EPRI Ocean Energy Program

OREG, October 19, 2005

Presented by:

Tom Key

EPRI Renewable and Distributed Energy

Background of EPRI People

Roger Bedard is EPRI Ocean Energy Leader

Renewable Energy Development Background (formerly managed energy projects at Acurex and JPL)

Tom Key is EPRI Technical Lead for Renewable and Distributed Energy

Electric Systems Background (formerly US Navy and Sandia)

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Outline

- Introduction / Participants
- The Ocean Energy Resource
- EPRI Collaborative Projects
- Technologies Considered – An Emerging Area
- Other US Ocean Energy Projects

EPRI Ocean Energy Feasibility Assessments

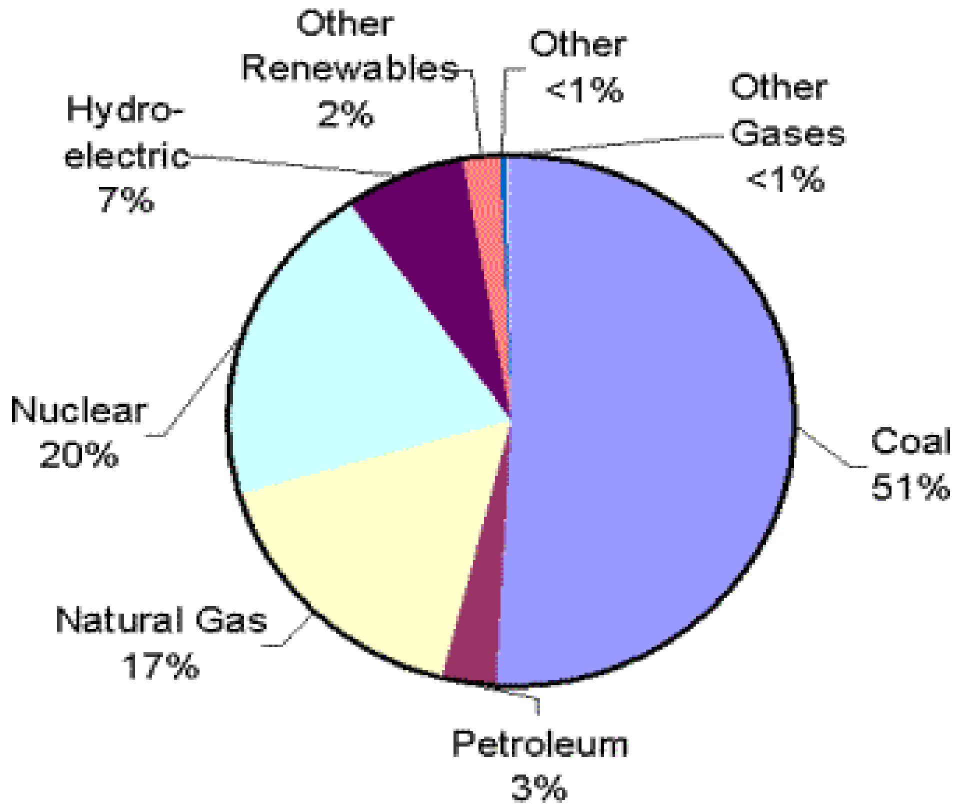
- **Motivation**
  - A diversity of energy sources is the foundation of a reliable electrical system
  - North America has significant wave and tidal in-stream energy resources
  - Technologies able to exploit these resources are becoming available
- **Objective**
  - Feasibility demonstration in North 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

Electric Energy Picture in US

- **US Total Electricity Consumption = 3.7 TWh/yr**
- **US primary energy required = 11.2 TWh/yr**
- **Annual US Wave and Tidal Energy Resource = 2.2 TWh/yr**

<u>Benefits of Ocean Energy</u>

- Diversify energy sources to improve energy security
- Zero emission and with low environmental impact
- Minimizes not in my back yard issues
- Economics look attractive (at significant scale)
- Reduces dependence on foreign energy supplies
- Job creation and local economic development



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Resource Comparison

	Solar CSP	Wind	Wave	Tidal Current
Development Status	Early Commercial	Commercial	Pre-Commercial	Pre-Commercial
Source	Sun	Uneven solar heating	Wind blowing over water	Gravity of moon & sun
Annual Average Power Density	200-300 watts/m^2 (southern & western US)	400-600 watts/m^2 (US Great Plains)	20-25 kW/m (US West Coast) 5-15 kW/m (US East Coast)	5-10 kW/m^2 (Alaska, Bay of Fundy) 1-2 kW/m^2 (Seattle, SF)
Intermittency	Day-night; clouds, haze, and humidity	Atmospheric fronts and storms (local winds only)	Sea (local winds) and swell (from distant storms)	Diurnal and semi-diurnal (advancing ~50 min./day)
Predictability	Minutes	Hours	Days	Centuries

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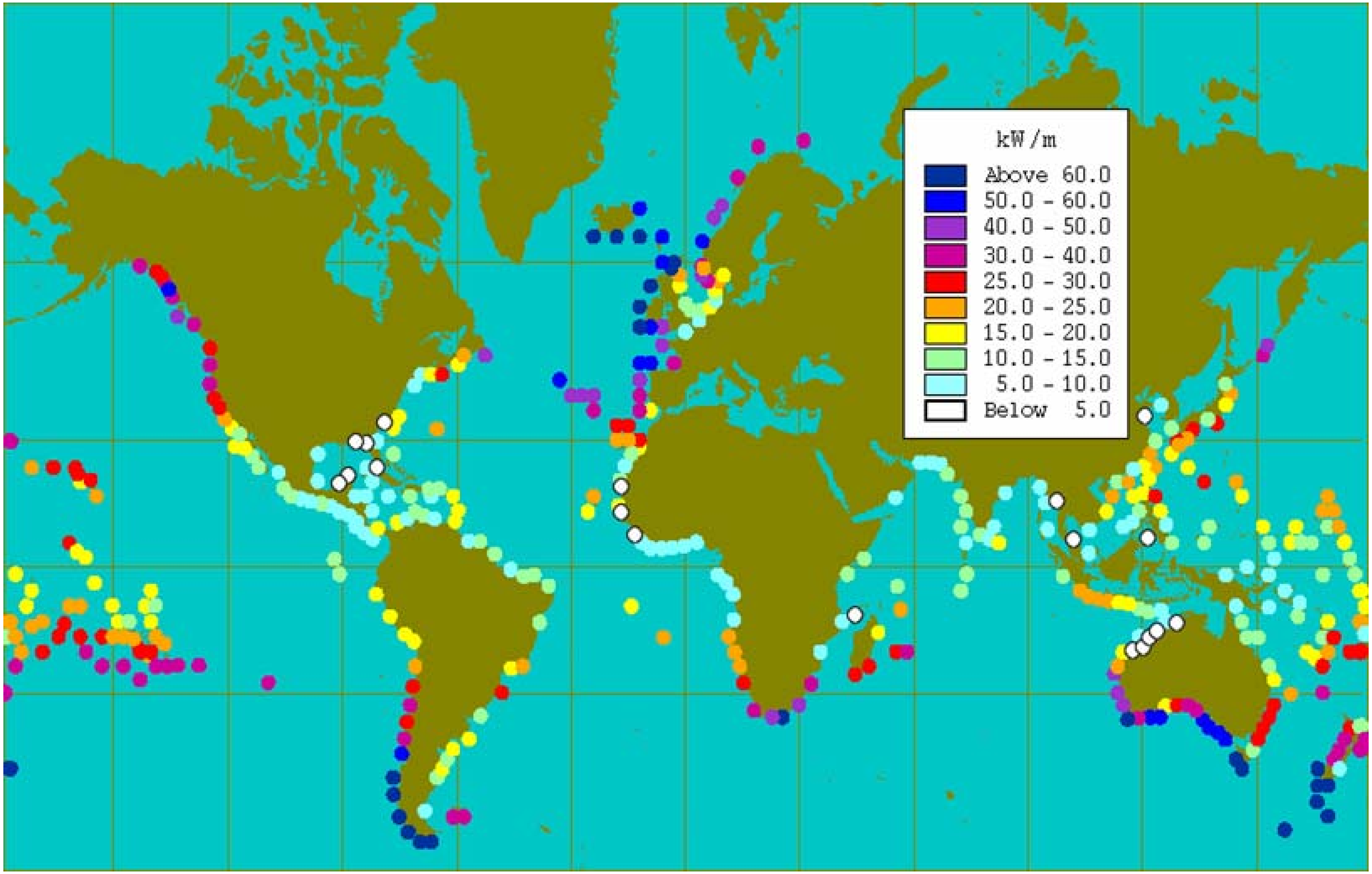
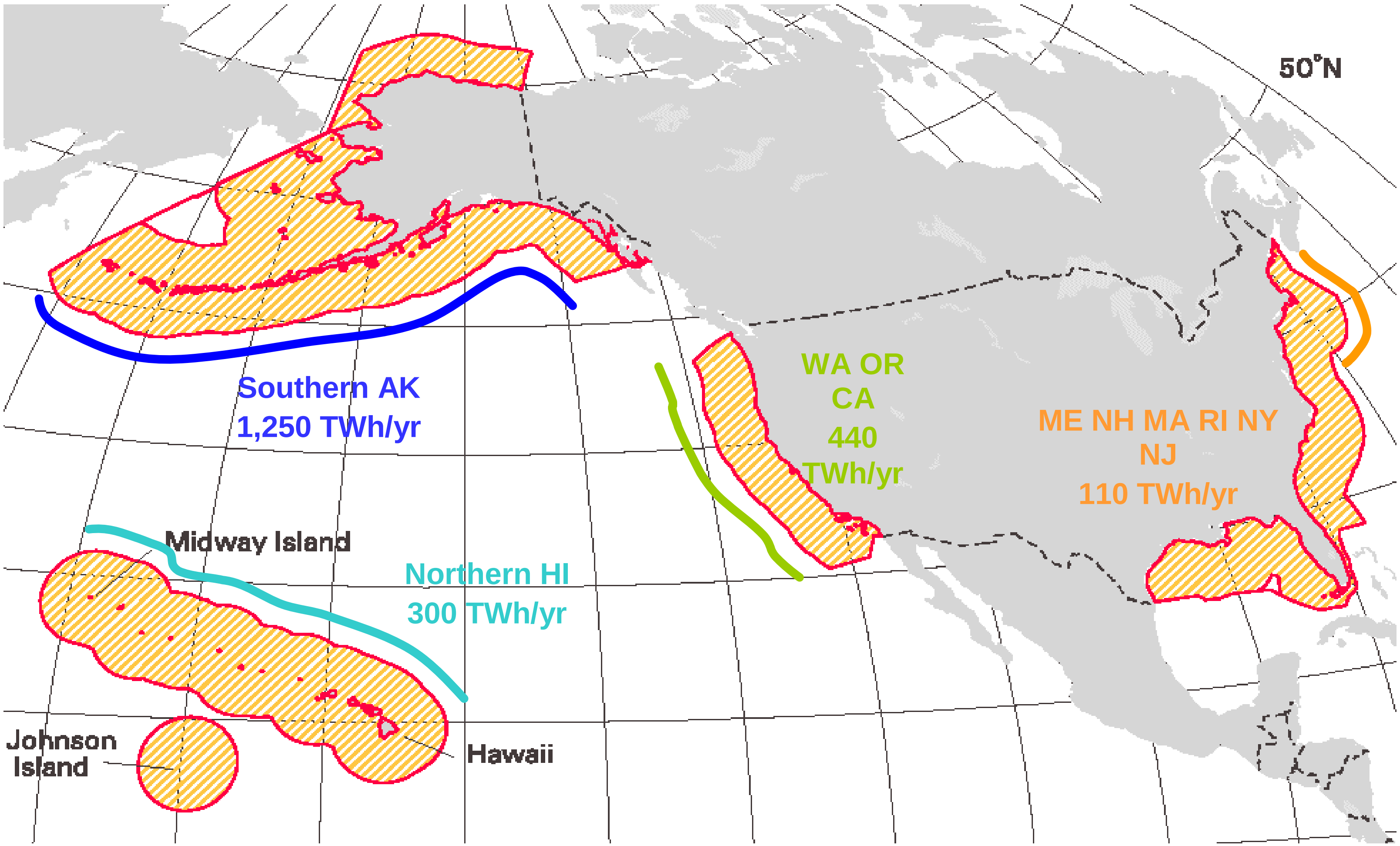
Global Offshore Wave Energy Resource



U.S. Offshore Wave Energy Resource

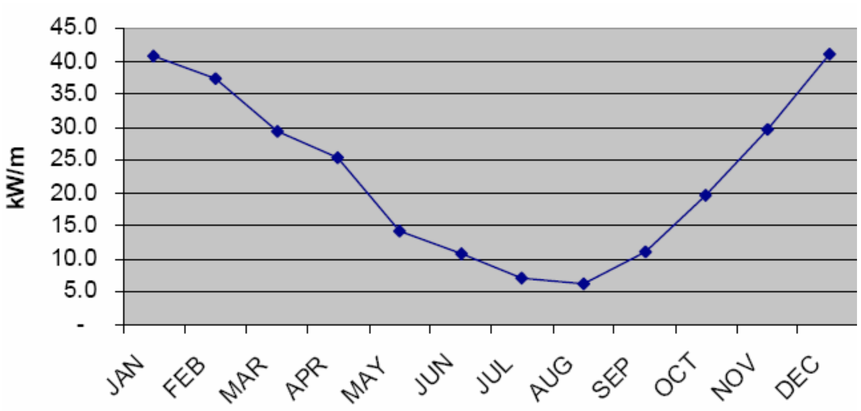


Harnessing 20% of offshore wave energy resource at 50% efficiency would be comparable to all US conventional hydro generation in 2003.
kW/meter x meter of shore line, at least 50-60m depth.

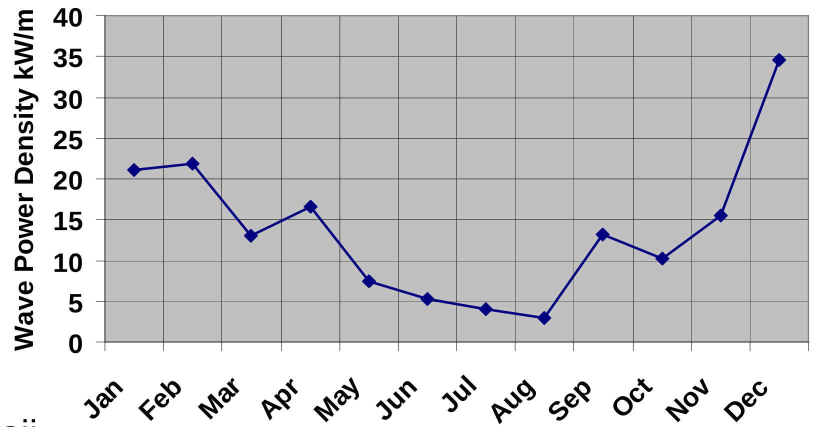
Wave Climates in US (~ 50 years data)

Hawaii	California	Oregon	Washington	Maine	Mass.
15.2 kW/m	20 kW/m	21.2 kW/m	26.5 kW/m	4.9 kW/m	13.8 kW/m

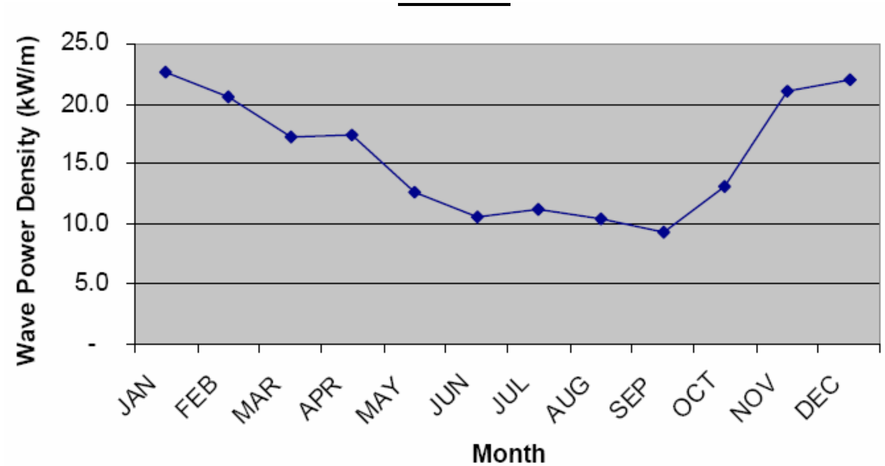
West Coast (Oregon)



East Coast (Mass)



Hawaii



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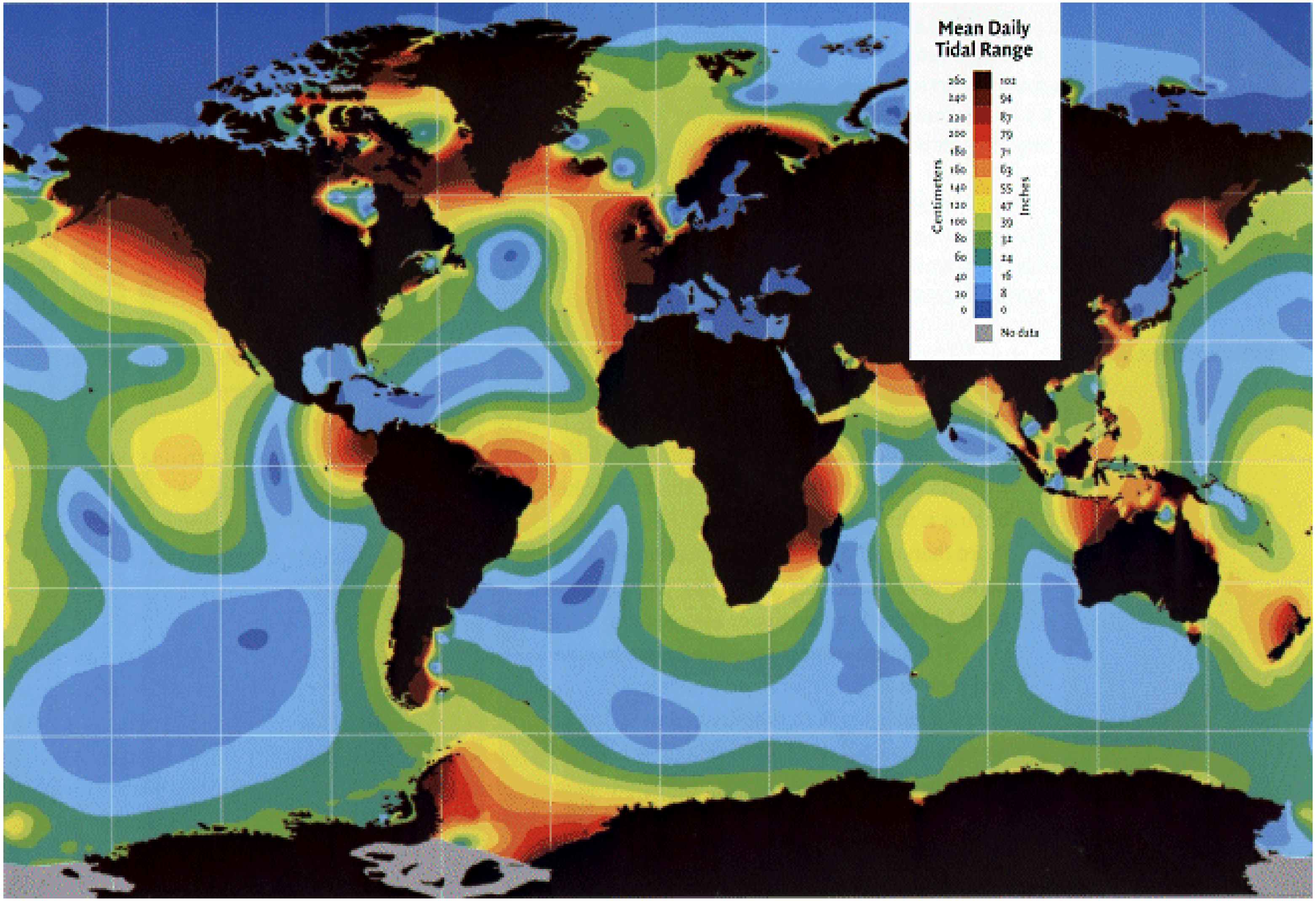
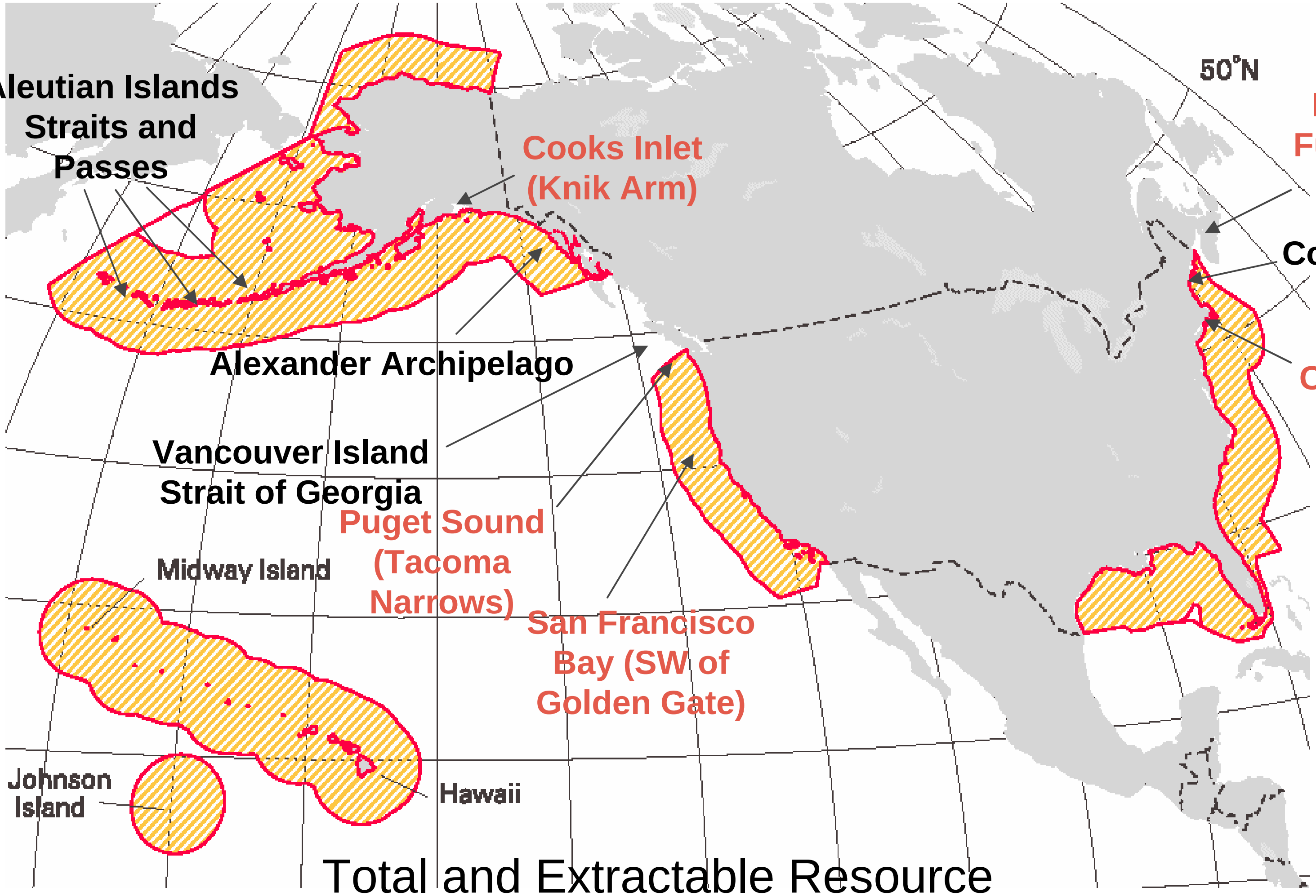
Global Distribution of Tidal Range



North American Tidal Stream Resources are Site Specific (background is wave data)



Total and Extractable Resource Estimation is On Going

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Three Feasibility Project Areas

- Completed
- In-progress
- Future

Offshore Wave Energy Conversion (OWEC)

Phase 1 Project Definition Study	Phase 1.5 Pre-Implementation Planning	Phase 2 Design, Permitting, & Financing	Phase 3 Construction	Phase 4 Operation & Evaluation
2004	2005	2006	2007	2008

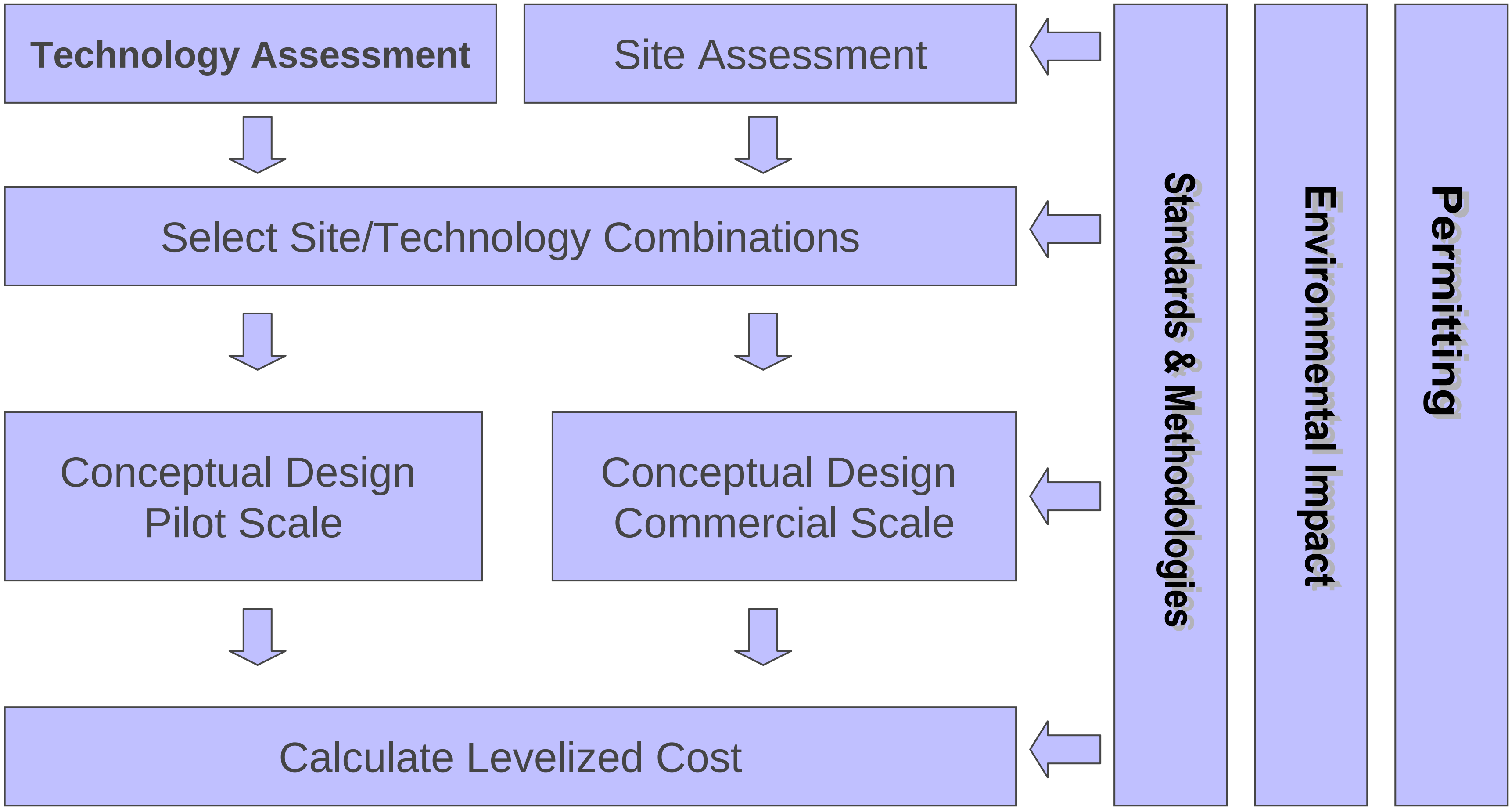
Tidal In-Stream Energy Conversion (TISEC)

Phase 1 Project Definition Study	Phase 2 Design, Permitting, & Financing	Phase 3 Construction	Phase 4 Operation & Evaluation
2005	2006	2007	2009

Hybrid Offshore Wind-Wave Energy Conversion (HOW-WEC)

Phase 1 Project Definition Study
2006

Typical Project Definition Phase



Participants

Technology Companies (30)

Wave & Tidal Power Developers

State/City Agencies (10)

Maine Tech Initiative

Mass Tech Collaborative

New Brunswick Ministry

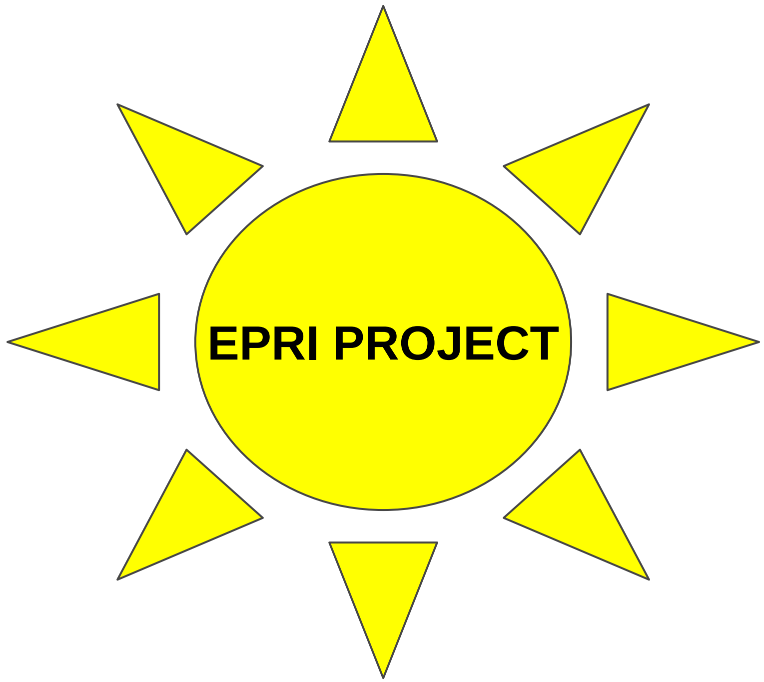
Nova Scotia Ministry

Alaska Energy Authority

Washington CTED

Oregon DOE

San Francisco, Marin County, Oakland CA



Utilities (18)

Bangor HydroCentral

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 County PUD

Portland General

Pacificorp

PG&E

HECO

Federal (2)

U.S. DOE

NREL

Universities (4)

Virginia Tech

Oregon State Univ.

Univ. of Washington

Univ of Mass

North America Wave Energy Projects* in the Water

	HI, Oahu Kaneohe	WA Makah Bay	RI Point Judith	CA, San Francisco	OR Gardiner
Developer	Ocean Power Tech	AquaEnergy	Energetech	SFPUC	Oregon State University
Development Stage	Deployed June 04	Permitting since 2002	Permitting since Feb 2005	Seeking funding for permitting	Seeking funding for permitting
Device	Power Buoy™	Aqua BuOY™	OWC	Pelamis (tentative)	TBD
Size	Single buoy 40 kW	4 buoys 1 MW	Single OWC 500kW	Single Unit 750 kW	TBD
Water Depth/ Distance from Shore	30 m 1 km	50 m 6 km	2 m 2 km	30 m 15 km	TBD

*** EPRI feasibility evaluations also took place at Kauai, MA, ME**

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Wave Project Achievements

- Developed standardized methodologies for estimating power production and performing economic assessments
- Surveyed, characterized potential North American Wave Farm sites
- Surveyed, and assessed energy conversion technology available for developers worldwide
- Established 5 Conceptual Designs for Pilot and Commercial Sized Plants
- Performed an independent cost and economic assessment for the commercial scale plants
- 2004 studies made a compelling case for investing in wave energy technology..

Wave Energy Conversion Devices

AquaEnergy

Ocean Power Delivery

Energetech OWC

Wave Dragon

Wave Energy Conversion Devices

Archimedes Wave Swing – TeamWorks, Netherlands

Wave Power Phase 1 Findings

- Northern California and Hawaii both have a good wave climate, coastal maritime infrastructure and high electricity prices (especially in Hawaii).
- Oregon has a good wave climate and coastal maritime infrastructure, favorable tax incentives, but low electricity prices (conventional hydro).
- Washington has a good wave climate, but less robust coastal utility grid than OR, and low competitive hydro electricity prices.
- Massachusetts has good wave climate in the winter, but poor in the summer; this disadvantage is somewhat offset by high electricity prices and a market for Renewable Energy Credits.
- Maine has a poor wave climate – wind is favorable.

North America Tidal Energy Projects* in the Water

	MA Amesbury (MTC)	NY East River (Nyserda)	BC Race Rocks (N CA)	CA SF (PUC)	DE Indian River Inlet (UEK)	WA Tacoma (TPC)
Developer	Verdant	Verdant	Clean Currents	SFPUC	UEK	Tacoma Power
Development Stage	2 Month Test Complete	Construction	NA	Formative	Permitting	Application Submitted
Device	Vertical axis	Horizontal axis	NA	TBD	Horizontal axis	TBD
Size	1m X 2.5 m 1 unit	5 m diameter 6 units	NA	TBD	3 m diameter 25 units	TBD
Power (kW) at Max Speed (m/s)	0.8 kW @ 1.5m/s	34 kW @ 2.1 m/s	NA	TBD	400 kW @ 3 m/s	TBD (Max 30MW)

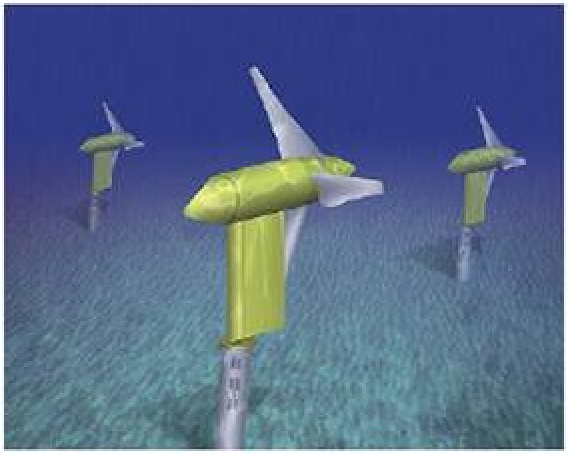
*** EPRI feasibility project also covering other sites in AK, NS, NB, MA and ME …. Looking for an Owner**

North America In Stream Tidal Demonstrations

East River, New York, NY

Amesbury, Merrimack River MA

Verdant Horizontal Axial Turbine



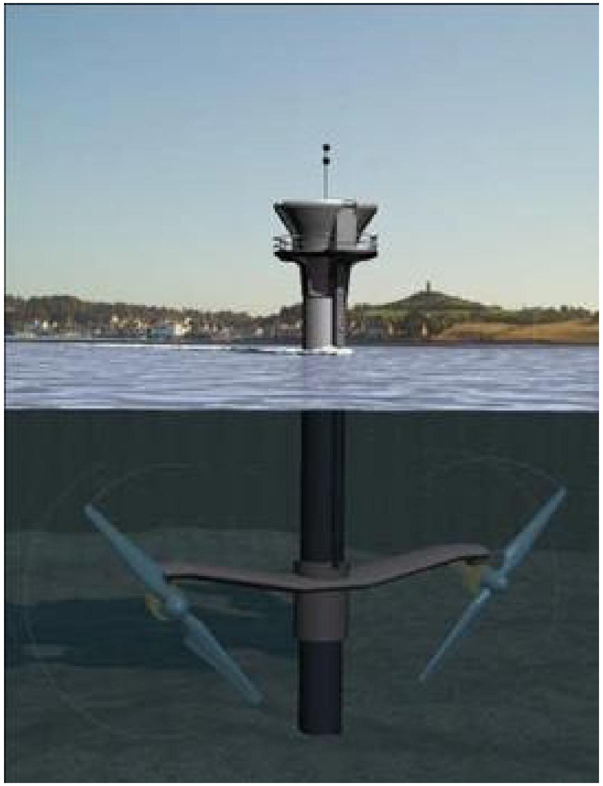
GCK Gorlov

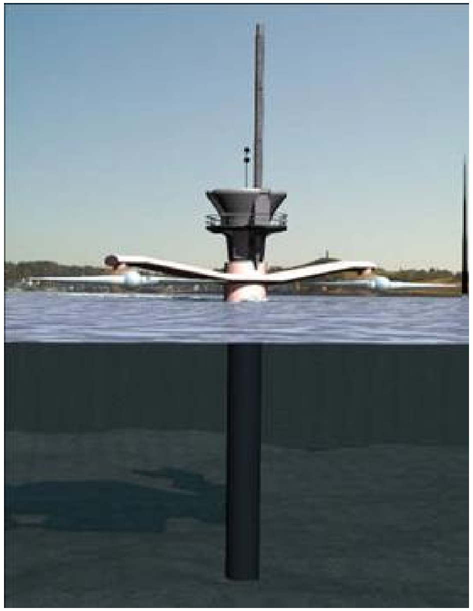
North American In Stream Tidal Demonstrations continued

UEK – Chesapeake Bay Test

Open Hydro Tests in Gulf Stream

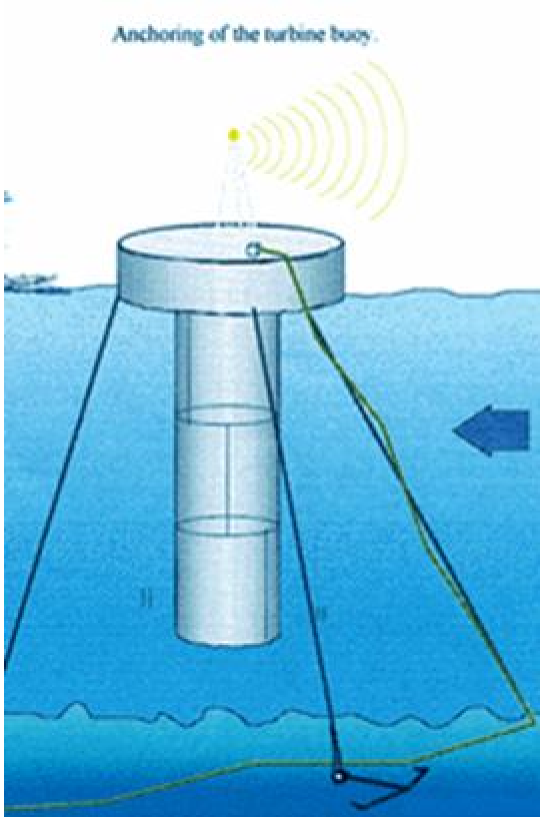
UK In-Stream Tidal Demonstration - MCT



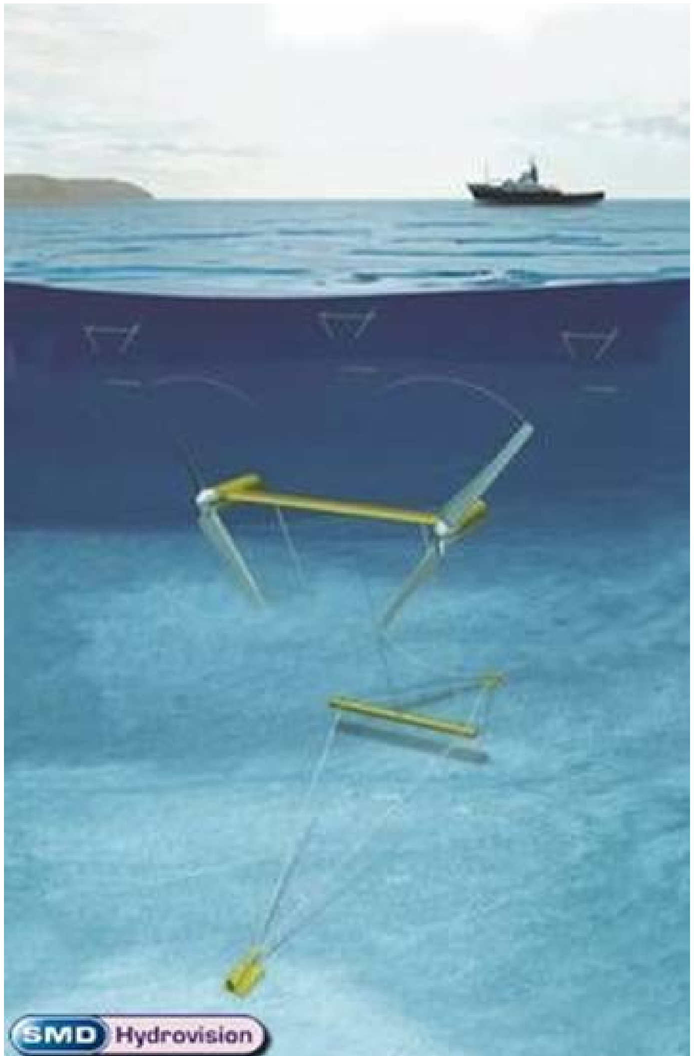


Two Years Experience In UK (more info in the device survey, 11/05)

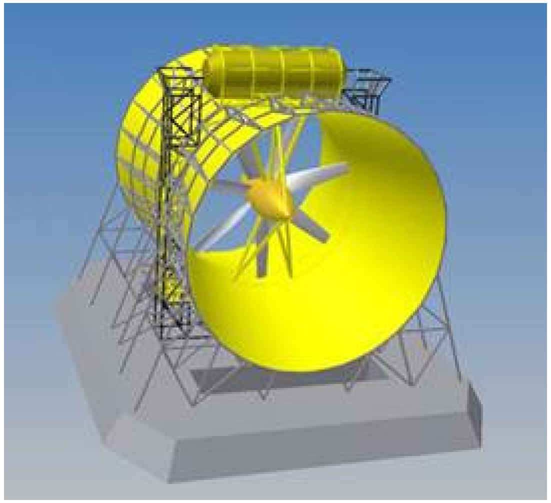
Swedish Vertical Axis Tidal Device - Seapower

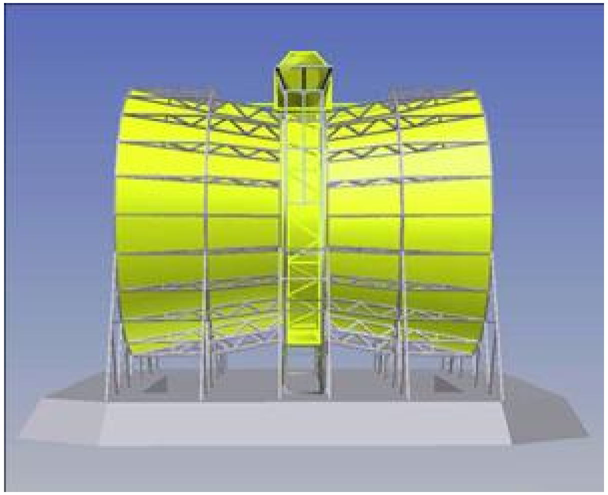


UK In-Stream Ancored Device - SMD Hydrovision



UK In-Stream Ducted Device – Lunar Energy (gravity base, on legs)





2006 Hybrid Wind-Wave Initiative

- Today offshore wind plants are in shallow water close to shore
- Further offshore wind plants are less visually intrusive, but cost more
- Offshore wave is an emerging technology with 1st commercial sale (25 MW plant) in 2005 in Portugal announced by OPD of the UK
- Hybridization of the two technologies is expected to produce lowest COE and soonest commercialization, however, advancements are needed…in floating platforms, operation, and maintenance

Over the horizon Hybrid Wind Wave Machines off the Cape Cod Coast

2006 Hybrid Wind-Wave Initiative (cont)

OBJECTIVES

Study the feasibility of deep water (>30m) over the horizon offshore hybrid wind-wave energy conversion technology to provide efficient, reliable, environmentally friendly and cost-effective electrical energy and to push towards the development of a sustainable commercial market for this technology.

WHY

Take advantage of synergies of an offshore hybrid wind-wave plant to reduce the cost of electricity and reduce the intermittency for ease of grid integration increase the reliability of ocean power.

WHO

EPRI has put together a world class team consisting of contractors, the DOE NREL and Universities including VA Tech, OSU and UMASS and wind, wave and platform vendors.

Task	Duration
1. Site Survey and Characterization (wave and wind energy resources and geophysical properties)	First 6 Months
2. Subsystem Survey and Characterization (wind and wave machines, platforms, moorings and cabling or alternate fuel production)	First 6 Months
3. System Level Design, Performance, Cost and Economics	Middle 6 Months
4. Trade Off Studies and Optimization for Minimum COE	Last 6 Months
5. Environmental Impact Issues and Avoidance/Mitigation and Regulatory Issues	Same 18 Months Semi annual reporting

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