# Marine and Hydrokinetic U.S. Resource Assessments and Technologies

***Presented by***

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***U.S. Department of Energy***

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# Water Power Program's Mission

**DOE Office of Energy Efficiency & Renewable Energy supports:**

- Applied research, development, and demonstration
- Policy/regulatory role limited to advice and recommendations

**Program Mission**

The **mission** of the Water Power Program is to ***research, test, and develop innovative technologies*** capable of generating renewable, environmentally responsible, and cost-effective electricity from water resources.

# Marine and Hydrokinetic Technology Development and Variety

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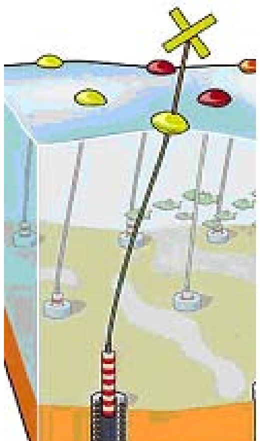
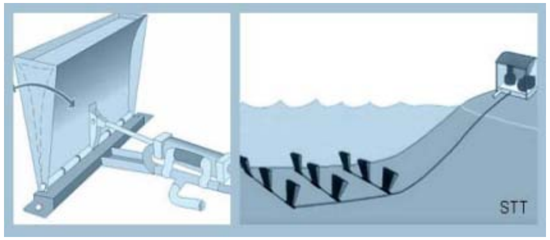
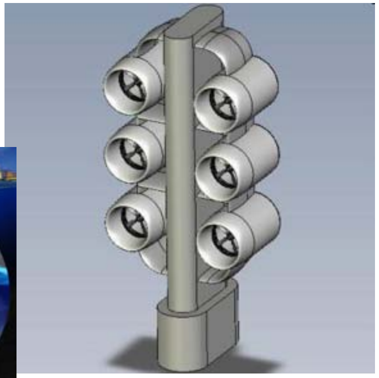
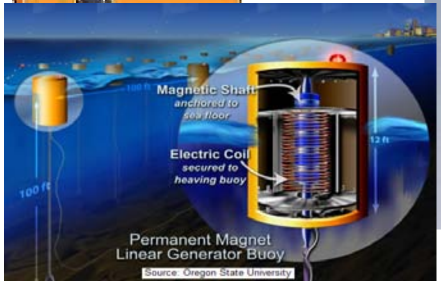
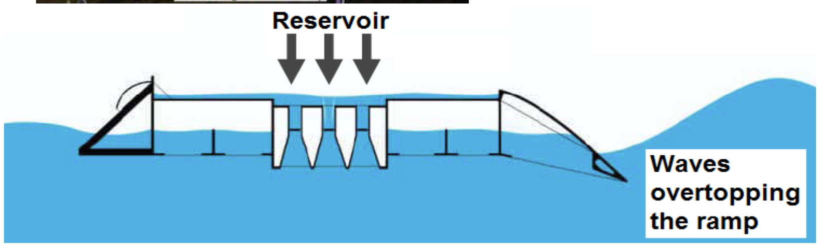
## 5-10 Years Ago




## Ocean Energy Today






DOE and international investment have turned device concepts into advanced generating systems in less than a decade

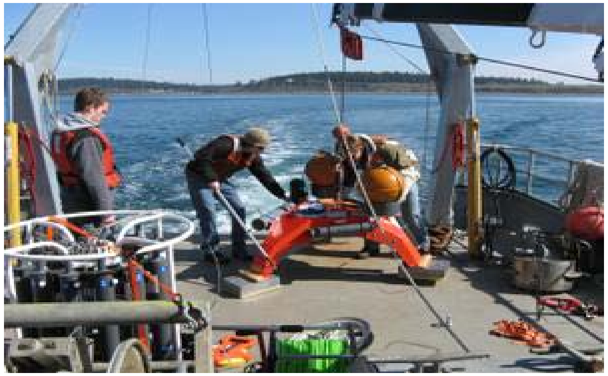
# MHK Resource Assessments

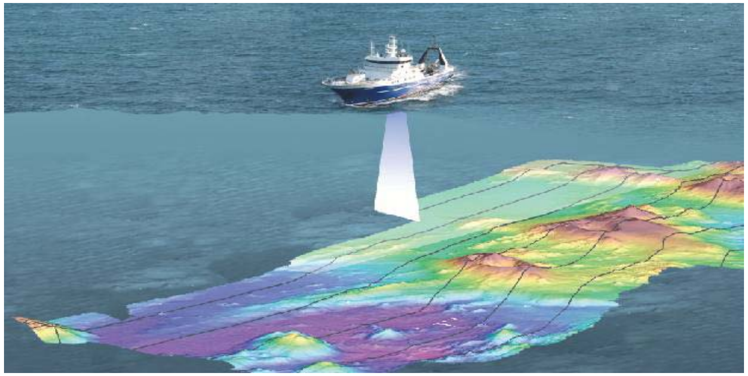


**Differences Between:**

- **Resource Assessments – national or regional scale, low to medium levels of detail, useful for comparing information between areas and technologies.**

- **Resource Characterizations – site specific, high levels of detail, useful for siting projects in optimum locations and finely tuning devices.**





# Different Types of Resource Assessments

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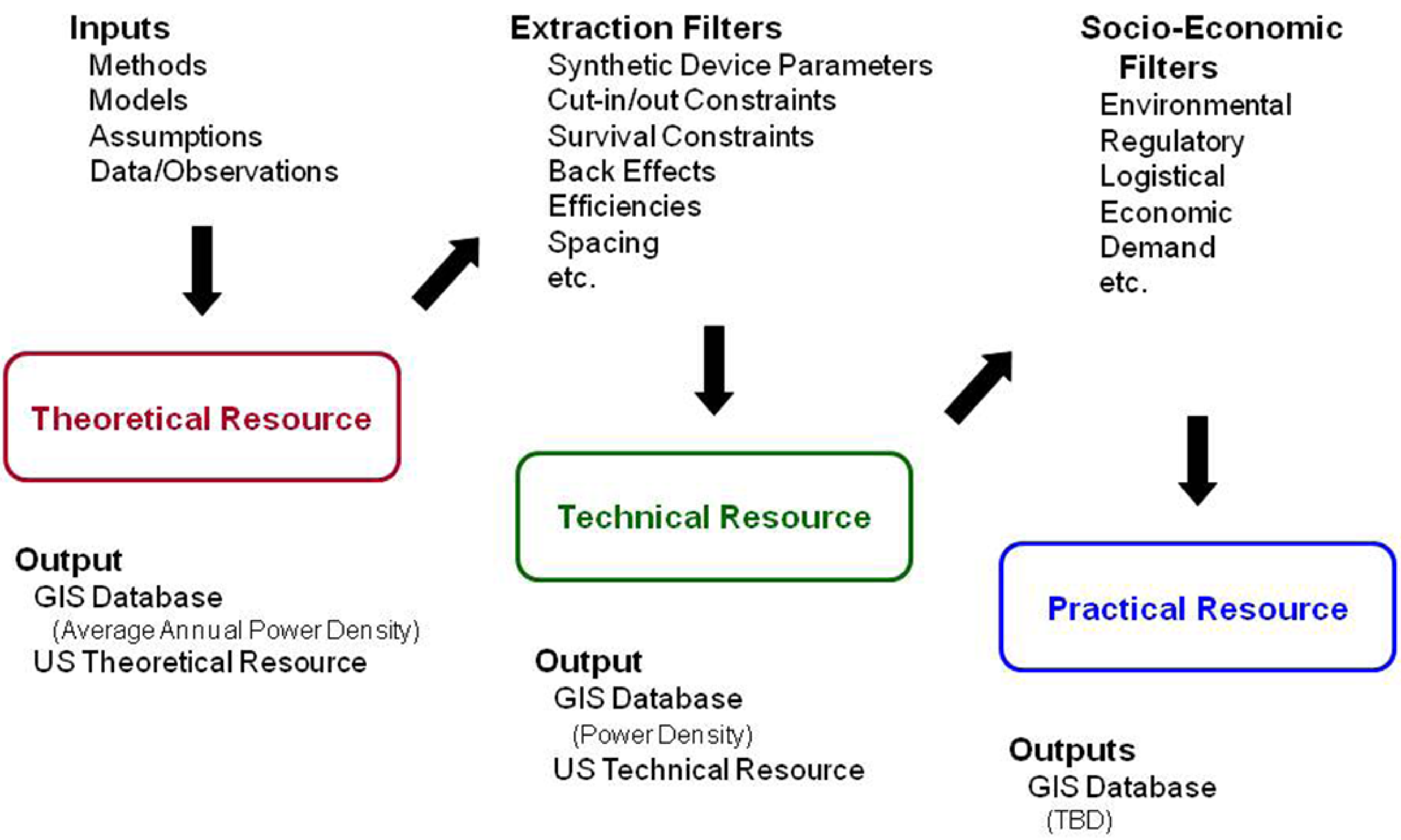

# DOE Funded MHK Resource Assessments

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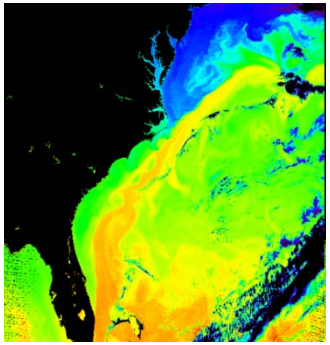
## Goals for Resource Assessments

- Determine maximum available energy (theoretical limit)
- If possible, calculate technically extractable energy based on achievable energy conversion rates, current and/or future technology performance, device spacing, etc.
- Characterize seasonal variability of resources
- Display results in GIS formatted database



Resource Assessment Awards:

- Wave: EPRI, end of FY 2008
- Tidal: Georgia Tech, end of FY 2008
- Ocean Current: Georgia Tech, end of FY 2009
- Riverine Hydrokinetic: EPRI, end of FY 2009
- Ocean Thermal: Lockheed Martin, end of FY 2009

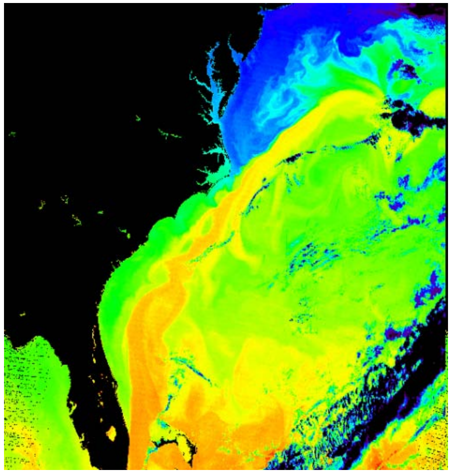
**END USERS:** DOE, Congress, State and Federal Regulators, Research Institutions, Developers

# MHK Resource Assessment Goals

1. Prioritize DOE's portfolio of future research
   - Within the Water program: comparing MHK resources to each other
   - Within DOE: comparing the characteristics of MHK resources to other generation technologies


Other necessary information:

- Technical assessments: device demonstrations and reference design models
- Environmental assessments: research to begin to determine possible severity of impacts and mitigation options



# MHK Resource Assessment Goals

2. Greater understanding of potential opportunities of MHK development on a national/regional level. Possible national goals or strategic plans for development of MHK technologies

For use by:

- national policy-makers, state + local governments

3. Indicate to device and/or project developers MHK resources and geographic areas of greatest promise.

4. Supports BOEMRE leases and FERC licenses - need energy generation estimates and capacity/availability factors

# Offshore Wind Resource Assessment

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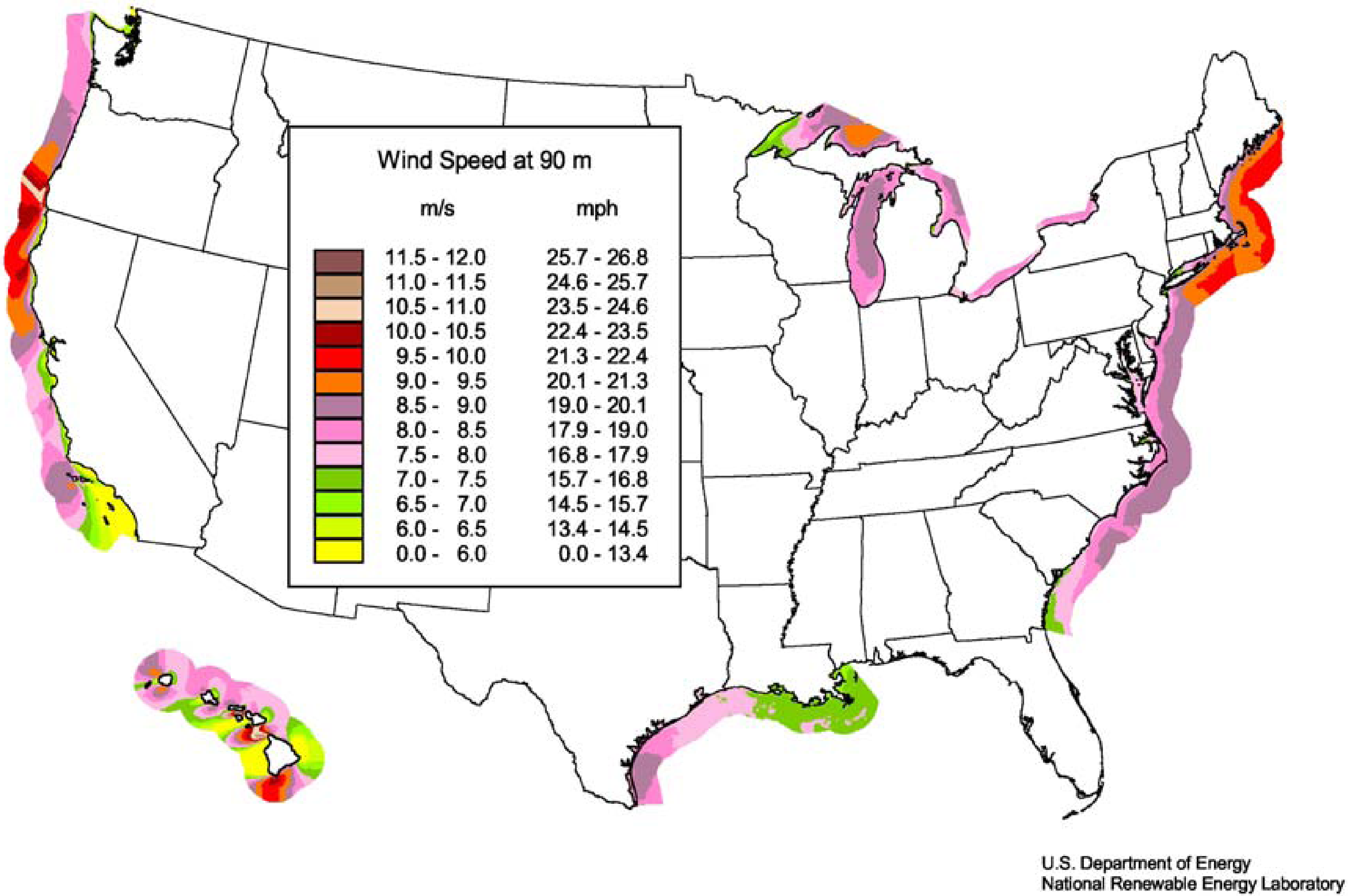
Resource Map from DOE National Offshore Wind Strategic Plan



# Offshore Wind Resource Assessment

- Offshore Wind Energy Potential at 90 m (GW):

- Wind resource maps from regional weather prediction models
- Annual average wind speed
- Validation at 50m
- Calculated out to 50 nm
- 5 MW/km$^2$ energy generating capacity applied
- No array effects
- No geographic exclusions
- Regional totals summed for national total

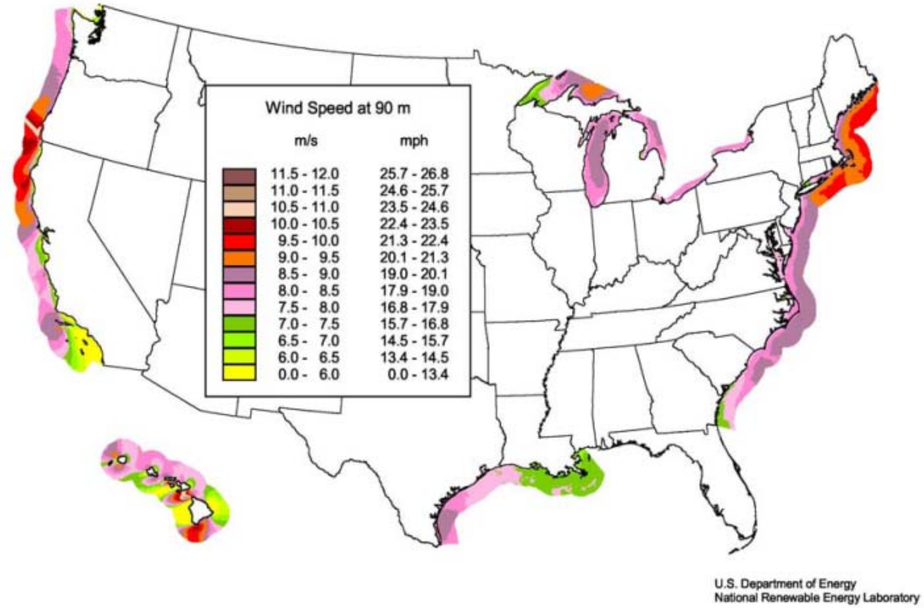



**Table 4-2. Offshore Wind Resource Potential by Region and Water Depth for Areas with Annual Average Wind Speeds 7.0 m/s or Greater at 90-m Elevation**

| Region | GW by Depth (m) 0–30 | 30–60 | >60 | Total |
|---|---|---|---|---|
| New England | 100.2 | 136.2 | 250.4 | 486.8 |
| Mid-Atlantic | 298.1 | 179.1 | 92.5 | 569.7 |
| South Atlantic Bight | 134.1 | 48.8 | 7.7 | 190.7 |
| California | 4.4 | 10.5 | 573.0 | 587.8 |
| Pacific Northwest | 15.1 | 21.3 | 305.3 | 341.7 |
| Great Lakes | 176.7 | 106.4 | 459.4 | 742.5 |
| Gulf of Mexico | 340.3 | 120.1 | 133.3 | 593.7 |
| Hawaii | 2.3 | 5.5 | 629.6 | 637.4 |
| Total | 1,071.2 | 628.0 | 2,451.1 | 4,150.3 |

Source: Schwartz et al. 2010.

Large Scale Offshore Wind Power in the United States (Musial 2010)

# Marine and Hydrokinetics Wave Resource Assessment

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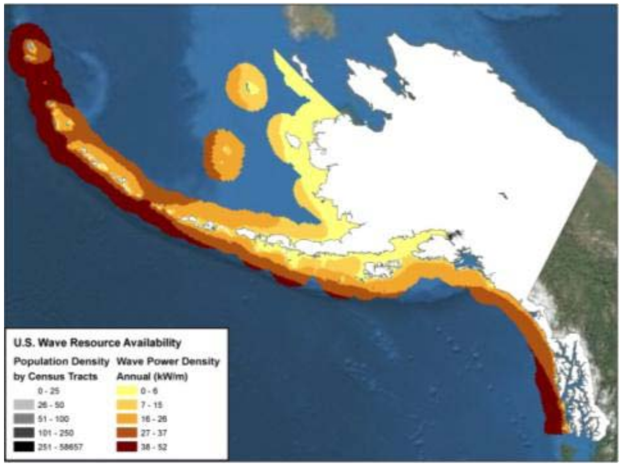

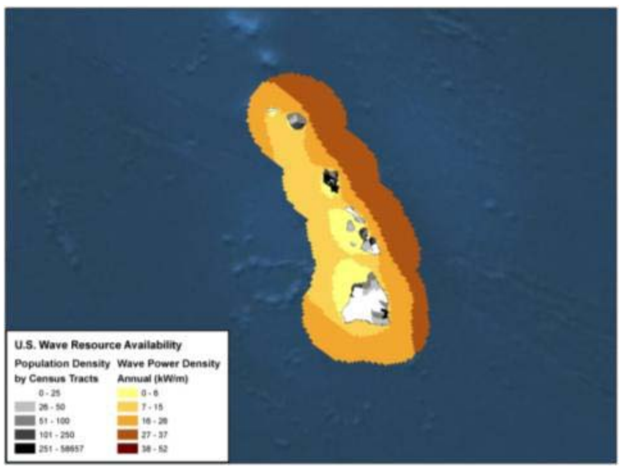

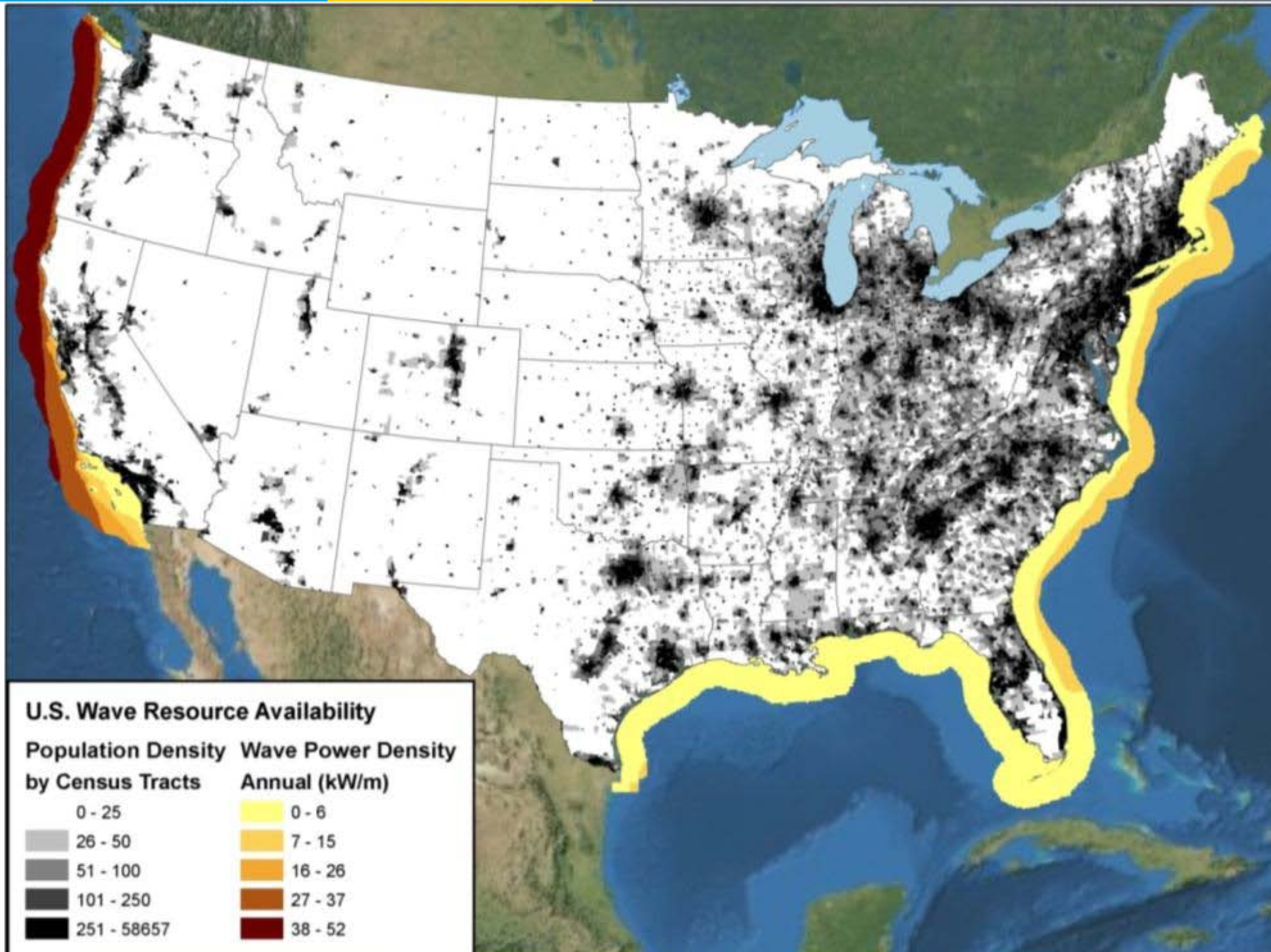


***Wave Energy is the dominant MHK resource available to the United States***

*2,640 TWh/yr Physical Potential*

*~1,170 TWh/yr Extractable*

Source: DOE funded U.S. Wave Energy Database: http://maps.nrel.gov/mhk_atlas

# Wave Energy Resource at Array Capacity Packing Density of 15 MW per km *

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| Coastline | Available Resource | Recoverable Resource |
|---|---|---|
| West Coast (WA,OR,CA) | 587 TWh/yr | 247 TWh/yr (42% of available) |
| East Coast (ME thru NC) | 197 TWh/yr | 128 TWh/yr (65% of available) |
| East Coast (SC thru FL-Atlantic) | 42 TWh/yr | 32 TWh/yr (76% of available) |
| Gulf of Mexico | 83 TWh/yr | 64 TWh/yr (77% of available) |
| Alaska (Pacific only) | 1,356 TWh/yr | 529 TWh/yr (39% of available) |
| Alaska (Bering Sea) | 194 TWh/yr | 95 TWh/yr (49% of available) |
| Hawaii | 130 TWh/yr | 83 TWh/yr (64% of available) |
| Puerto Rico | 28 TWh/yr | 21 TWh/yr (76% of available) |
| **TOTAL** | **2,617 TWh/yr** | **1,199 TWh/yr** (46% of available) |

* Three packing densities that were evaluated: 10 MW, 15 MW, and 20 MW per kilometer, with the two lower values bracketing the current state of technology, and the upper value representing an achievable improvement.

# Marine and Hydrokinetics Tidal Resource Assessment

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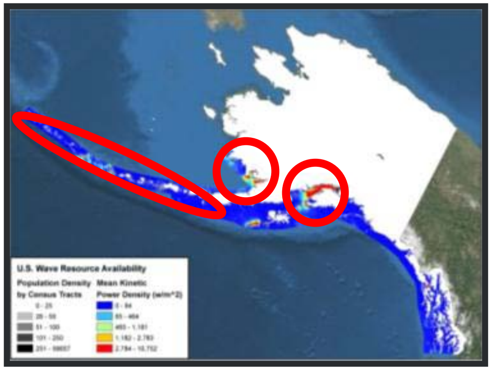
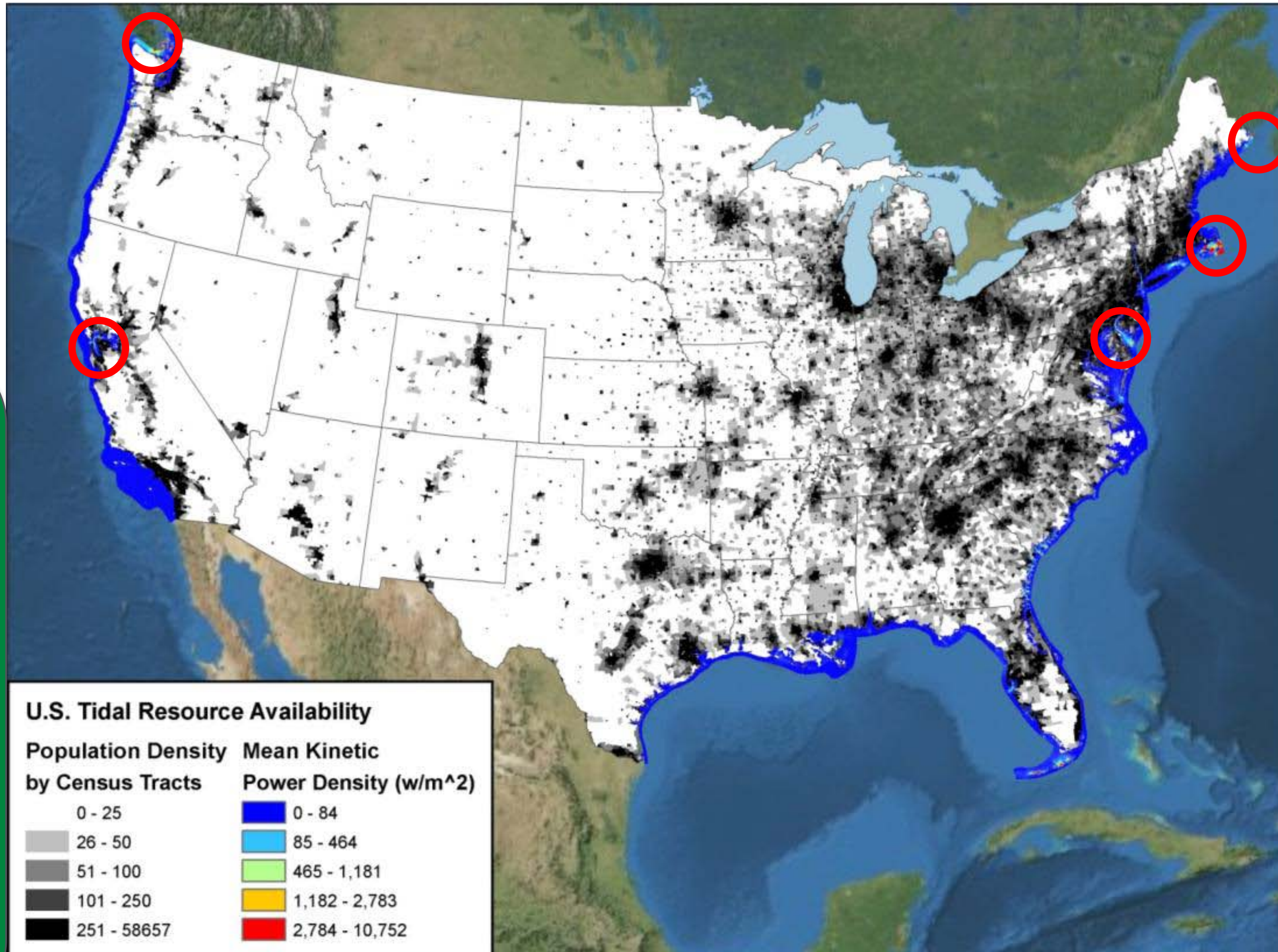


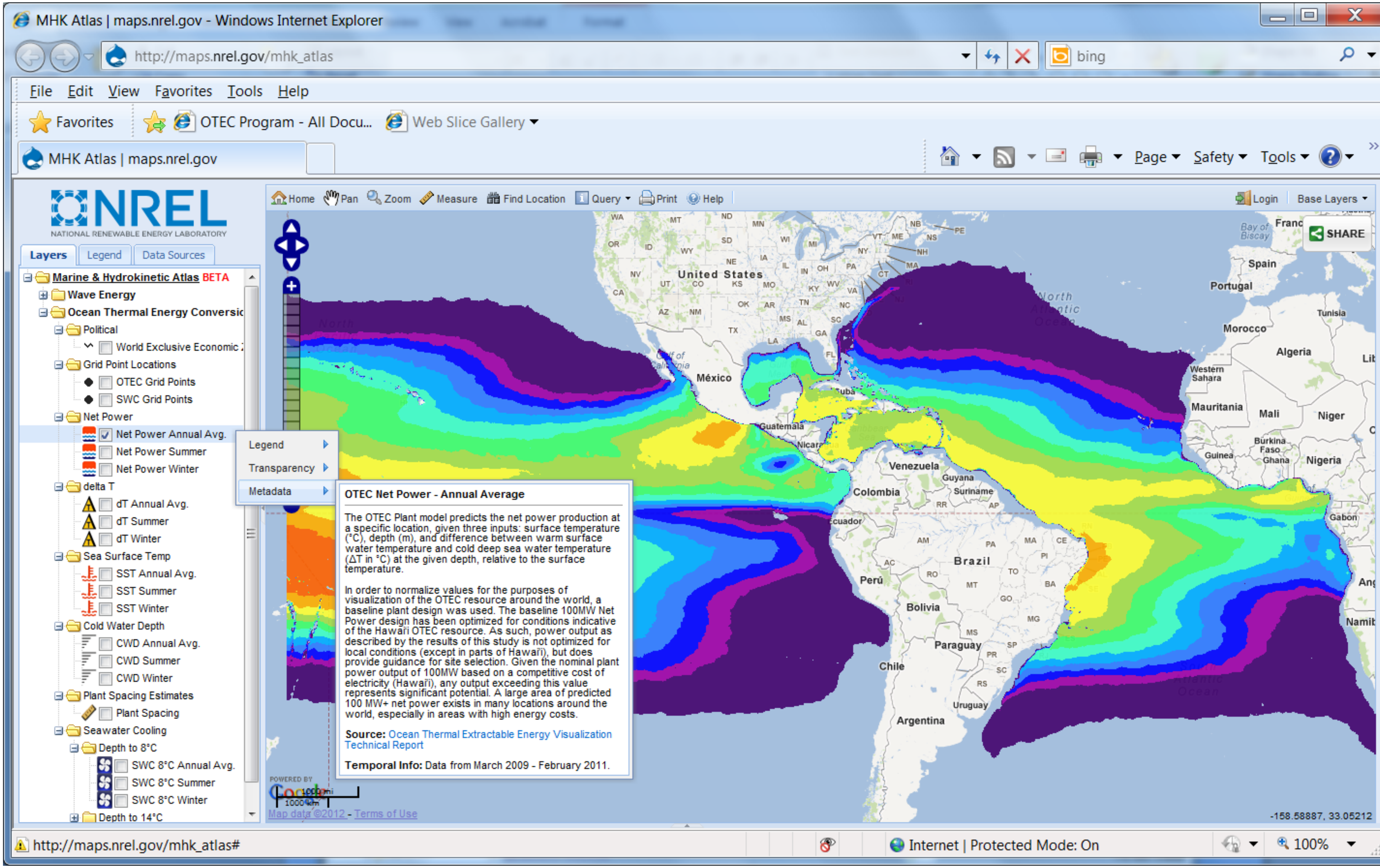
CONUS tidal resources (~445 TWh/yr) are concentrated and exist in close proximity to major coastal load centers…

However, over 90% of the overall resource (~410 TWh/yr) is located in Alaska.




Source: DOE funded U.S. Tidal Energy Database: [http://www.tidalstreampower.gatech.edu/](http://www.tidalstreampower.gatech.edu/)

# Marine and Hydrokinetics OTEC Resource Assessment



# Next Steps for Assessing Resources



**Possible additional activities:**

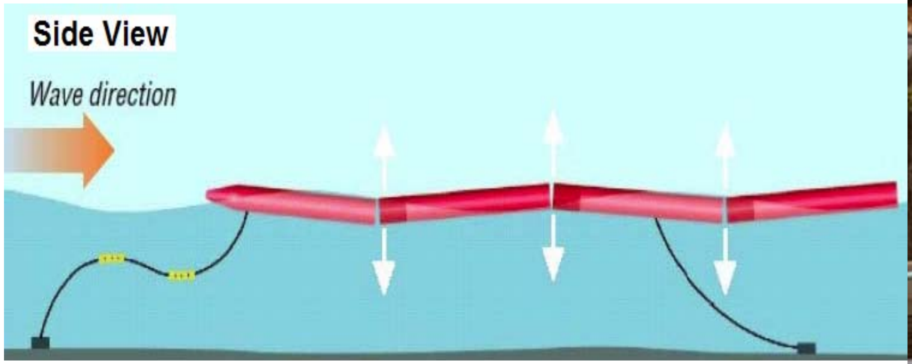
- Improvements to existing resource assessments
- More detailed assessment or characterization of highest priority areas
- Development of instrumentation for cost-effective site characterization by developers
- Development of forecasting tools / models
- Request for Information (RFI) released by DOE; goal is to collect information on the highest priority areas for further research into MHK and Offshore Wind Resource Assessment / Characterization

# MHK Similarities with Early Wind Industry

# Technology Types – Wave

- **Attenuator**
- Oscillating Water Column (OWC)
- Oscillating Wave Surge Converter (OWSC)
- Point Absorber
  - Floating
  - Submerged Pressure Differential
- Other

**Description:** An attenuator is a long, semi-submerged floating structure aligned in parallel with wave direction and anchored to the seafloor. Existing forms of this technology are composed of multiple sections that rotate relative to one another in a pitch-and-heave motion. The differing heights of the waves create an up and down motion of the sections, creating a flexing at the hinges, which is turned into electricity via hydraulic pumps or other forms of power take-offs.

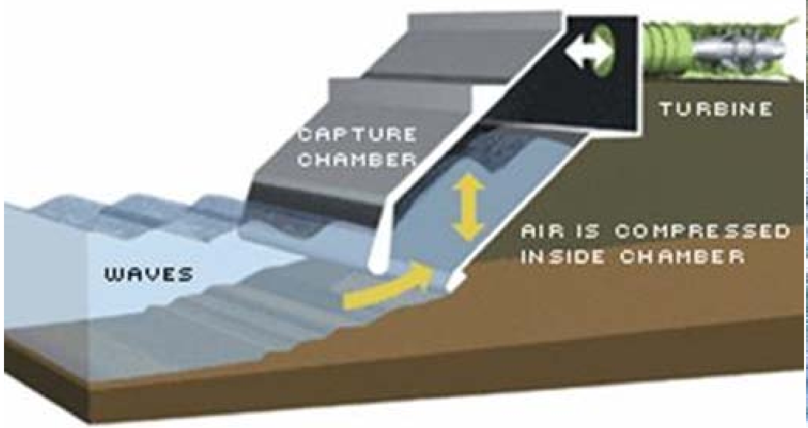



# Pelamis – Scotland

# Technology Types – Wave

- Attenuator
- **Oscillating Water Column (OWC)**
- Oscillating Wave Surge Converter (OWSC)
- Point Absorber
  - Floating
  - Submerged Pressure Differential
- Other

**Description:** There are two types of OWC: (1) shore/breakwater mounted and (2) floating. Both OWCs operate by the same principle in which water enters a chamber through a subsurface opening. The wave action causes this column of water to move up and down much like a piston - compressing and decompressing the air. The changes in air pressure are channeled through an air turbine (usually a bi-directional Wells turbine) making use of airflow in both directions.




# Technology Types – Wave

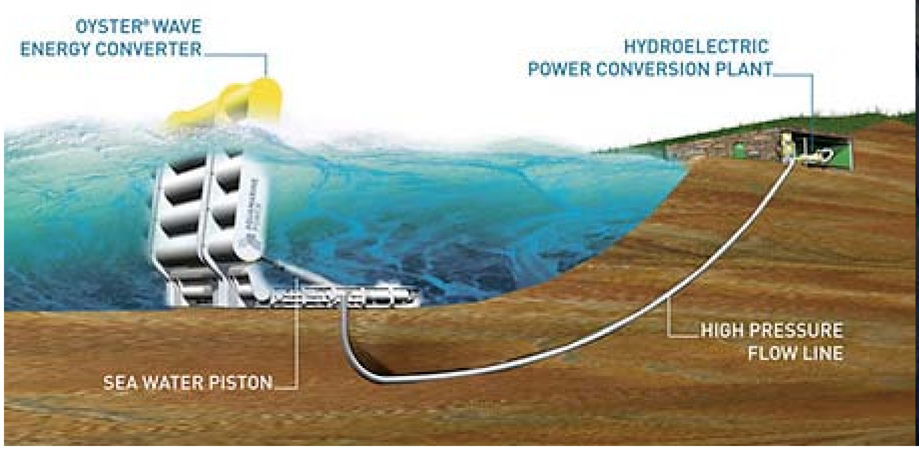
Oceanlinx Device – Australia

# Technology Types – Wave

- Attenuator
- Oscillating Water Column (OWC)
- **Oscillating Wave Surge Converter (OWSC)**
- Point Absorber
  - Floating
  - Submerged Pressure Differential
- Other

**Description:** An OWSC is a shoreline or near-shore device situated perpendicular to the direction of the waves that extracts the horizontal energy that exists in waves caused by the movement of water particles within them. The device consists of a paddle arm pivoting back-and-forth on a horizontal axis. The oscillation of the paddle arm is absorbed by a hydraulic pump to create electricity.

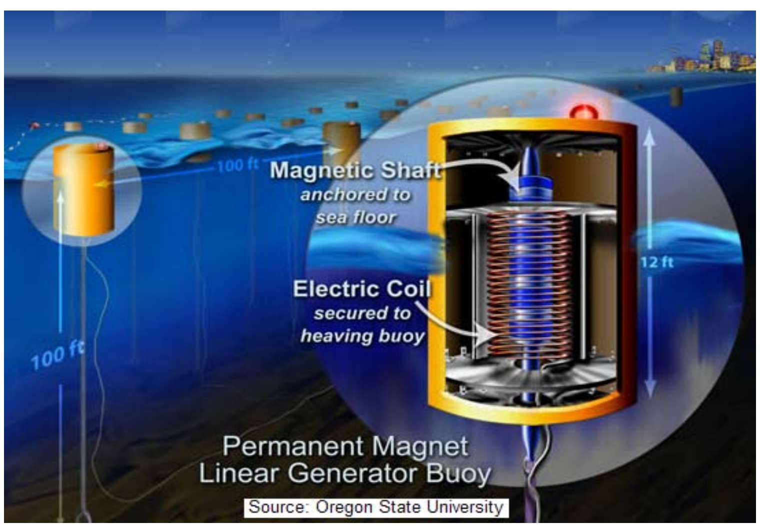
**Oyster Device – Aquamarine Power – Scotland**




# Technology Types – Wave

- Attenuator
- Oscillating Water Column (OWC)
- Oscillating Wave Surge Converter (OWSC)
- **Point Absorber**
  - **Floating**
  - Submerged Pressure Differential
- Other

**Description:** There are two types of point absorbers: (1) floating and (2) submerged pressure differential. Wave action causes the components of both types to move relative to each other. A floating point absorber absorbs energy in all directions through its movements at/near the water surface. The wave action drives an electromechanical or hydraulic energy converter.



Source: Oregon State University

# Technology Types – Tidal Current

- **Horizontal axis turbine**
- Vertical axis turbine
- Other

**Description:** A horizontal axis tidal current rotary device extracts energy from water moving parallel  to the axis of the rotor's rotation. Devices can be housed within ducts – e.g. Venturi – to create secondary flow effects by concentrating the flow of water and producing a pressure differential. Most devices have a central axle. However, some devices, like OpenHydro's Open-Centre Turbine, do not have a central axle, but rather utilize a stator to keep the rotors fixed.


Verdant Power – New York


OpenHydro – Ireland

# Technology Types – Tidal Current

- Horizontal axis turbine
- **Vertical axis turbine**
- Other

**Description:** A vertical axis tidal current rotary device has a main rotor shaft arranged vertically as to extract energy from the flow of moving water in any horizontal direction. An example of the vertical axis turbine include the Gorlov helical turbine.


Ocean Renewable Power Company – Maine

# Open Water Deployments – U.S.

## *Columbia Power Technologies*

– Recovered after ~13 months of continuous operation in Puget Sound, WA, 2011

## *Resolute Marine Energy*

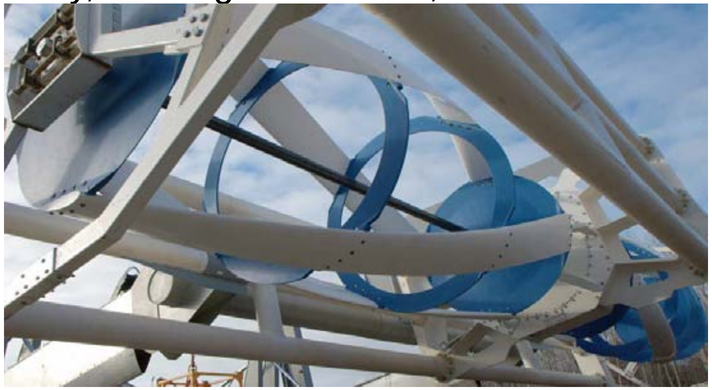
– Surge WEC testing off Jennette's pier in Nags Head, NC conducted in December, 2011

## *Free Flow Power*

– 40 kW river in-stream turbine deployed twice in 2011 for performance testing

## *Ocean Renewable Power Company*

– Deployment of the first of five, 60 kW tidal turbines in a grid connected array in Cobscook Bay, ME began in March, 2012



Thank you!

Questions?