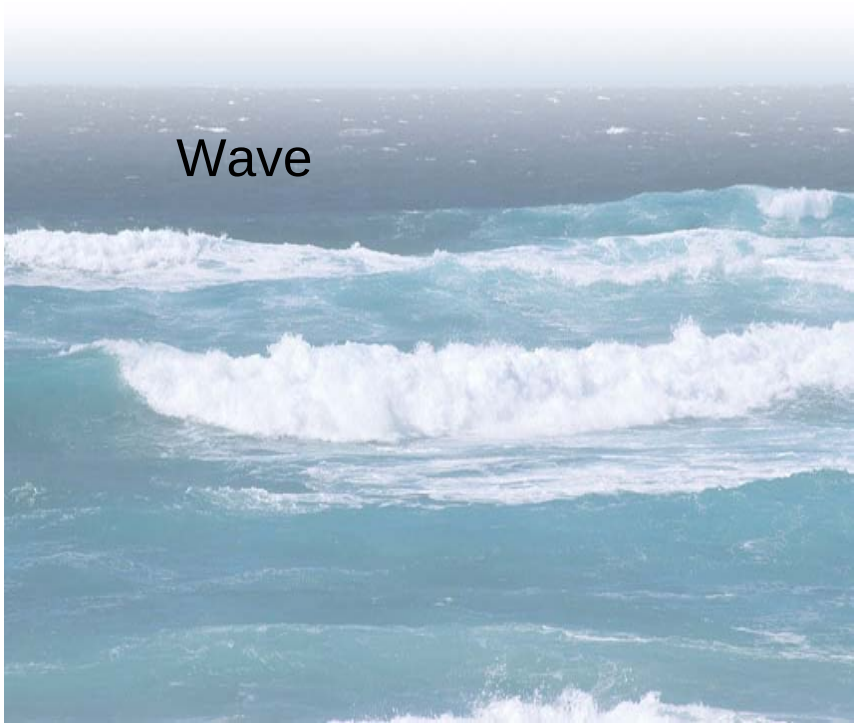
HydroKinetic Energy “Lay of the Land”



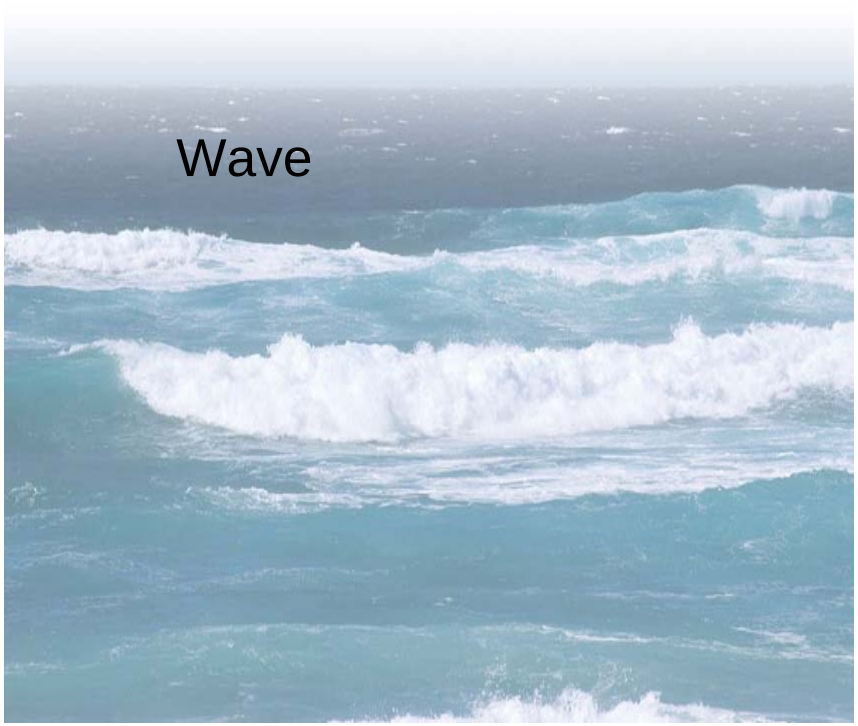
DOE HydroKinetic Workshop

October 26, 2005

Presented by: Roger Bedard /EPRI

EPRI

or as Alla Weinstein says: “Motion of the Ocean”



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Outline

- Classification of Wave and Tidal Stream Energy Conversion Devices

- Ocean Energy – HydroKinetic Energy – Marine Energy Terminology

Terminology: HydroKinetic

- Hydro = Greek word for water (*hydor*)
- Kinetic = of, relating to, or provided by motion
- Therefore, HydroKinetic Energy is “the energy possessed by a body of water because of its motion ($KE = 1/2\ mv^2$)
- And HydroStatic Energy is “the energy possessed by a body because of its position or location at an elevation or height above a reference or datum ($PE = mgh$)

Terminology: Applying this Definition to Hydro Based Power (Static and Kinetic)

Energy Source	Example Plants	Hydro Static	Hydro Kinetic
On Land Wind	40,000 MW installed worldwide		Aero Kinetic
Offshore Wind	600 MW installed in Europe, None in the US, Example is Arklow IR (GE 3.6MW)		Aero Kinetic
Hydro Electric (with storage)	Grand Coulee Dam, Hoover Dam, etc	Yes	
Run of River (without storage)	Wailuku River (1.25, 2.25 & 11 MW plants), Hilo, Island of Hawaii	Yes	
Tidal Hydro	240 MW LaRance France, 20 MW Annapolis, Nova Scotia	Yes	
Tidal/River In Stream	Marine Current Turbine SeaFlow		Yes
Ocean Current	None		Yes
Ocean Waves	Ocean Power Delivery Pelamis		Yes
Hybrid Wind Wave	None		Yes -Wave is Hydro

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Terminology – EPRI Ocean Energy vs DOE Hydrokinetic Energy Definitions: Which definition does a particular energy source fall under?

Energy Source	EPRI Wind and Hydro	EPRI Ocean Energy	DOE Wind and Hydro	DOE Hydro Kinetic
On Land Wind	Yes	No	Yes	No
Offshore Wind	Yes	Yes	Yes	No
Hydro Electric	Yes	No	Yes	No
Run of River	Yes	No	Yes	No
Tidal Hydro	Yes	No	Yes	No
Tidal In Stream	No	Yes	No	Yes
River In Stream	No	Yes	No	Yes
Ocean Current	No	Yes	No	Yes
Ocean Waves	No	Yes	No	Yes
Hybrid Wave Wind	No	Yes	?	?

Conclude that EPRI Ocean Energy = DOE Hydro Kinetic except for Hybrid Offshore Wind – Wave Energy

Terminology: Ocean Energy Glossary

All those who choose to participate in the EPRI Ocean Energy Program must understand the marine energy glossary published by the Carbon Trust in the UK (except of course for funders)\

http://www.thecarbontrust.co.uk/ctmarine3/res/MarineEnergyGlossary.pdf

The following glossary definitions are in the EPRI Wave Project Final Summary Report, available at, and again, courtesy of, the Marine Carbon Trust

www.epri.com/oceanenergy/

- ***Placement*** – Devices may convert wave power at the shoreline, near to the shore or offshore. The distinction between near-shore and offshore is often related to design requirements for water depth (this generally increasing with distance from shore), the energy content of waves (this being greater offshore), and access for deployment, retrieval, operation and maintenance.
- ***Fixing*** – Near-shore and offshore devices may be either bottom-mounted or floating, the former being fixed to the seabed by a static member and the latter moored to hold on station.
- ***Reaction*** – Wave energy devices need a system of reacting forces in order to extract energy and this is one of the biggest design challenges. To create such a system, two or more bodies need to move relative to each other, while at least one body interacts with the waves. There are numerous approaches. One approach is to allow one body to move freely with the waves, while another is held static (as in the case of a floating buoy reacting against the seabed). Alternatively, all of the bodies may be dynamic.

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Terminology (cont)

Wave energy devices can be classified by means of their reaction system, but it is often more instructive to discuss how they interact with the wave field. In this context, each moving body may labeled as either a displacer or reactor.

- ***Displacer*** – This is the body moved by the waves. It might be a buoyant vessel, or, as in the case of Oscillating Water Column (OWC) devices, a mass of water. If buoyant, the displacer may pierce the surface of the waves or be submerged.
- ***Reactor*** – This is the body that provides reaction to the displacer. As suggested above, it could be a body fixed to the seabed, or the seabed itself. It could also be another structure or mass that is not fixed, but moves in such a way that reaction forces are created (e.g. by moving by a different amount or at different times). A degree of control over the forces acting on each body and/or acting between the bodies (particularly stiffness and damping characteristics) are often required to optimize the amount of energy captured.

In some designs, the reactor is actually inside the displacer, while in others it is an external body. Internal reactors are not subject to wave forces, but external ones may experience loads that cause them to move in ways similar to a displacer. This can be extended to the view that some devices do not have dedicated reactors at all, but rather a system of displacers whose relative motion creates a reaction system.

The generality of the above might suggest there are many ways in which a wave energy device can be configured and indeed this is the case.

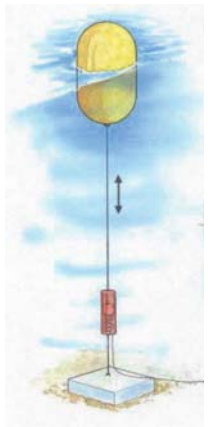
Terminology (finished)

Some of the most well-known device concepts are introduced below.

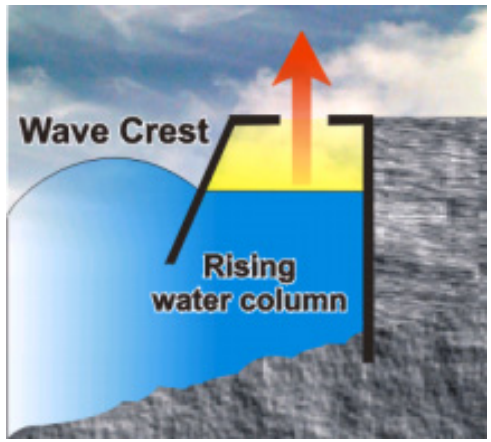
- ***Oscillating Water Column (OWC)*** – This comprises a partly submerged structure ('collector') which is open to the sea below the water surface so that it contains a column of water. Air is trapped above the surface of the water column. As waves enter and exit the collector, the water column moves up and down and acts like a piston on the air, pushing it back and forth. The air is channeled towards a turbine and forces it to turn. The turbine is coupled to a generator to produce electricity.
- ***Overtopping*** – This consists of a structure over which the waves topple, a reservoir to collect the water and hydro turbines installed at the bottom of the reservoir. The head of collected water turns the turbines as it flows back out to sea and the turbines are coupled to generators to produce electricity.
- ***Point absorber*** – This is a floating structure that absorbs energy in all directions by virtue of it's movements at or near the water surface. It may be designed so as to resonate – that is, move with larger amplitudes than the waves themselves. This feature is useful to maximize the amount of power that is available for capture. The power take-off system may take a number of forms, depending on the configuration of displacers/reactors.
- ***Terminator*** – This is also a floating structure that moves at or near the water surface, but it absorbs energy in only a single direction. The device extends in the direction normal to the predominant wave direction, so that as waves arrive, the device restrains them. Again, resonance may be employed and the power take-off system may take a variety of forms.
- ***Attenuator*** – This device is a long floating structure like the terminator, but is orientated parallel to the waves rather than normal to them. It rides the waves like a ship and movements of the device at its bow and along its length can be restrained so as to extract energy. A theoretical advantage of the attenuator over the terminator is that its area normal to the waves is small and therefore the forces it experiences are much lower

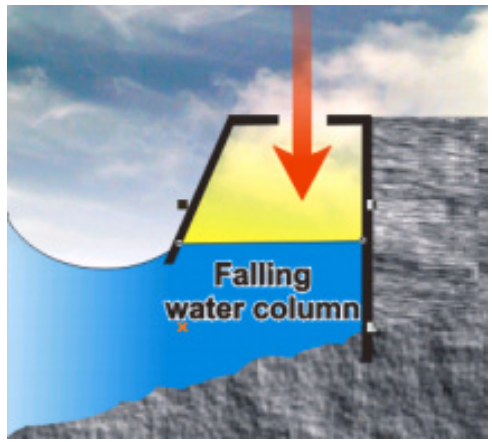
4 Primary Types of Wave Energy Conversion

Point Absorber

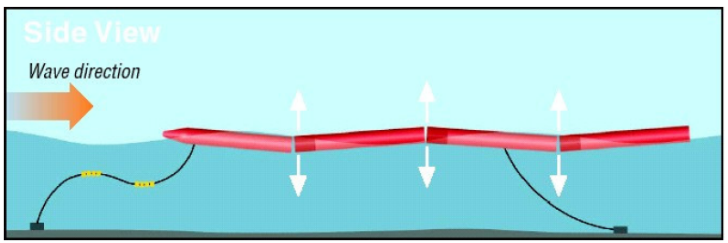


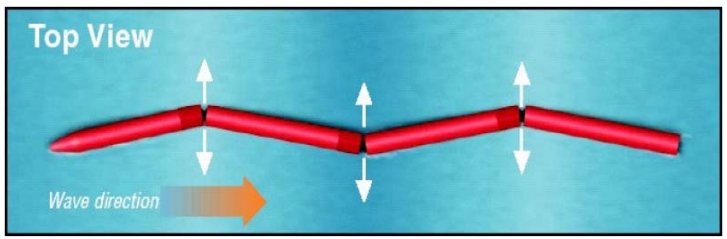
Terminator- Oscillating Water Column



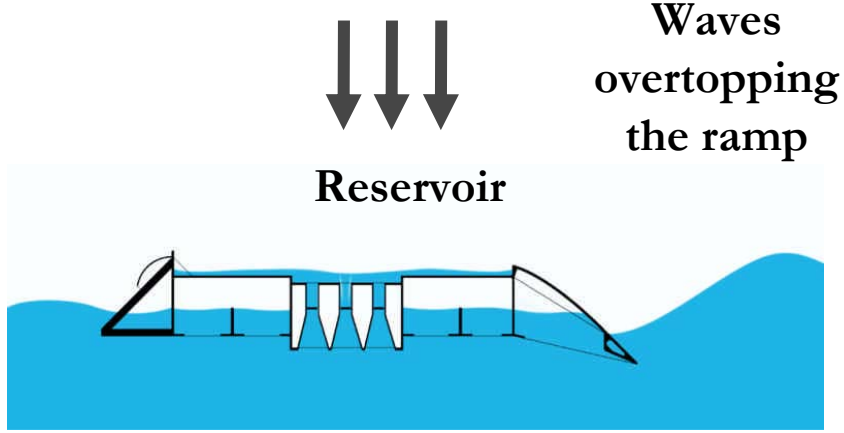


Attenuator





Overtopping



Examples of Wave Energy Devices (WECs)

Point Absorber (AquaEnergy AquaBuOY)

Terminator (Energetech Oscillating Water Column)

Attenuator (OPD Pelamis)

Overtopping (Wave Dragon)

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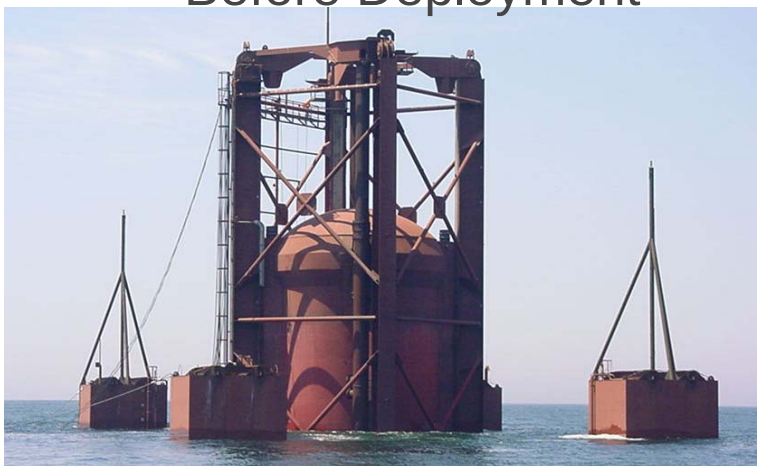
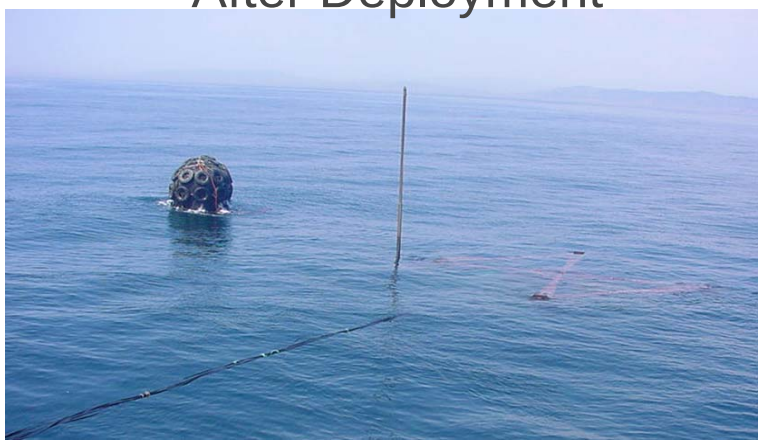
More Examples of WECs

Point Absorber TeamWork
Archimedes Wave Swing
Before Deployment

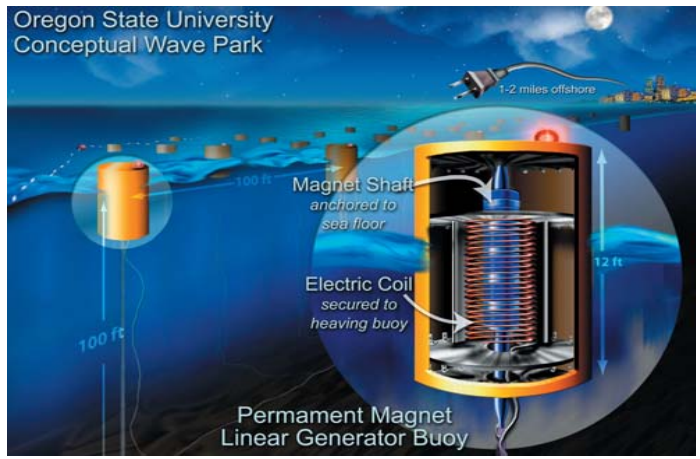


After Deployment



Point Absorber
Ocean Power
Delivery
PowerBuoy

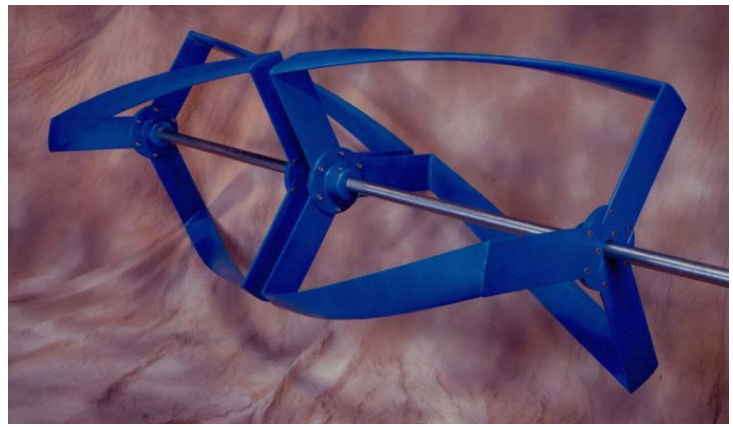
Point Absorber OSU PM Direct Drive



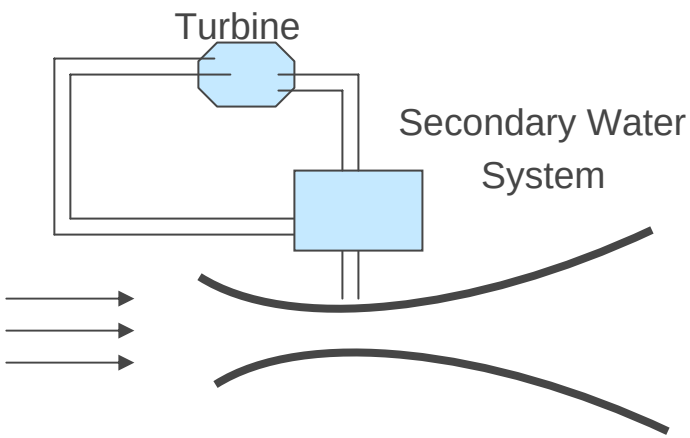
Four Primary Types of In Stream Tidal Flow Energy Conversion Devices (TISECs)

Horizontal Axis Turbines

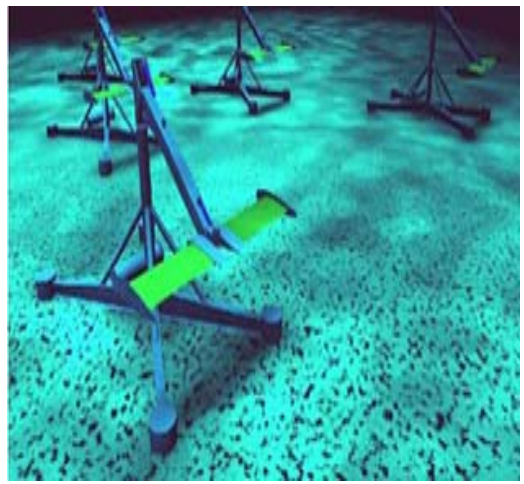
Vertical Axis Turbines



Venturi



Oscillatory



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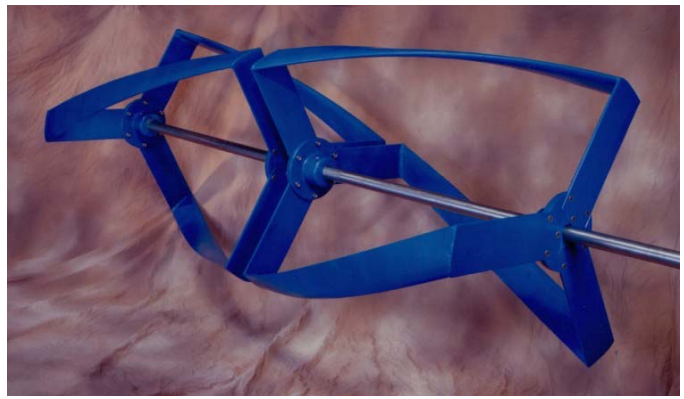
Examples of Tidal Stream Technology

Horizontal Axis - Marine Current Turbines SeaGen

Vertical Axis - Gorlov



Venturi -

Oscillatory - Engineering Business Stingray

Two US Tidal Flow Demonstrations

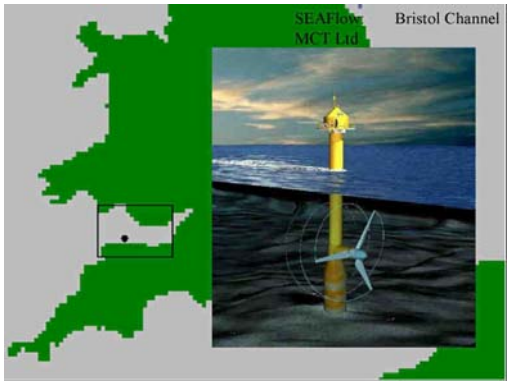
East River, New York, NY

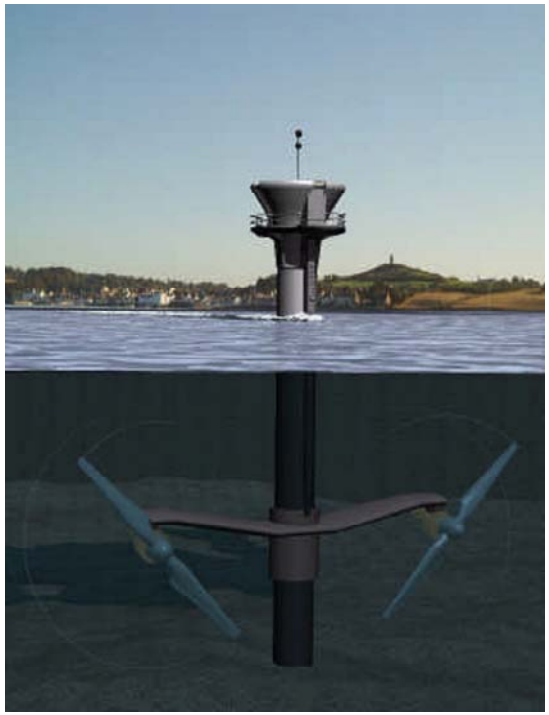
Merrimack River, MA

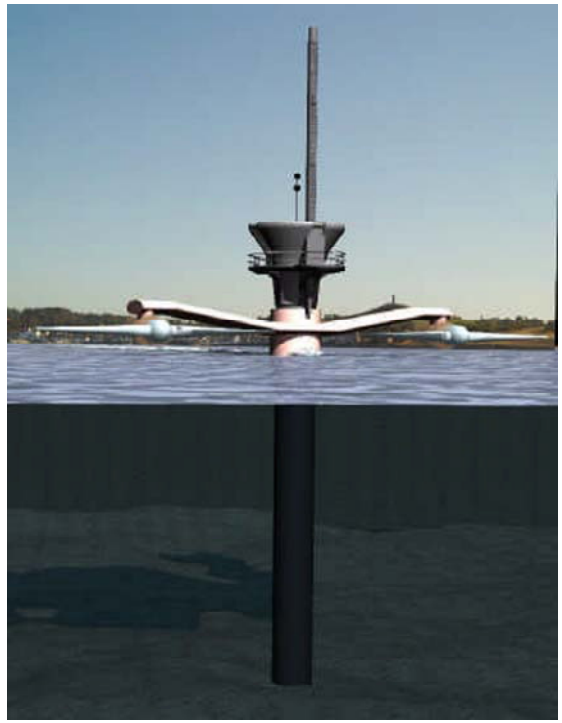
Verdant Horizontal Axial Turbine

Gorlov Vertical Axis Turbine

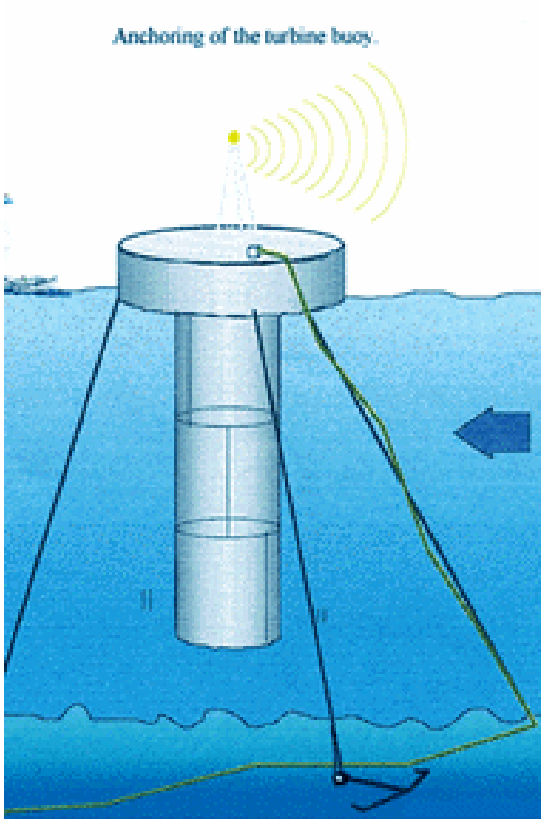
UK In-Stream Tidal Demonstration - MCT



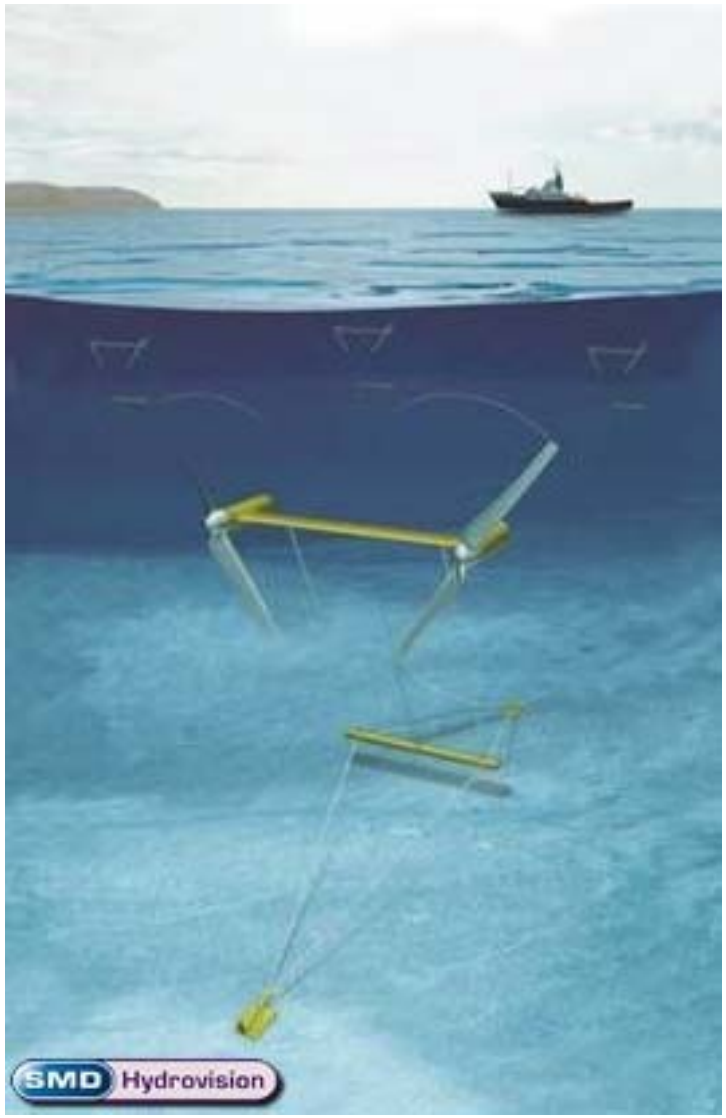




Swedish Vertical Axis Device - Seapower



UK In-Stream Device - SMD Hydrovision



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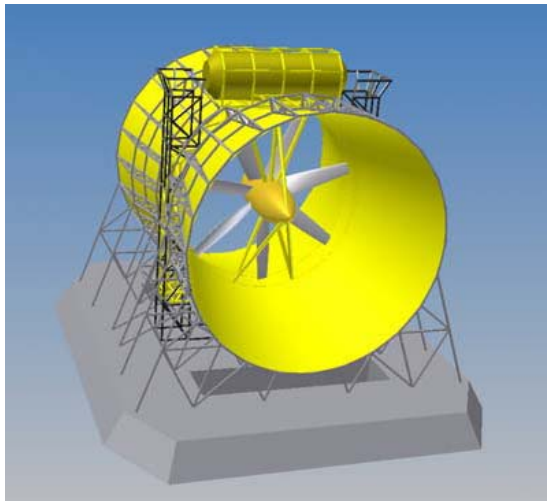
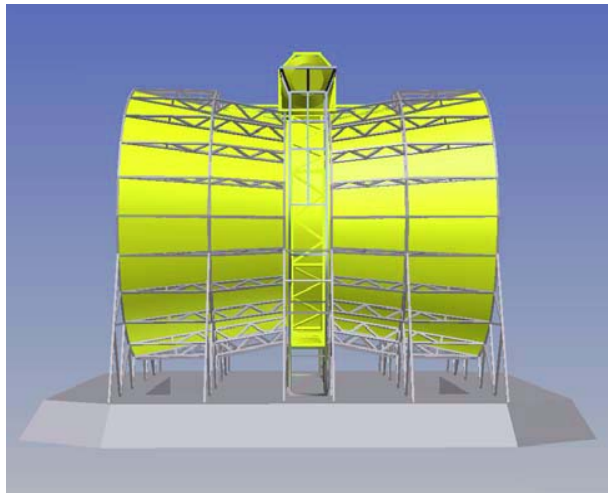
UK In-Stream Device – Lunar Energy

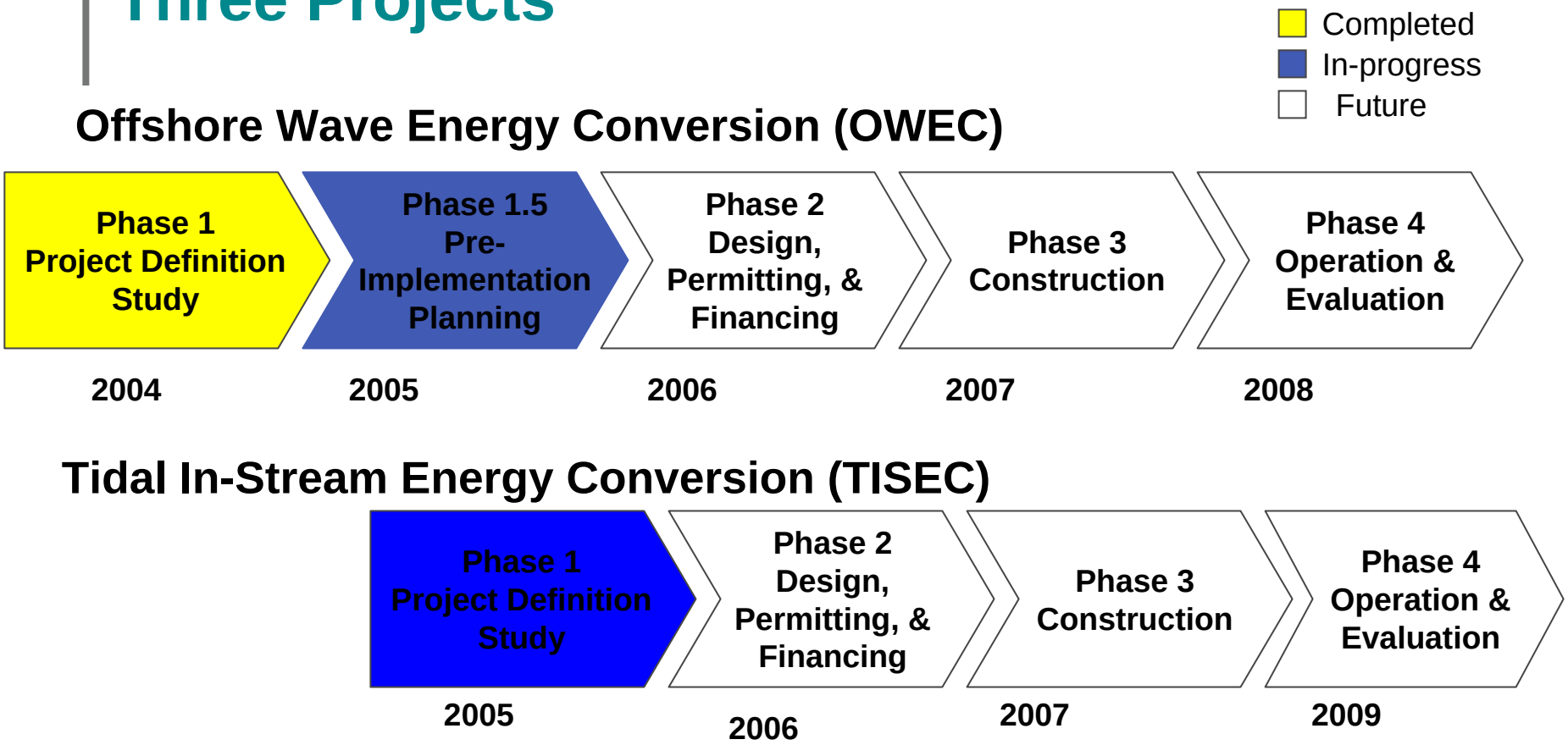




EPRI Ocean Energy Feasibility Assessments

- **Motivation**
  - A diversity of energy sources is the foundation of a reliable electrical system
  - North America has significant wave and tidal in-stream energy resources
  - Technologies able to harness these resources are becoming available
- **Objective**
  - Feasibility demonstration in North America
  - Accelerate sustainable commercialization of the technology
- **Approach**
  - Facilitate public/private collaborative partnership between coastal states, involving state agencies, utilities, device develops, interested third-parties, and the DOE

Three Projects



Participants (Funders – cash and in-kind)

State/City Agencies (9)

- Maine Tech Initiative
- Mass Tech Collaborative
- New Brunswick Ministry
- Nova Scotia Ministry
- Alaska Energy Authority
- Washington CTED
- Oregon DOE
- San Francisco & Oakland CA

Federal (2)

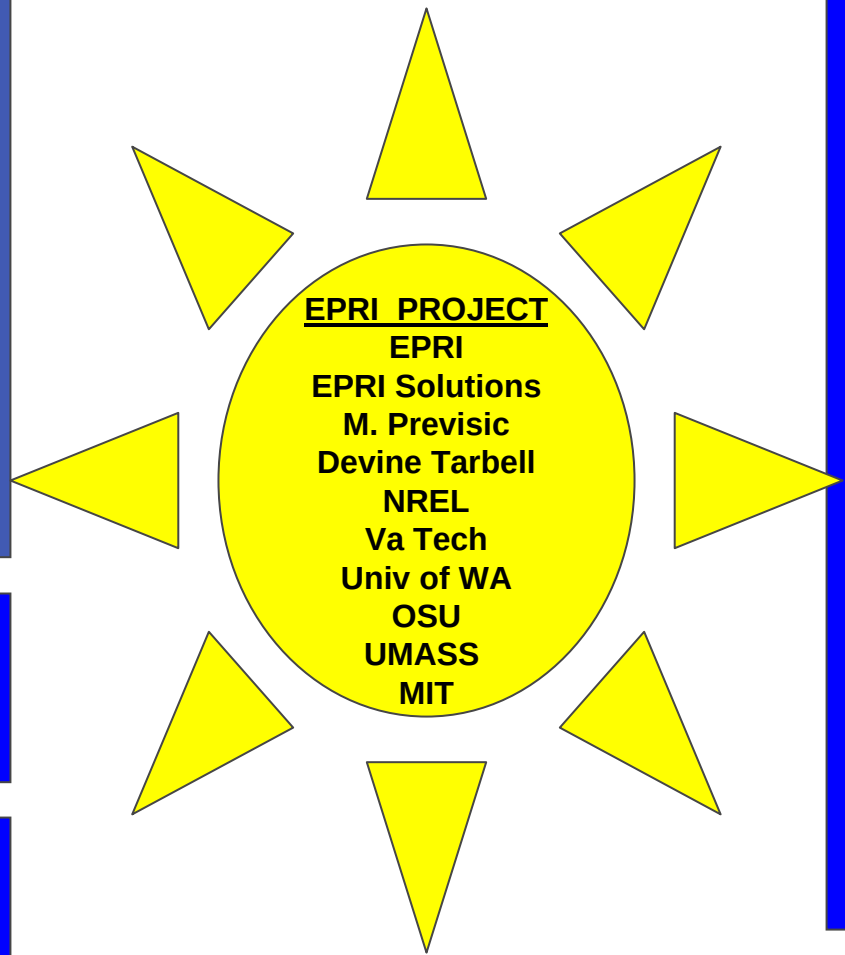
- U.S. DOE
- NREL

Institutes

- Bedford Oceanography
- Alexandria Research

Technology Companies (30)

- Wave & Tidal Power Developers



Utilities (19)

- Bangor Hydro Central
- Maine Power
- National Grid
- NSTAR
- NB Power
- NS Power
- Chugach
- Tacoma Power
- Puget Sound Energy
- Seattle City and Light
- Snohomish PUD
- Bonneville Power
- Central Lincoln PUD
- Douglas Electric Co-op
- Portland General
- Pacificorp
- PG&E
- HECO and KIUC

Summary

EPRI Ocean Energy Program is for the Public Benefit

All Technical Work Totally Transparent

All Reports Available:

Project Reports - www.epri.com/oceanenergy/

Monthly Progress Reports - rbedard@epri.com