Marine Renewable Energy and the Environment: Progress and Challenges

Brian Polagye
Assistant Professor
Department of Mechanical Engineering
University of Washington
Northwest National Marine Renewable Energy Center

IGERT Program on Ocean Change
January 22, 2014
Motivation

- Increasing concern over impacts of climate change, particularly on ocean ecosystems
- Part of the solution is transitioning to low-carbon sources of power generation
- The oceans are a potential source of sustainable power
Offshore Wind Energy

Horns Rev
(160 MW Array)

Statoil Hywind
(2 MW demonstration platform)

Principle Power WindFloat
(2 MW demonstration platform)
Tidal Current Energy

- Andritz Hydro/Hammerfest (1.0 MW)
- Siemens/MCT SeaGen (1.2 MW)
- Ocean Renewable Power Company (0.2 MW)
- Alstom/Tidal General Limited (1.0 MW)
Wave Energy

Pelamis (0.8 MW)

Wave Dragon (4.0 MW)

Columbia Power Technology (< 0.1 MW)

Wello Oy Penguin (0.5 MW)

Aquamarine Oyster (0.8 MW)
Power Generation Landscape

- The United States has more than 107,000 MW of coal-fired generation capacity. Natural gas has a similar capacity and is expanding rapidly.

- The United States has more than 60,000 MW of terrestrial wind generation capacity (13,200 MW added in 2012)

- The United States currently has about 0 MW of installed marine renewable generation capacity
Global Economic Challenge: Shale Gas

Can marine renewable energy compete with electricity generation from shale gas?

Hydraulic fracturing site in Bradford County, Penn
Source: Appalachian Voices
# Marine Energy Economics

<table>
<thead>
<tr>
<th>Generation Technology</th>
<th>Current</th>
<th>Long Term Projection</th>
</tr>
</thead>
<tbody>
<tr>
<td>Combined Cycle Natural Gas</td>
<td>40-80 $/MWh</td>
<td>?</td>
</tr>
<tr>
<td>Offshore Wind (deep water)</td>
<td>100-300 $/MWh</td>
<td>60-100 $/MWh</td>
</tr>
<tr>
<td>Tidal Current</td>
<td>300-400 $/MWh</td>
<td>50-150 $/MWh</td>
</tr>
<tr>
<td>Wave</td>
<td>400-500 $/MWh</td>
<td>50-100 $/MWh</td>
</tr>
</tbody>
</table>
Global Technical Challenge: Proving System Reliability

Can we prove that a turbine can reliably produce power over $N$ years in much less than $N$ years?

1 MW Alstom turbine mobilization (Orkney, UK)
Tidal Energy: Engineering Approaches

Lower Efficiency
Mechanical Simplicity

Higher Efficiency
Mechanical Complexity

Design Philosophy Spectrum

DCNS/OpenHydro (1.0 MW)

Siemens/MCT (1.2 MW)
Global Social Challenge:
Non-exclusionary Use of the Ocean

Can marine renewable energy complement existing uses of the ocean or enable new uses?
Societal Influences

- Opportunity for society to help shape the evolution of marine energy technology
- Outreach is critically important
  - In the absence of information society draws its own conclusions.
- “Sustainability of Tidal Energy”
  - Integrated engineering, environmental and societal considerations
  - NSF Sustainable Energy Pathway
Global Environmental Challenge:
“Retiring Risk”

Can we prove whether or not a marine renewable energy development will have environmental impacts over in $N$ years of operation in much less than $N$ years?
First Question – What are we studying?

- **Stressor**: An alteration to the environment by installation, operation, or maintenance of a marine renewable energy converter
- **Change**: A detectable or measurable alteration
- **Effect**: A change threshold denoting biological importance – specific to site and project scale

**Impact**
- Negative effect

**Benefit**
- Positive effect

w/ John Horne at the NSF Workshop: Research at the Interface of Marine/Hydrokinetic Energy and the Environment, October 6, 2011
Second Question – Why should we study?

Satisfy Regulatory Requirements

Identify Commercial-Scale Impacts

Pre-empt Impacts by Design
Third Question – What are the pathways?

Source: Simon Geerlofts, Pacific Northwest National Laboratory
Fourth Question – What are the priorities?

### Physical environment:
- **Near-field**
- **Far-field**

### Habitat

### Invertebrates

### Fish:
- **Migratory**
- **Resident**

### Marine mammals

### Seabirds

### Ecosystem interactions

#### Device presence:
- **Static effects**
- **Dynamic effects**

#### Chemical effects

#### Acoustic effects

#### Electromagnetic effects

#### Energy removal

#### Cumulative effects

**Potential Significance**
- Low
- Moderate
- High

**Scientific Uncertainty**
- Low
- Moderate
- High

Monitor Changes or Mitigate Risks?

“The Lesson from Strangford Lough”

Siemens/Marine Current Turbines SeaGen
Northern Ireland
Strangford Lough Experience

- SeaGen installed and commissioned in 2008

- Risk factors for impacts to harbor seals
  - Activity in the Lough – foraging and transits to Irish Sea
  - Scale of project
  - Risk for injury (tip velocity, mechanism for tip contact)

- Post-installation blade strike mitigation: “Shut down turbine when harbor seals within X m.”
  - Problem 1: How do you tell when a harbor seal is X m away from the turbine?
  - Problem 2: What information does this give us about the actual risks to harbor seals?
Progress on High-Priority Concerns

- Since 2010 – multiple commercial demonstrations of wave and tidal technology in US and Europe, most with substantial monitoring programs

- Key Outcomes
  - Fish mortality for tidal turbines is infrequent (none observed to date)
  - Marine energy converters produce sound
  - Subsea structures are colonized by marine life
Environmental Monitoring Paradox

- At existing proportion of total project cost, environmental monitoring is economically crippling to industry
- If early commercial projects cause environmental harm, the industry may also be crippled
- How do we avoid impacts without incurring high costs?
Challenge: “Retiring Risk”

- Often, the objective of monitoring is to collect information that improves certainty in evaluating environmental risk (frequency x outcome)

- *Ideally, over time:*
  - Significant risks can be recognized and mitigated through changes to converter design or operation
  - Insignificant risks can be selectively “retired” from monitoring programs

- For high-priority risks, no agreed upon framework for reaching either of these end states
Challenge: “Data Mortgages”

- Often, risks of greatest concern are serious outcomes with low probabilities of occurrence
- Spatial *comprehensive* and temporally *continuous* monitoring of converters requires the least time to resolve risk – “collect everything”
- Data bandwidth for “brute force” approaches to this is problematic – “data mortgages”

**Example:** Continuous stereo-optical monitoring for a single system. Comprehensive monitoring would require multiple systems.
Options to Retire Risk without Mortgages

- Instruments that intrinsically produce information
  - *Example*: recording and transponding tags
  - Tend to be expensive to deploy in large numbers

- Automated processing that mines data for information
  - *Example*: split-beam echosounders
  - Requires ability to “trash” raw data

- Is it reasonable to expect a “silver bullet” software solution for all instruments?
A Better Alternative? Integrated Packages

- Intermediate option to pure hardware or software solutions

*Example:* Detect, track, and identify a marine mammal approaching a MEC

Passive Acoustic Detection
- Processing in near real-time
- Omni-directional coverage at ranges on the order of 1 km

Split-beam Echosounder
- Processing in near real-time
- Tracking capability at ranges beyond 100 m

Optical Camera
- Requires archival processing
- Short range and limited field of view
Adaptable Monitoring Package (AMP)

with Andy Stewart, James Joslin, Ben Rush, Paul Gibbs, ...
Data and Power Needs

Data Bandwidth (MB/s)

<table>
<thead>
<tr>
<th>Instrument</th>
<th>Data Bandwidth</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Doppler Profiler</td>
<td>$1 \times 10^{-5}$</td>
<td>(1 Hz Sampling)</td>
</tr>
<tr>
<td>Imaging Sonar</td>
<td></td>
<td>(15 fps)</td>
</tr>
<tr>
<td>Acoustic Array</td>
<td></td>
<td>(4 elements @ 400 kHz)</td>
</tr>
<tr>
<td>Stereo-Optical</td>
<td></td>
<td>(2 Mpx @ 10 fps)</td>
</tr>
</tbody>
</table>

Need a cabled connection to shore...

...but so does the marine energy converter.
Integration with Marine Energy Converter

OpenHydro Open Centre turbine (6 m diameter)
Deployment and Recovery System

- SAAB SeaEye Falcon
- AMP
- Custom skid w/ SeaView Systems
- Docking Station
  - Power and fiber wet-mate
AMP Deployment Approach

At-sea flight tests starting by fall 2014...
Conclusions

- Marine renewable energy must overcome significant challenges, but has significant potential.

- Progress requires a coupled engineering, environmental, societal, and economic approach to problem solving.

- Broad collaboration between researchers (multi-disciplinary), industry, regulators, and public required.
Acknowledgements

This material is based upon work supported by the Department of Energy

DOE Environmental Webinar series starts tomorrow morning – Monitoring Instrumentation

This material is based upon work supported by the National Science Foundation (NSF 1230426)

This material is based upon work supported by Snohomish PUD