Presentation Outline

- US Energy Demand
- MHK Resource
- MHK Technology Summary
- Manufacturing and Logistics
- Deployment
- Array Production
- Barriers
- High Profile DOE Projects
- Testing Infrastructure
- Questions
Summary Annual Production (2011):

4105 TWh
14 Quads
469 GW Average Power Consumption

Source: EIA Annual Energy Report
http://www.eia.gov/totalenergy/data/annual/
# Marine and Hydrokinetics

## Total Energy by Resource

<table>
<thead>
<tr>
<th>Marine and Hydrokinetics</th>
<th>Current US Resource Estimates (technically recoverable)</th>
<th>23GW+</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wave Energy (&gt;90% in Alaska)</td>
<td>1,199 TWh/yr (~400 GW)</td>
<td>EPRI, 2011</td>
</tr>
<tr>
<td>Tidal Current Energy (&gt;90% in Alaska)</td>
<td>250 TWh/yr (~50 GW)</td>
<td>Georgia Tech, 2011</td>
</tr>
<tr>
<td>Ocean Current Energy (&gt;90% in Southeastern U.S.)</td>
<td>1-2 GW</td>
<td>DOE, 1980 Updated Georgia Tech assessment underway</td>
</tr>
<tr>
<td>River Current Energy</td>
<td>101 TWh/yr (~20 GW)</td>
<td>EPRI, 2012</td>
</tr>
<tr>
<td>Ocean Thermal Energy (&gt;90% in Pacific Islands)</td>
<td>4,642 TWh/yr (~600 GW)</td>
<td>Lockheed, 2012</td>
</tr>
</tbody>
</table>

- **Total Domestic Energy Use**: ≈ 98 Quads (9,300 MHK-GWeq)
- **Total Electrical Energy Use**: ≈ 13 Quads (1,200 MHK-GWeq)
- **MHK Potential Program Goal**: > 5 Quads (>500 GW) ≈ .25 Quads (23 GW)

## Summary:

- **Total Domestic Energy Use**: ≈ 98 Quads
- **Total Marine Energy Potential**: ≈ 26 Quads
- **Total Electrical Energy Use**: ≈ 14 Quads
- **Existing Marine Contribution**: ≈ 0 Quads
Wave Resources:

- Wave Energy is the dominant MHK resource available to the United States
- Magnitude of potential wave power $\approx 2,640 \text{TWh/yr}$:
  - $\approx 300 \text{ GW (9 Quad/yr)}$

### Total Wave Energy Resource Potential by Region

<table>
<thead>
<tr>
<th>Region</th>
<th>TWh/yr</th>
</tr>
</thead>
<tbody>
<tr>
<td>West Coast</td>
<td>590</td>
</tr>
<tr>
<td>East Coast</td>
<td>240</td>
</tr>
<tr>
<td>Alaska</td>
<td>1,570</td>
</tr>
<tr>
<td>Hawaii</td>
<td>130</td>
</tr>
<tr>
<td>Gulf of Mexico</td>
<td>80</td>
</tr>
<tr>
<td>Puerto Rico</td>
<td>30</td>
</tr>
<tr>
<td><strong>Total:</strong></td>
<td><strong>2,640</strong></td>
</tr>
</tbody>
</table>

CONUS Tidal Resources

- Magnitude of potential tidal power at 250TWhr/yr is significantly less than wave
- ~3 GW concentrated and exist in close proximity to major coastal load centers...
- However, over 90% of the overall resource (~47 GW) is located in Alaska.

Source: Tidal Energy Database: [http://www.tidalstreampower.gatech.edu/](http://www.tidalstreampower.gatech.edu/) (DOE Funded)
• Most are radically new technologies... devices and system concepts only at the first generation/pioneering stage of development
• Limited existing technical expertise and modeling platforms—what is applicable comes from O&G and maritime engineering
• LCOE of early-stage technologies at 40-60 cents per kWh
Current technologies are based upon validated wind turbine technologies adapted for marine environments:

- Axial Flow $\rightarrow$ Horizontal Axis Turbine
- Cross Flow $\rightarrow$ Vertical Axis Turbine

The flow physics remain virtually unchanged with notable exceptions:

- Water is 784 times denser than air
- Preventing cavitation is a major blade design driver
- Rotor inflow debris hazards & blade fouling

Reopened many of the technological/cost-effectiveness debates settled for wind:

- Ducting
- Horizontal vs. Vertical vs. Cross-flow orientation

Wind expertise and extensive modeling capability can be adapted to an offshore, underwater environment.

Architectures are developing at an accelerated pace:

- 2nd & 3rd generation design iterations
- Full-scale deployment already occurring (ORPC, Verdant)

LCOE at 15-25 cents per kWh (3x greater than wind)
Domestic MHK Industry

Wave Technology
- Capacity: 20 – 200 kW
- Deployment depths: 50 – 70 m
- Draft of devices: 12.8 – 35 m
- Distance from shore: 1.15 – 6 nautical miles
- Moorings: single to 3-point mooring lines using gravity anchors or anchors buried in seafloor
- Weight: 30 – 417 metric tons
- Vessels required: tugs, barges, and land based cranes placed on barges

Current (Tidal, River and Ocean) Technology
- Capacity: 17.5 – 150 kW
- Deployment Depth: 9 – 26 m
- Distance below surface: 1 – 9.75 m
- Distance from shore: 17 – 610 m
- Moorings: 1 -10 pilings per device
- Weight: 4.7 – 79 metric tons
- Vessels required: tugs, barges, and land based cranes placed on barges
Wave Device Examples

**Point Absorbers**
- Can be either floating or submerged
- Stationary portion moored to bottom
- The device moves up and down with the waves to generate electricity
- The relative motion is used to drive a generator

**Surge**
- Deployed on the seabed
- The surging motion of waves underwater moves a flap back and forth like an inverted pendulum
- The motion of the flap pump high pressure fluid to drive a generator

**Oscillating Water Column (OWC)**
- The device is partially submerged
- Waves cause the water level in the column to rise and fall
- The changing air pressure spins a turbine which drives a generator

OPT PowerBuoy

Aquamarine Power Oyster

Ocean Energy Limited OWC
Wave Device Examples

Attenuator

- Floats on the surface of the water
- The motion of the waves cause the attenuator to move
- The relative motion of the components of the device causes pressurized fluid to flow through the device
- Pressurized fluid is used to drive a turbine to generate electricity

Pelamis WEC

Overtopping

- Partially submerged structure
- A collector funnels waves over the top of the structure into a reservoir
- Water runs from the reservoir through a turbine and drives a generator
- The water then flows back out to sea

Wave Dragon WEC
The motion of the water from the current/tide creates lift on the blades causing them to turn.
- The rotation drives a generator which produces electricity.
- The turbine can be either open or ducted.

Tide/current flows past the device.
- This creates lift and drag forces which cause the device to oscillate.
- The oscillation feeds into a power conversion system which produces energy.

The motion of the water from the current/tide creates lift on the blades causing them to turn.
- The rotation drives a generator which produces electricity.
- The devices can either be vertical or horizontal axis turbines.
Power Take-Off (WECs)

PTO is the combination of the drivetrain and generator that converts mechanical power into electrical power

- 4 Generally used PTOs
  - Air Turbine
    - Commonly used in OWC
    - Turbine converts reciprocating air flow to unidirectional torque that drives an electrical generator
  - Hydraulics
    - Commonly used in attenuators and surge devices
    - A hydraulic circuit which transfers absorbed power of wave to a hydraulic motor which drives an electrical generator
  - Mechanical Drive
    - Commonly used in point absorbers
    - Converts linear motion of the float to rotary motion of the generator along with speed conversion as necessary
  - Direct Drive
    - Commonly used in point absorbers
    - No mechanical conversion needed
Power Take-Off (CECs)

Moving water causes the turbine to rotate; the subsystem that converts that rotational motion to electricity is called the power take off (PTO).

- Turbine drives gears
- Gear output shaft drives generator
- Generator can be driven with or without gearbox

- In a rim generator the stator is on the outer rim of the duct with a shaft-less rotor
Devices are quite large and require large assembly areas.

Heavy-lift equipment is required to handle device structures and components.

Typical components that need to be fabricated, sourced and assembled are:
- Main structural components (device dependent: nacelle, blades, tubes, “flaps”, buoy, etc.)
- Hydraulics and control systems
- Subcomponents (gearbox, generator, bearings, etc.)

Transportation can be difficult due to device size and weight.

Local manufacturing has been identified as industry needs.
Assembled device handling can be a challenge due to size and weight.

There is limited availability of vessels that can be used to deploy MHK devices (especially as devices increase in scale).

Typical deployment vessels/equipment include: tugs, barges, and land-based cranes placed on barges.

Specialized vessels and facilities may be required to support O&M of devices and arrays.

Port facilities and vessels will be necessary for assembly, deployment, and O&M.
Example WEC Array
- 1.5 MW (10, 150 kW units) array under development
- Depth of deployment is between 50 m and 69 m
- A single mooring can be leveraged by more than one device
- Transmission cable will be trenched in the seafloor
  - Subsea junction box to allow for a single cable back to shore

Example CEC Array
- 1.05 MW (30, 35 kW units) array
- Deployed on the seafloor with a piling at a depth between 9 and 25 m
- A 140-foot-wide and 21-foot-deep navigation channel will be maintained adjacent to the project area
Future arrays are expected to have around a 100 MW capacity and consist of 100 devices.

Construction of multiple large scale devices requires large assembly areas near deployment sites. Small shipyards could support MHK array scale production.

How can this be scaled up to manufacture 100 MHK devices?
Barriers for Water Power

- **Immature Technology**
  - Lack of design tools, standards, and validation data are preventing disciplined approach to design.
  - High technical and cost uncertainty due to lack of experience.
  - Test facilities are needed where new technologies can be proven outside the commercial regulatory path.

- **Siting and Permitting**
  - Conventional hydro regulatory paradigm for single device MHK technology is hindering development.
  - Deployment is limited to a handful of proof of concept devices.
  - 2009 MHK promotion act in play for more stream-line adaptive management system.
High Profile Projects

• Ocean Renewable Power Company (ORPC)
  – First grid connected, commercial tidal power project
  – Bay of Fundy, Eastport, Maine
  – 80 kW, cross flow turbine
  – 78 metric tons
  – Dimensions
    • 30 m long, 4.3 m high and 5.8 m wide
High Profile Projects

- Verdant Power Company
  - Planned current power array in East River, NY
  - FERC license for 30 devices rated at 35kW (1050kW total capacity)
  - Vertical axis turbine
  - 5 meter diameter turbine
  - 4.7 metric tons
High Profile Projects

- Northwest Energy Innovations (NWEI)
  - ½ scale WET-NZ point absorber
  - Planned deployment at US Navy’s Wave Energy Test Site (WETS) in Hawaii
  - Tested off the coast of Oregon, using the Northwest National Marine Renewable Energy Center’s Ocean Sentinel
  - 30 metric tons
  - Dimensions:
    - Hull height: 15.0 m
    - Hull width: 3.8 m
    - Float diameter: 2.4 m
High Profile Projects

• Columbia Power Technologies
  – StingRAY WEC
  – Earlier 1/7th scale prototype deployed for approximately in Puget Sound, WA
  – 418 metric tons
  – Dimensions
    • Length(fore to aft): 15.4 m
    • Beam(port to starboard): 12.5 m
    • Overall Height: 20.5 m
    • Draft: 18.75 m
    • Freeboard: 1.7 m
Testing Infrastructure

• Center for Ocean Renewable Energy (CORE) – University of New Hampshire
  – Works with industry to define MHK testing requirements and collect environmental and resource data to support test site development
• NNMREC – Wave and Tidal Test Facility
  – Completed permitting requirements for an open water WEC test site in Reedsport, OR
  – Demonstrated a new testing device (Ocean Sentinel) for WECs equipped with an array of measuring
  – Working to complete the design of a full scale, grid connected ocean energy test facility at NNMREC capable of accommodating commercial scale devices
• PMEC
  – Will be the first full scale, grid-connected test center in the U.S.
• SNMREC - Ocean Current Test Facility
  – Working on installation of a non-grid-connected offshore test berth and deployment of an experimental ocean current-energy conversion research device.
• HINMREC – Wave and Ocean Thermal Energy Conversion Test Facility
  – Working on build-out of the Navy’s Wave Energy Test Site (WETS) for testing in water depths ranging from 30 m to 70 m
Questions?

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Key MHK Resources

• Subscribe to Water Power Program News: http://www1.eere.energy.gov/water/financial_opportunities.html

• Visit the OpenEI Water Gateway for DOE and other community news, data, and reports: http://en.openei.org/wiki/Gateway:Water_Power

• Sign up for RSS feeds of MHK Technology Development Journal Publications at: http://mhktechpapers.wordpress.com

• View MHK Environmental Studies at: http://mhktechpapers.wordpress.com