5</td>
<td>~USD 560M</td>
<td>~USD 1,117.3M</td>
</tr>
<tr>
<td></td>
<td>CapEx = $ 406.5M OpEx = $6.63M/yr</td>
<td>CapEx = $ 811.8M OpEx = $13.25M/yr</td>
</tr>
<tr>
<td></td>
<td>ROI = 32% IRR = 6% Profit = ~USD 177M Payback = ~11 yrs</td>
<td>ROI = 35% IRR = 6% Profit = ~USD 354M Payback = ~11 yrs</td>
</tr>
<tr>
<td>17</td>
<td>~USD 984M</td>
<td>~USD 1,966.3M</td>
</tr>
<tr>
<td></td>
<td>CapEx = $ 810.2M OpEx = $6.63M/yr</td>
<td>CapEx = $ 1,620.3 M OpEx = $13.25M/yr</td>
</tr>
<tr>
<td></td>
<td>ROI = 1% IRR = 3% Profit = ~USD 9M Payback = ~16.2 yrs</td>
<td>ROI = 1% IRR = 3% Profit = ~USD 20M Payback = ~16.2 yrs</td>
</tr>
</tbody>
</table>

## 200 MW

<table>
<thead>
<tr>
<th>FIT (PhP/kWh)</th>
<th>Total Project (20-Years)</th>
<th>Total Project Cost (20-Years)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>~USD 378M</td>
<td>~USD 753.5M</td>
</tr>
<tr>
<td></td>
<td>CapEx = $ 233.2M OpEx = $6.63M/yr</td>
<td>CapEx = $ 465.3M OpEx = $13.25M/yr</td>
</tr>
<tr>
<td></td>
<td>ROI = 95% IRR = 14% Profit = ~USD 358M Payback = ~6.5 yrs</td>
<td>ROI = 95% IRR = 14% Profit = ~USD 718M Payback = ~6.5 yrs</td>
</tr>
<tr>
<td>13.5</td>
<td>~USD 560M</td>
<td>~USD 1,117.3M</td>
</tr>
<tr>
<td></td>
<td>CapEx = $ 406.5M OpEx = $6.63M/yr</td>
<td>CapEx = $ 811.8M OpEx = $13.25M/yr</td>
</tr>
<tr>
<td></td>
<td>ROI = 32% IRR = 6% Profit = ~USD 177M Payback = ~11 yrs</td>
<td>ROI = 35% IRR = 6% Profit = ~USD 354M Payback = ~11 yrs</td>
</tr>
<tr>
<td>17</td>
<td>~USD 984M</td>
<td>~USD 1,966.3M</td>
</tr>
<tr>
<td></td>
<td>CapEx = $ 810.2M OpEx = $6.63M/yr</td>
<td>CapEx = $ 1,620.3 M OpEx = $13.25M/yr</td>
</tr>
<tr>
<td></td>
<td>ROI = 1% IRR = 3% Profit = ~USD 9M Payback = ~16.2 yrs</td>
<td>ROI = 1% IRR = 3% Profit = ~USD 20M Payback = ~16.2 yrs</td>
</tr>
</tbody>
</table>
Multi-Site, Multi-Device, Multi-Criteria Geographic Information System

OceanPixel
Data Analytics, Intelligence, Suitability, Decision Support

Suitability Maps

Multi-Metric Scoring Tools

Data Analytics
- Energy Density
- Project Dev’t Planning
- Environmental Scores
- Technology Library
- Distance-to-Shore
- Resource Analysis
- Cost Ranging
- Resource Data
- Decision Support Maps
- Navigation & Shipping Considerations
Summary / Conclusions

- There are Marine Renewable Energy Resources in SEA

- Unique ecosystem in SEA will (hopefully) increase the uptake of marine renewables in the region

- Need for actual projects beyond R&D in SEA...

- Project Pathways may take different forms: from community-scale to commercial grid-connected projects.

- Progressive Development of Sites (Phased Approach) seems to be an attractive strategy for developers
Thank you.

mike@oceanpixel.org
+65 9066 3584

Unit #02-15 CleanTech One Bldg.
1 CleanTech Loop,
Singapore 637141