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Marine & Hydrokinetic Technologies

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Presentation Outline

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

Electrical Power Generation by Source

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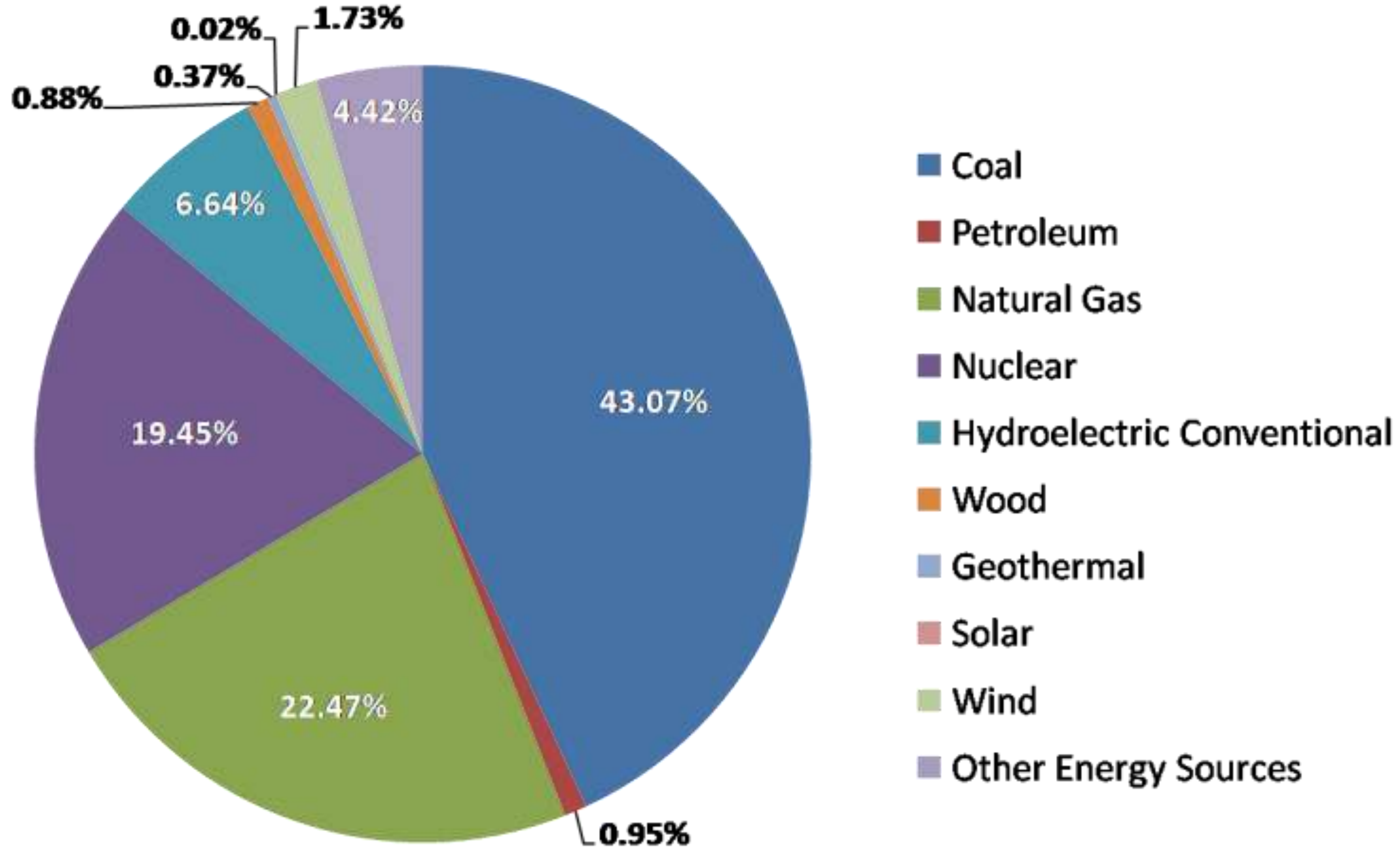

Summary Annual Production (2011) :

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

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Marine and Hydrokinetics	Current US Resource Estimates (technically recoverable)		23GW+
Wave Energy (>90% in Alaska)	1,199 TWh/yr (~400 GW)	EPRI, 2011	19.5 GW
Tidal Current Energy (>90% in Alaska)	250 TWh/yr (~50 GW)	Georgia Tech, 2011	1.5 GW
Ocean Current Energy (>90% in Southeastern U.S.)	1-2 GW	DOE, 1980 Updated Georgia Tech assessment underway	Resource Assessment to be completed in FY 2013
River Current Energy	101 TWh/yr (~20 GW)	EPRI, 2012	2 GW
Ocean Thermal Energy (>90% in Pacific Islands)	4,642 TWh/yr (~600 GW)	Lockheed, 2012	N/A
Total Domestic Energy Use **Total Electrical Energy Use**	**≈ 98 Quads (9,300 MHK-GWeq)** **≈ 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**

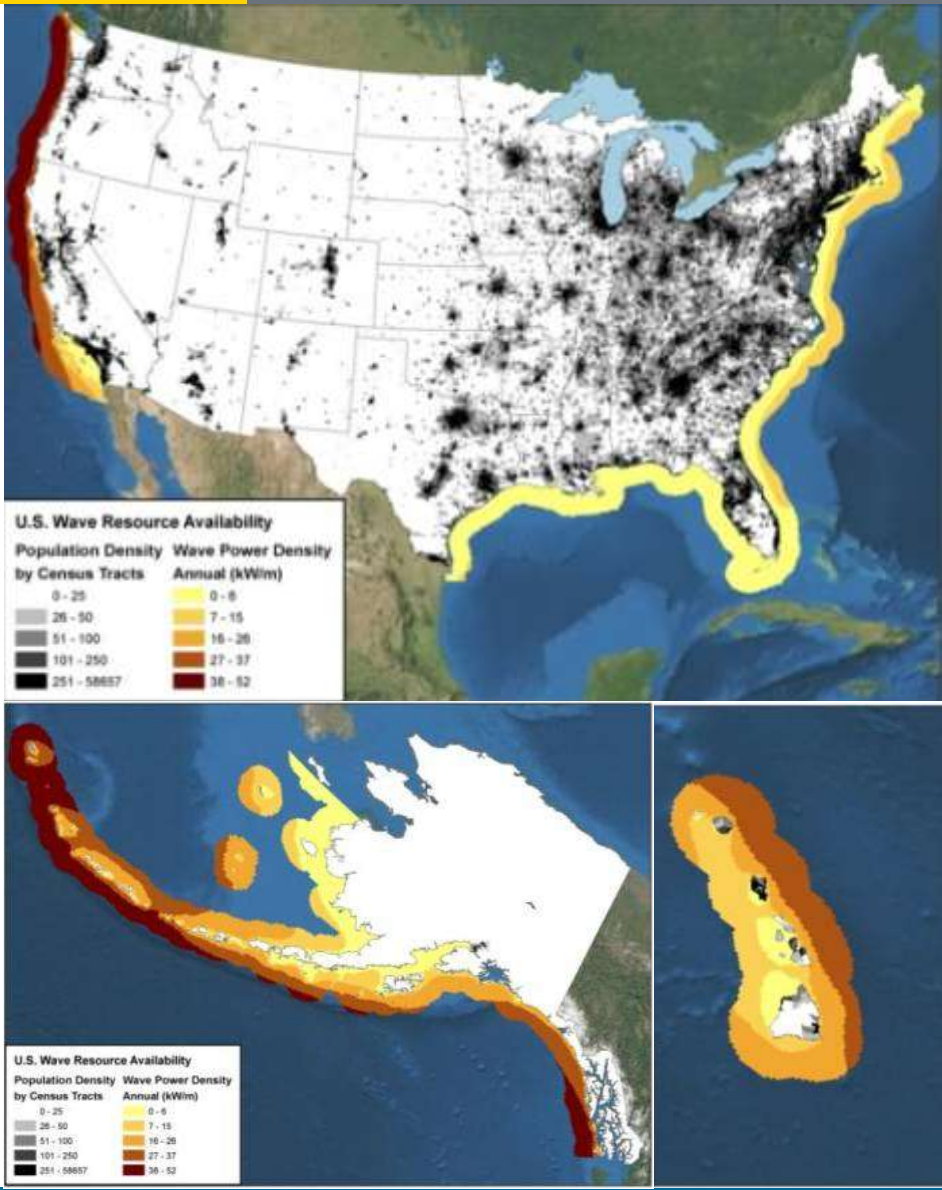
Marine and Hydrokinetics
Wave Resource Assessment

Wave Resources:

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

Total Wave Energy Resource Potential by Region		
West Coast	590	TWh/yr
East Coast	240	TWh/yr
Alaska	1,570	TWh/yr
Hawaii	130	TWh/yr
Gulf of Mexico	80	TWh/yr
Puerto Rico	30	TWh/yr
Total:	2,640	TWh/yr

Source: "Mapping & Assessment of the United States Ocean Wave Energy Resource", EPRI 2011



Marine and Hydrokinetics
Tidal Resource Assessment

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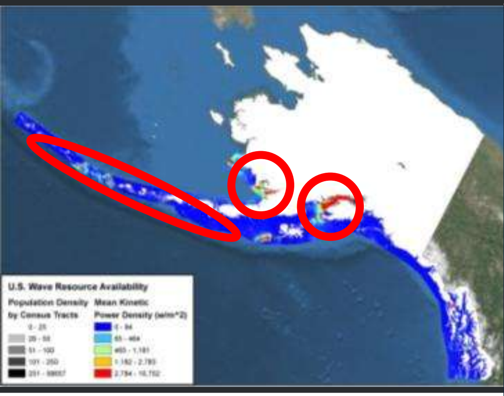
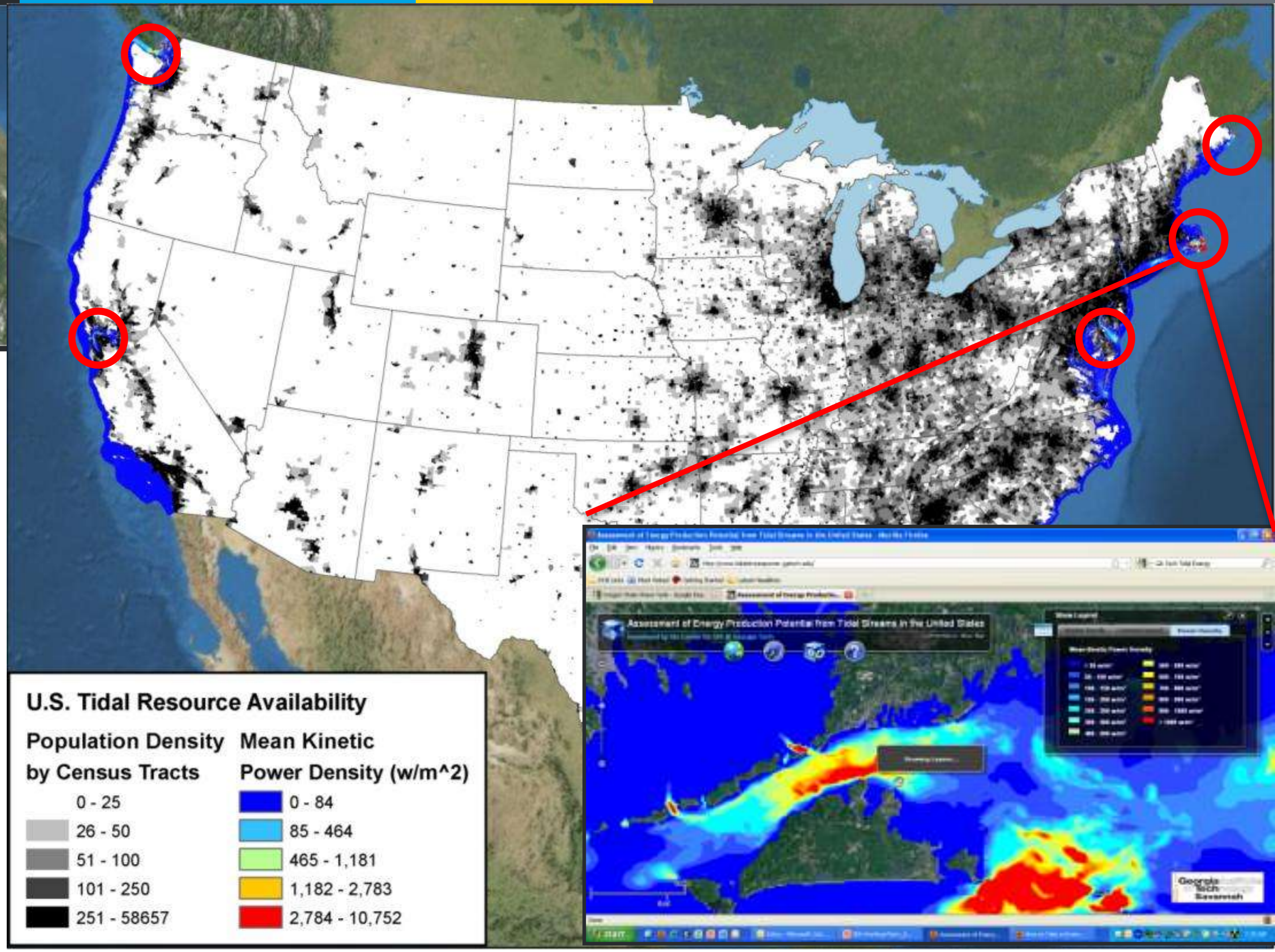


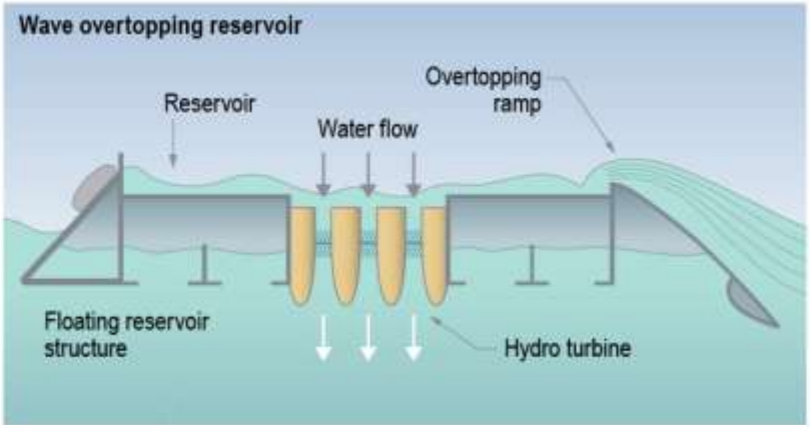


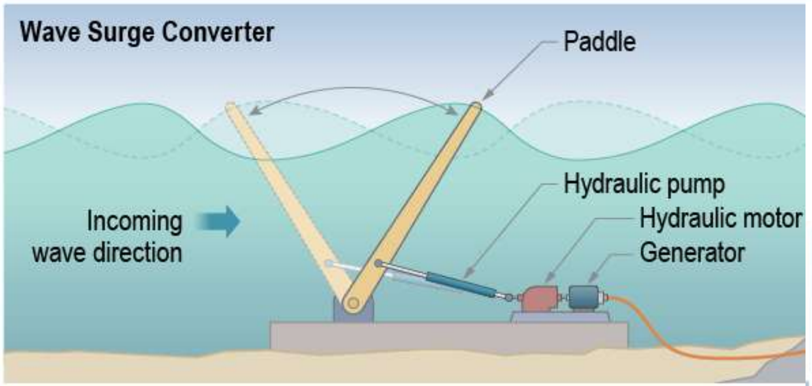
CONUS Tidal Resources

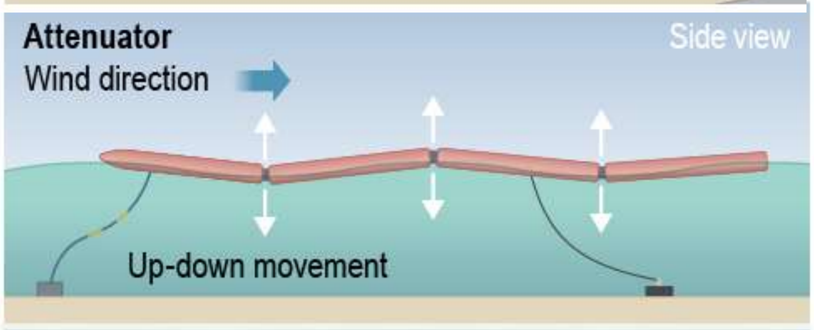
- **Magnitude of potential tidal power at 250TWhr/yr is significantly less than wave**
- **~3 GW concentrated and exist in close proximity to major coastal load centers…**
- **However, over 90% of the overall resource (~47 GW) is located in Alaska.**

Source: Tidal Energy Database: http://www.tidalstreampower.gatech.edu/ (DOE Funded)

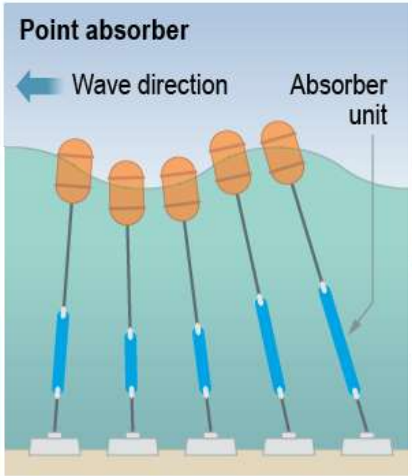
Wave Technologies

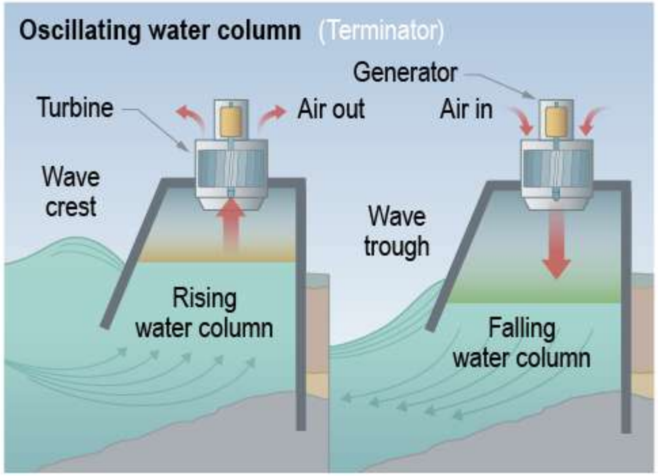






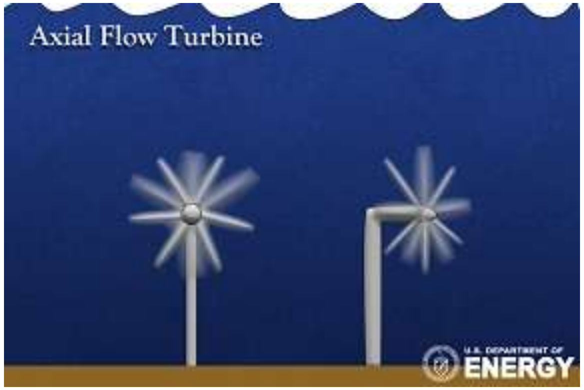
- Most are radically new technologies… devices and system concepts only at the first generation/pioneering stage of development
- Limited existing technical expertise and modeling platforms—what is applicable comes from O&G and maritime engineering
- LCOE of early-stage technologies at 40-60 cents per kWh

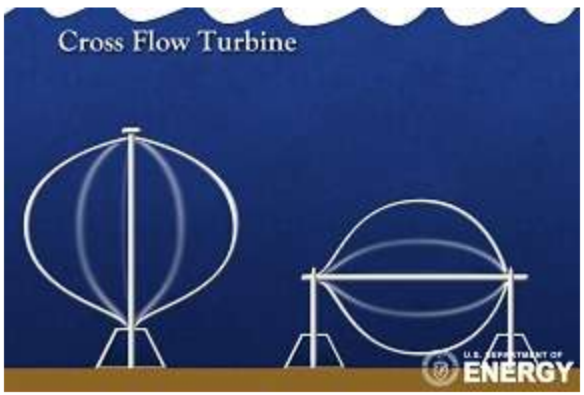




Marine and Hydrokinetics

Current (Tidal, Ocean and River) Technologies





- Current technologies are based upon validated wind turbine technologies adapted for marine environments:
  - Axial Flow → Horizontal Axis Turbine
  - Cross Flow → 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 fowling
- 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

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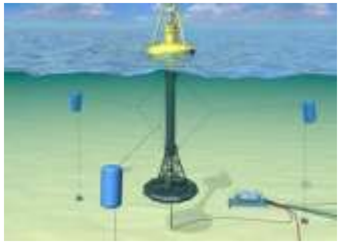
Wave Technology

- 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

OPT PowerBuoy

- 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

Aquamarine Power Oyster

- 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)

Ocean Energy Limited 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

Wave Device Examples

Attenuator

Pelamis WEC

- 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

Overtopping

Wave Dragon WEC

- 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

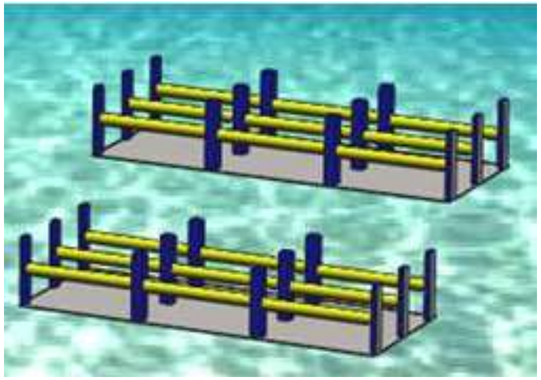
Current Device Examples

Axial Flow

Verdant Power axial flow turbine

- 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

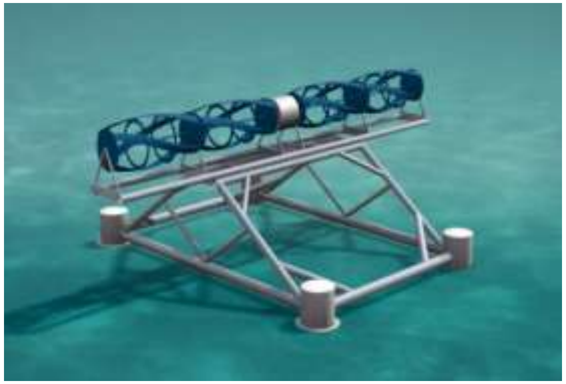
Reciprocating



Vortex Hydro reciprocating device

- 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

Cross Flow



ORPC cross-flow tidal turbine

- 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)

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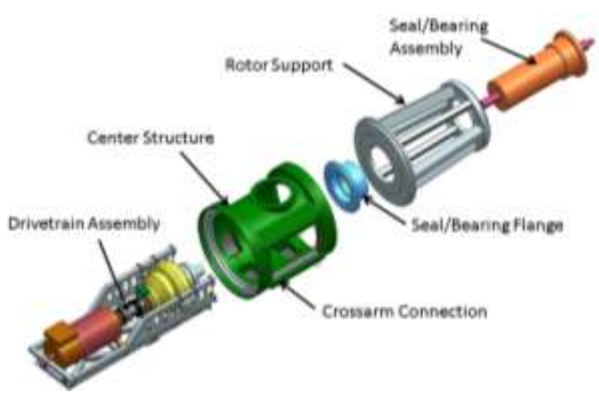
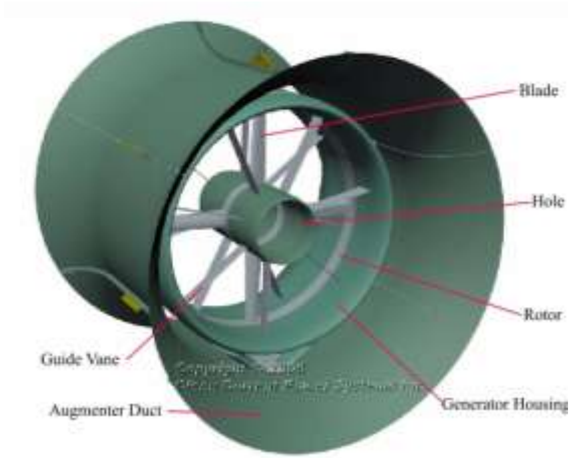
PTO is the combination of the drivetrain and generator that converts mechanical power into electrical power

- 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

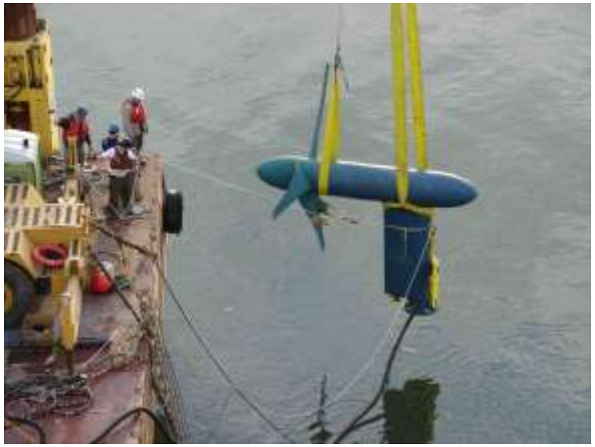
Assembly

- 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.

Deployment, Retrieval, and O&M

- 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

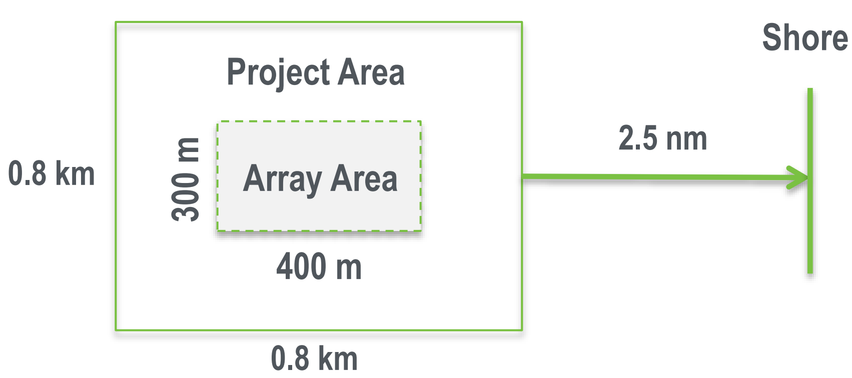


Port facilities and vessels will be necessary for assembly, deployment, and O&M

Arrays

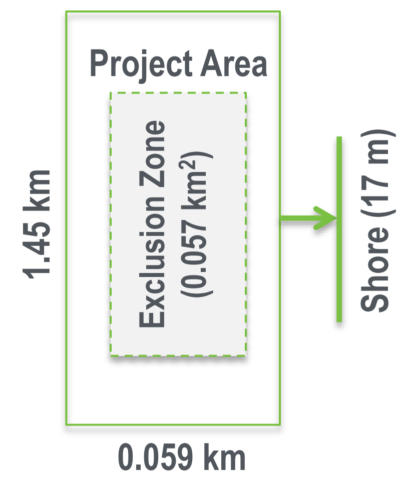
Example WEC Array

- 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



Production Manufacturing of Arrays

- 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

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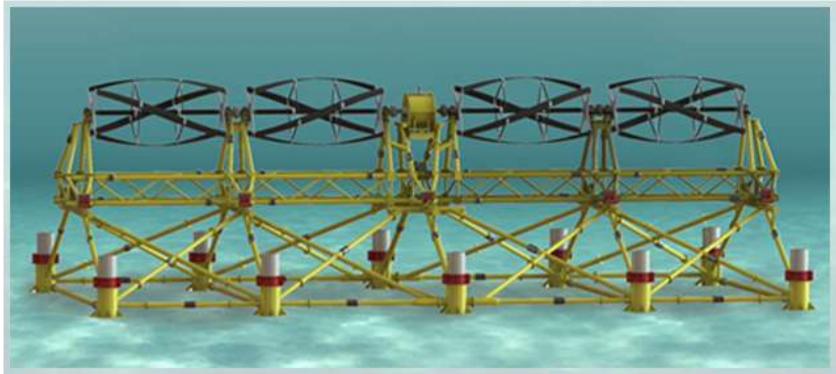
- Immature Technology
  - Lack of design tools, standards, and validation data are preventing disciplined approach to design.
  - High technical and cost uncertainty due to lack of experience.
  - Test facilities are needed where new technologies can be proven outside the commercial regulatory path.

- 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.

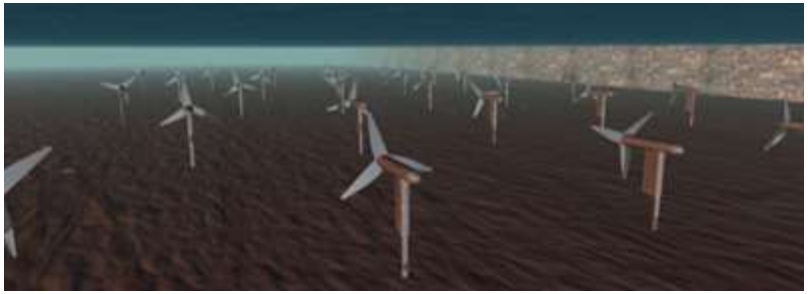
High Profile Projects

- 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



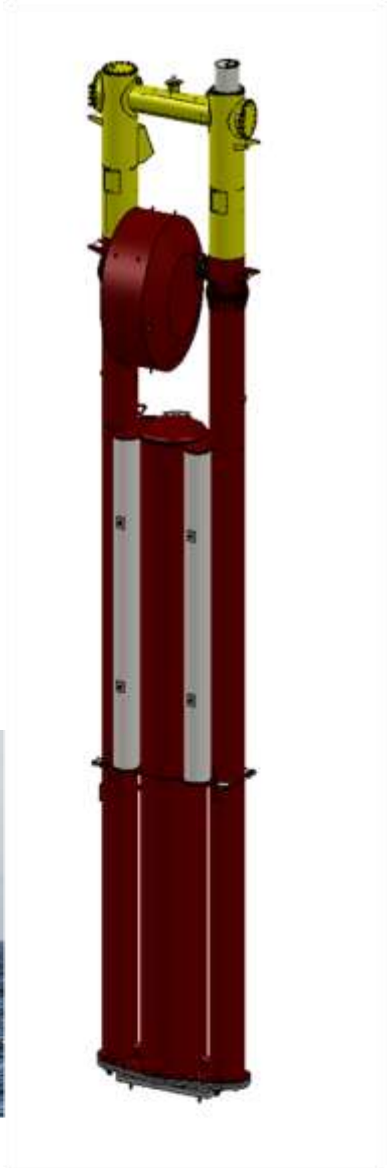
High Profile Projects

- 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



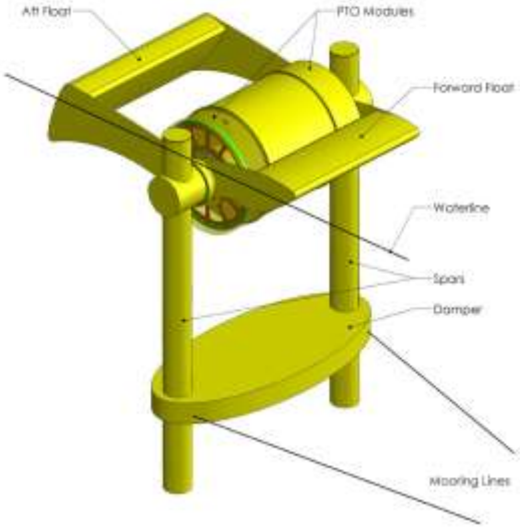
High Profile Projects

- 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

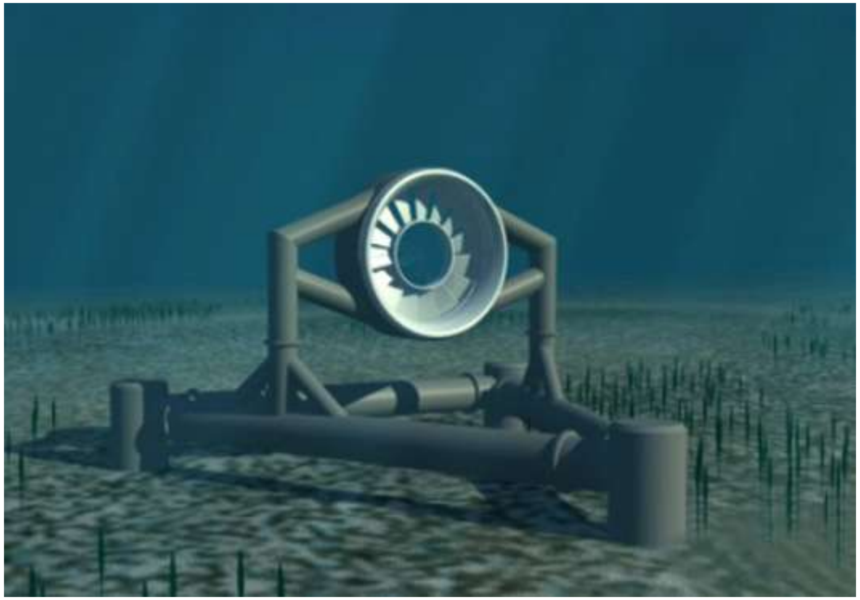
- Columbia Power Technologies
  - StingRAY WEC
  - Earlier 1/7th scale prototype deployed for approximately in Puget Sound, WA
  - 418 metric tons
  - Dimensions
    - Length(fore to aft): 15.4 m
    - Beam(port to starboard): 12.5 m
    - Overall Height: 20.5 m
    - Draft: 18.75 m
    - Freeboard: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

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- 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

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