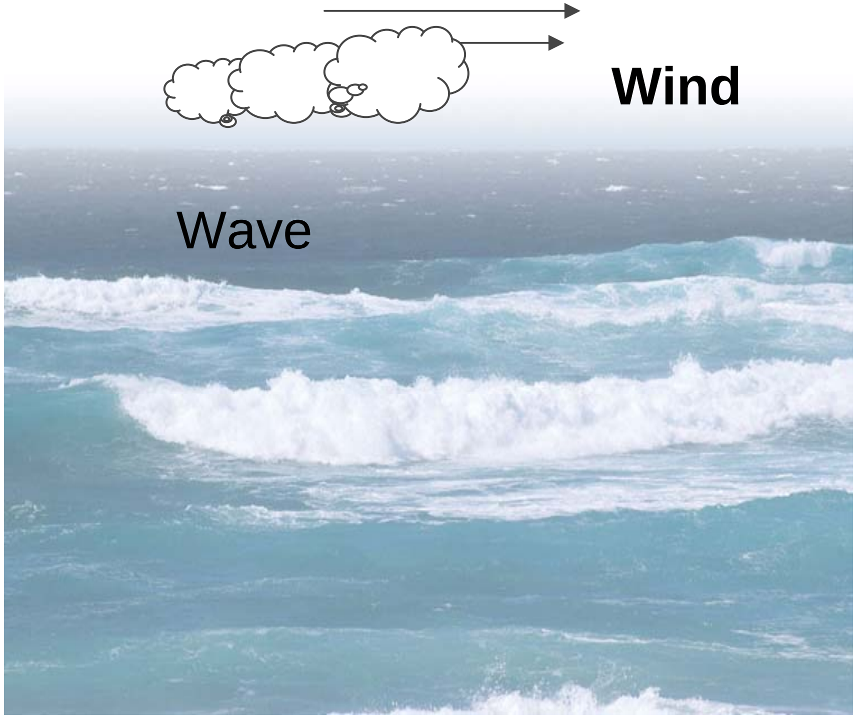
Overview: EPRI Ocean Energy Program



International Energy Agency – Ocean Energy Systems

November 16, 2005

Presented by: Roger Bedard /EPRI

Outline

- Introduction / Participants
- The U.S. Ocean Wind, Wave and Tidal Resource
- EPRI/DOE/EPRI Wave and In-Stream Tidal North American Collaborative Projects
- U.S. Wave and In Stream Tidal 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

The Big Picture

- US Total Electricity Consumption = 3,700 TWh/yr

  (source EIA)
- US primary energy required = 11,200 TWh/yr

  (assumes 33% energy conversion efficiency)
- Total Annual US Wave Energy Resource = 2,100 TWh/yr

  (calculated by EPRI)
- Extractable energy is less but significant

FUEL TYPE	
Coal	50%
Nuclear	20%
Natural Gas	18%
Hydroelectric	7%
Fuel Oil	2%
Biomass	2%
Geothermal	1%
Wind	<1/2%
PV	<1/20%

<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

Participants

Technology Companies (30)

Wave & Tidal Power Developers

Utilities (19)

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 Electric Co-op
Portland General
Pacificorp
PG&E
HECO and KIUC

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

EPRI PROJECT

EPRI
EPRI Solutions
M. Previsic
Devine Tarbell
NREL
Va Tech
Univ of WA
OSU
UMASS
MIT

Federal (2)

U.S. DOE
NREL

Institutes

Bedford Oceanography
Alexandria Research

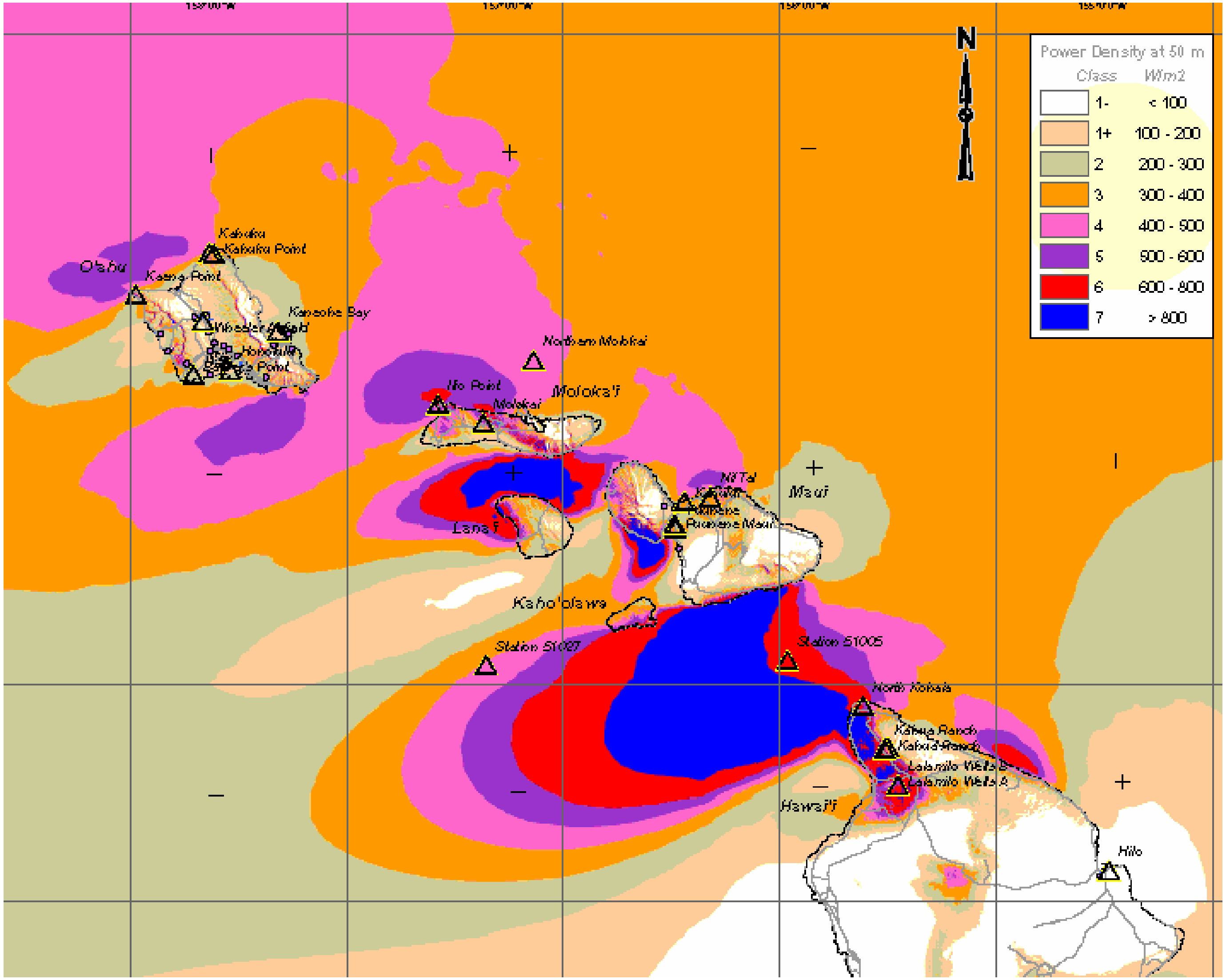
U.S. Offshore Wind Resource

GW by Depth (m)

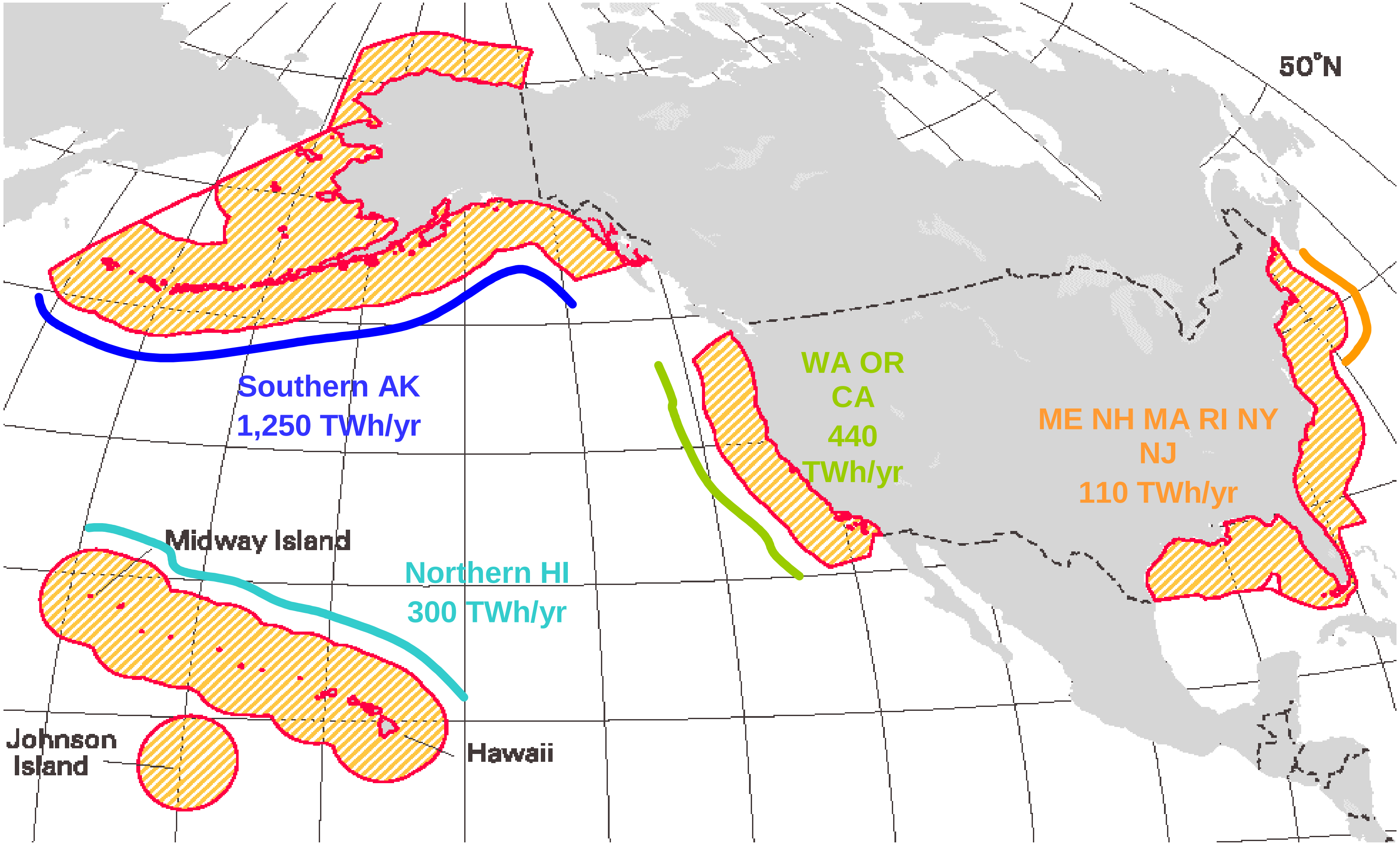
Region	0-30	30-60	60-900	>900
North East	10.3	43.5	130.6	0.0
Mid-Atlantic	64.3	126.2	45.3	30.0
Great Lakes	15.5	11.6	193.6	0.0
California	0.0	0.3	47.8	168.0
Pacific NW	0.0	1.6	100.4	68.2
Total	90.1	183.2	517.7	266.2

(Source: Walt Musial/DOE NREL "Offshore Wind Energy Potential for the United States" May 19, 2005 Wind Powering America- Annual State Summit, Colorado

Hawaii Offshore Wind 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.

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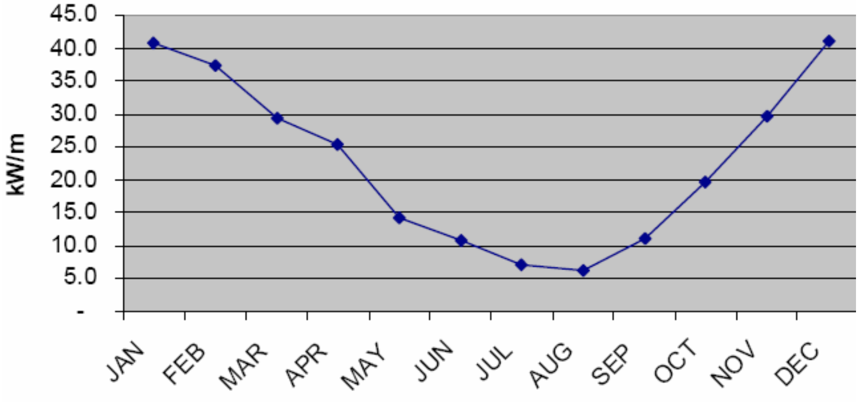
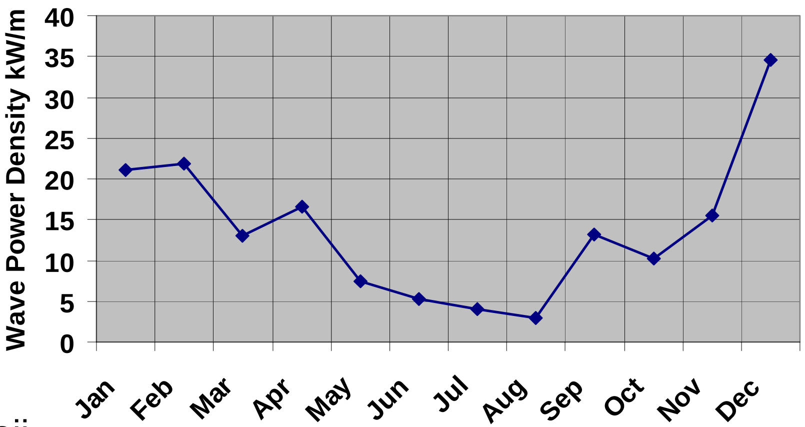
Wave Climate Summary

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

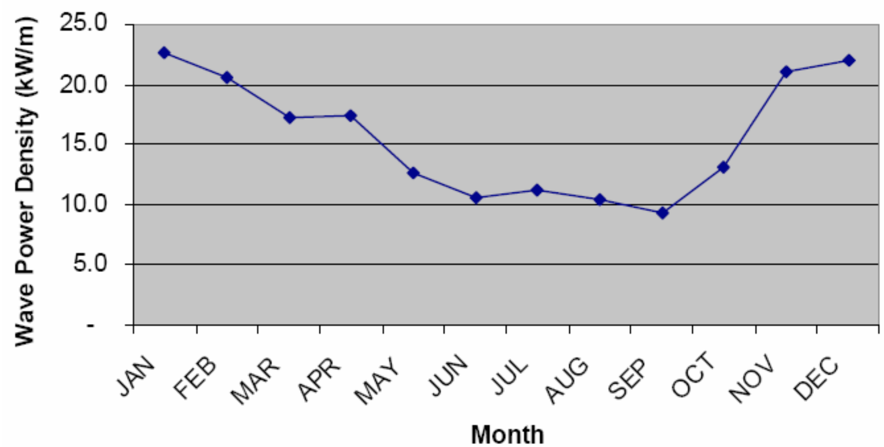
West Coast (Oregon)



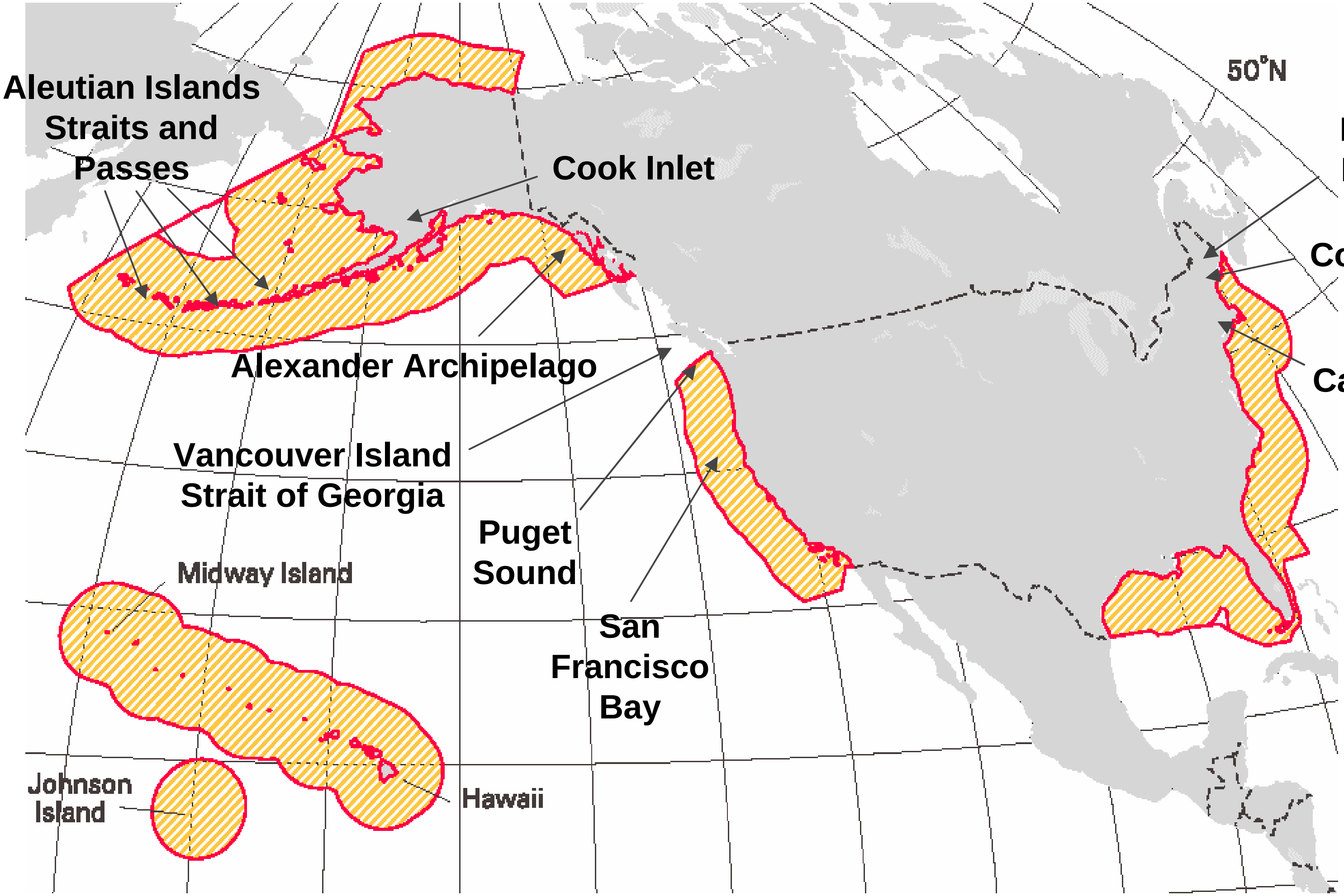
East Coast (Mass)



Hawaii



North American Tidal Stream Resource



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

Three EPRI/DOE/NREL Projects

- 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

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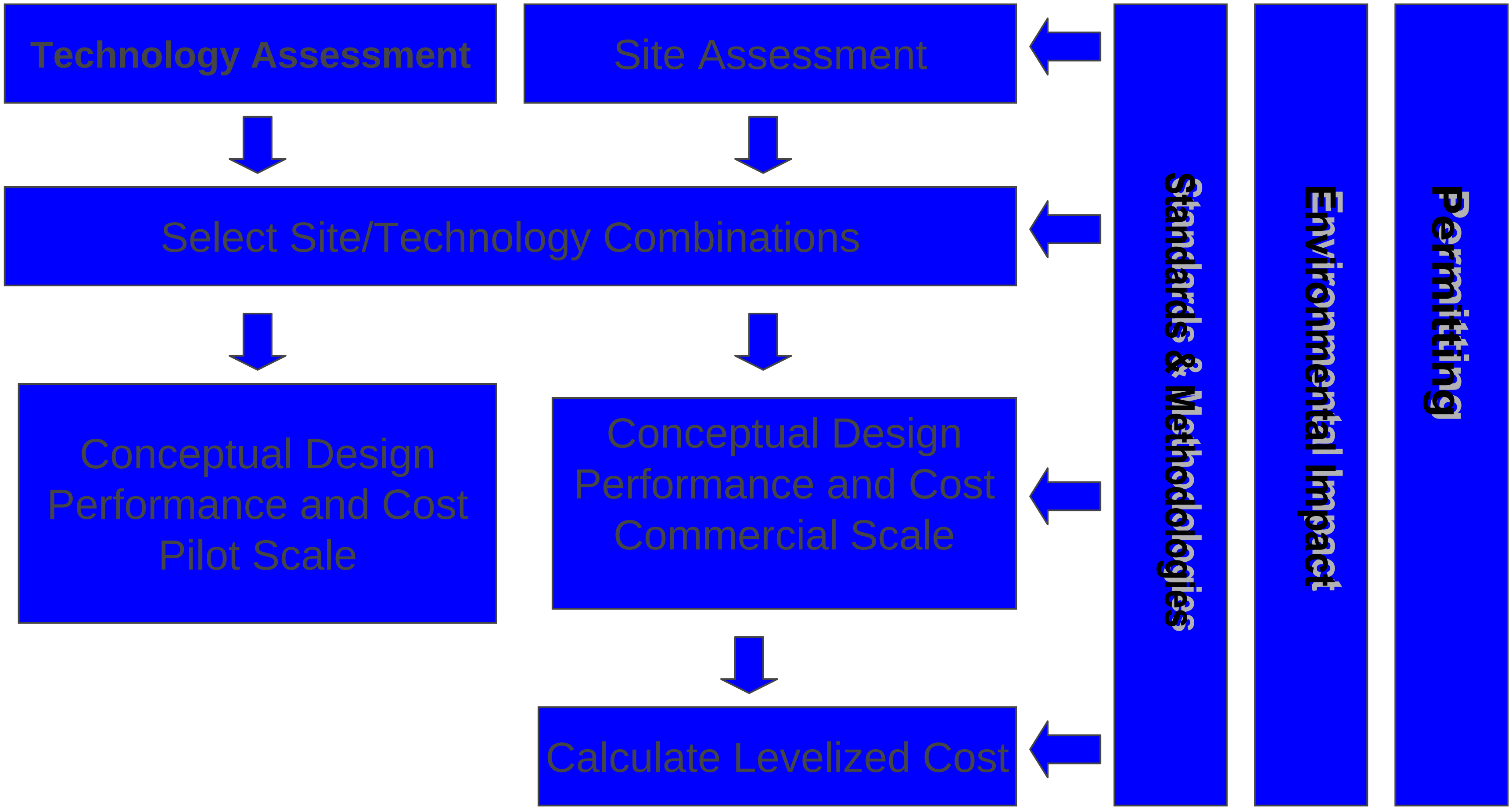
Project Definition Phase



Wave Project

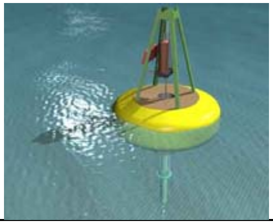
OBJECTIVES

Demonstrate the feasibility of wave power to provide efficient, reliable, environmentally friendly and cost-effective electrical energy

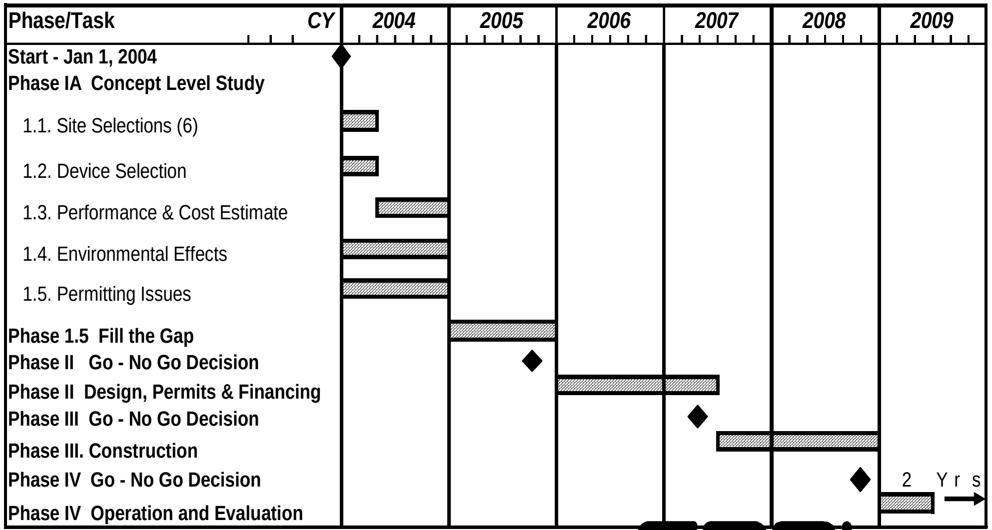
Create a push towards the development of a sustainable commercial market for this technology.

WHY

Wave Energy is an energy resource that is too important to overlook



Phase	Duration	Key Assumptions	Cost	Funding
Phase I – Project Definition Study (including site and device selection) Phase 1.5	1 Year 1 Year	Evaluate 5 Site-Device options Two site-device options	Phase I $240K Phase I.5 - OR - $40K	EPRI State Energy Agencies/Trusts Utilities DOE & Others
Phase II – Design, Permitting and Financing	12 – 18 Months	Design 1 Site – Device option	$500-800K	Private owner or collaborative financing
Phase III – Construction	12 -18 Months	500 KW Plant	$1,500 2,5000K	Private Owner or Collaborative financing
Phase IV -Operation	2 Years	Plant O&M costs	$100-250K	Private Owner or collaborative
Phase IV – Evaluation	2 Years	Additional cost due to RD&D	$100-250K	50% DOE 50% EPRI
Total	**5 1/2 - 7 Yrs**		**$2.5 –4.1 M**	



FUNDERS

✓**Hawaii** –HECO & KIUC (in-kind)

✓**Washington State** –Snohomish PUD and Seattle City Light (In-kind)

✓**Oregon** – Bonneville Power, Central Lincoln PUD, PGE and Pacificorp

✓**California** – SF PUC and City of Oakland, PG&E (In-kind)

✓**Maine** – MTI, CMP (In-kind) and Bangor Hydro Electric (In-kind)

✓**Massachusetts** - MassTech

✓**DOE/NREL (**Cash and In-kind) and **EPRI –** SS&T

2004 Wave Project Achievements

- Developed standardized methodologies for estimating power production and performing economic assessments
- Surveyed, characterized potential North American Wave Farm sites
- Surveyed, characterized, 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.

North America Wave Energy Projects

	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	SF Seeking funding for permitting	OSU Seeking funding for permitting
Device	Power Buoy™	Aqua BuOY™	OWC	Pelamis (tentative)	TBD
Size	Single buoy 40 kW Buildout to 1 MW	4 buoys 1 MW	Single OWC 500kW	Single Unit 750 kW Buildout to Com'l Plant	TBD - RD&D Center
Water Depth/ Distance from Shore	30 m 1 km	50 m 6 km	2 m 2 km	30 m 15 km	TBD

EPRI North American Tidal Flow Power Feasibility Demonstration Project

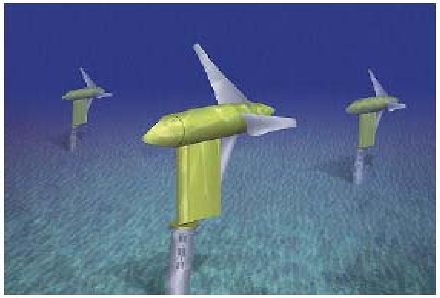
OBJECTIVES

Demonstrate the feasibility of tidal flow power to provide efficient, reliable, environmentally friendly and cost-effective electrical energy

Create a push towards the development of a sustainable commercial market for this technology.

WHY

Tidal Flow Energy is an energy resource that is too important to overlook



Phase	Duration	Key Assumptions	Cash Cost	Expected Cash Funding
Phase I – Scoping or Project Feasibility Definition Study	1 Year	Five site survey and characterizations; Device survey and characterization; Eight system level design, performance analysis, cost estimate and economic assessment; environmental, regulatory and permitting issues	$350K With Prob Factor + $150K In – kind Cont	Full $60K Maine $50K Mass $60K Washington $60K New Brunsw $60K Nova Scotia $10K DOE Design Only $40K San Fran $40K Alaska
Phase II – System Design	12-18 Months	System Design, permitting and financing - 1 Site – Device	$500-1,000 K	Private Owner or collaborative
Phase III - Construction	12 - 18 Months	1,500 MWe per year Plant (500 kW at 40% capacity factor)	$1,500 - 2,700 K	Private Owner or collaborative
Phase IV - Operation	1-2 Years	Plant O&M costs	$100-250K	Private Owner or collaborative financing
Phase IV - Evaluation	1-2 Years	Additional cost due to RD&D needs	$100-250K	50% DOE 50% EPRI
Total	**5 - 7 Yrs**		**$3-5 M**	

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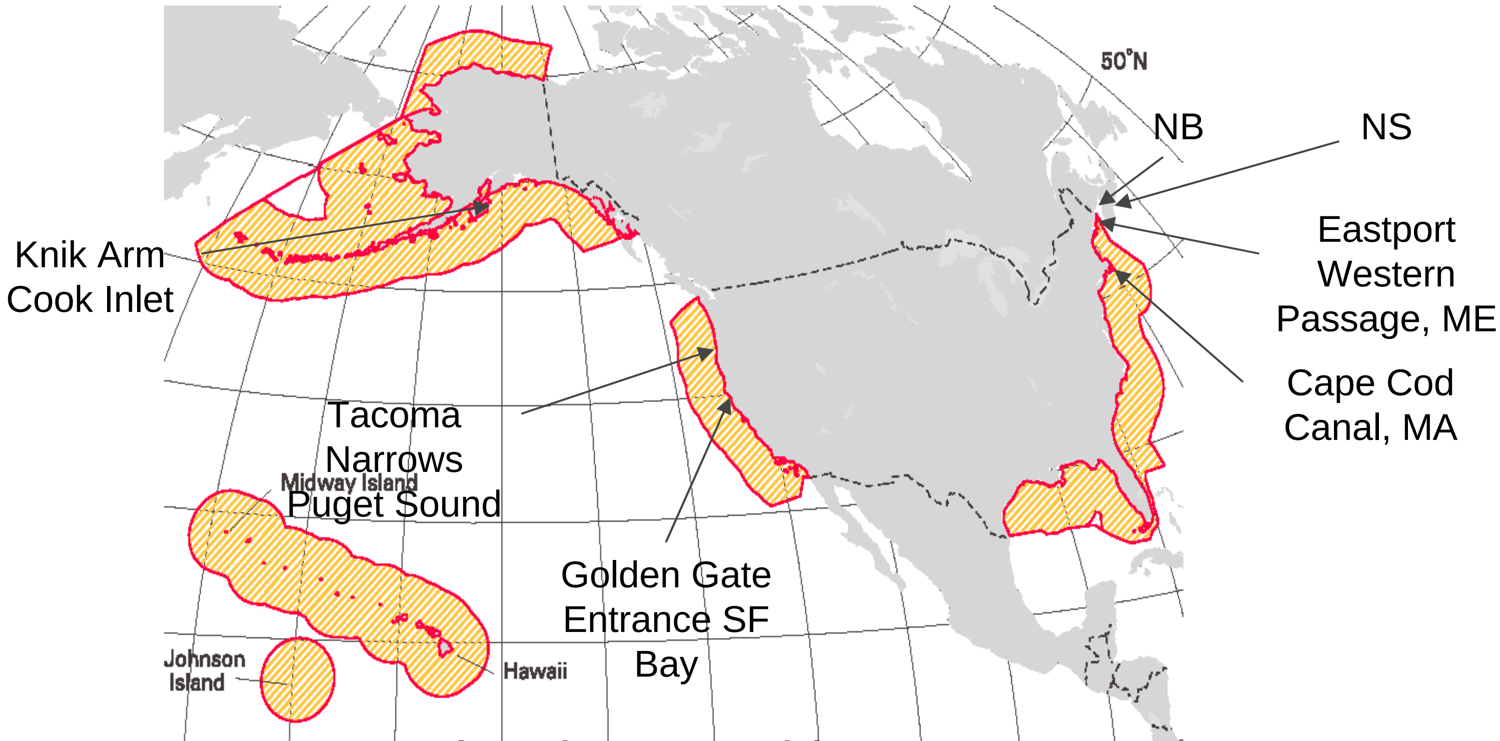
No. American Tidal Flow Resources in EPRI Feasibility Study



Total and Extractable Resource Estimation is On Going

North America Tidal Energy Projects

	MA Amesbury	NY NY, East River	BC Race Rocks	CA, SF Golden Gate	DE Indian River Inlet	WA Tacoma Narrows
Developer	Verdant	Verdant	Clean Currents	SFPUC	UEK	Tacoma Power
Development Stage	2 Month Test Complete	Construction	NA	Formative	Permitting	Tacoma Power Filed for permit with FERC
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

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

4 General Types of Wave Energy Devices

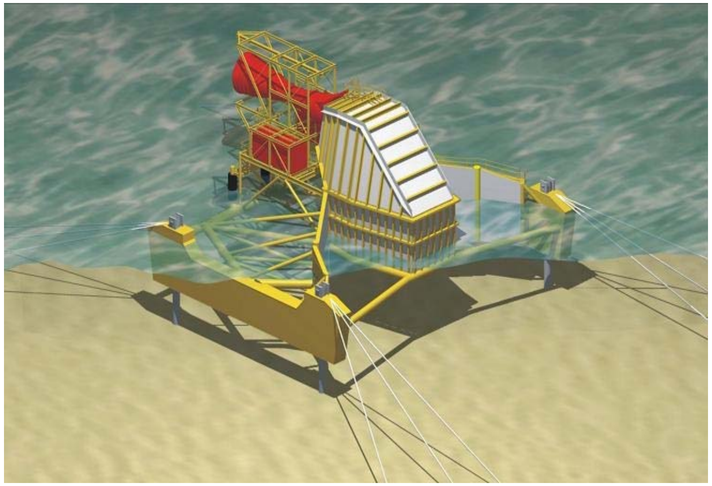
Point

Absorber

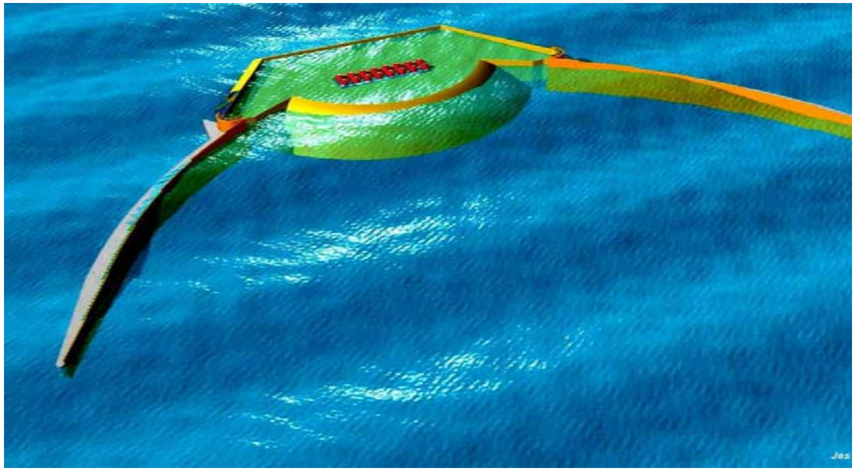
Attenuator

Terminators

Oscillating Water Column



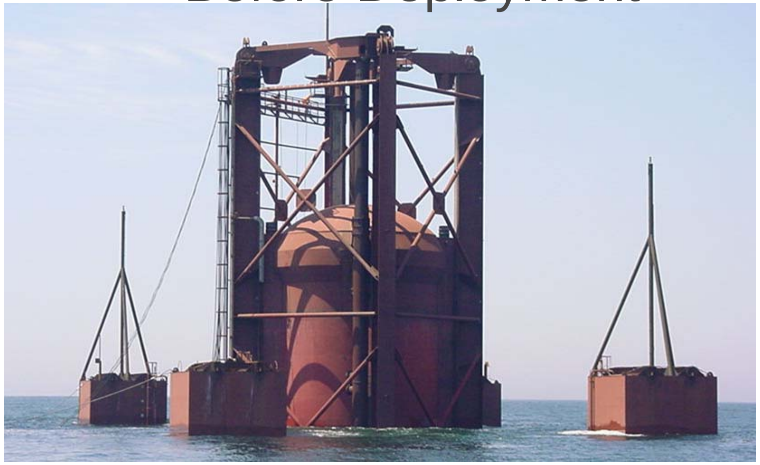
Overtopping



More Examples of WECs

Point Absorber TeamWork Archimedes Wave Swing

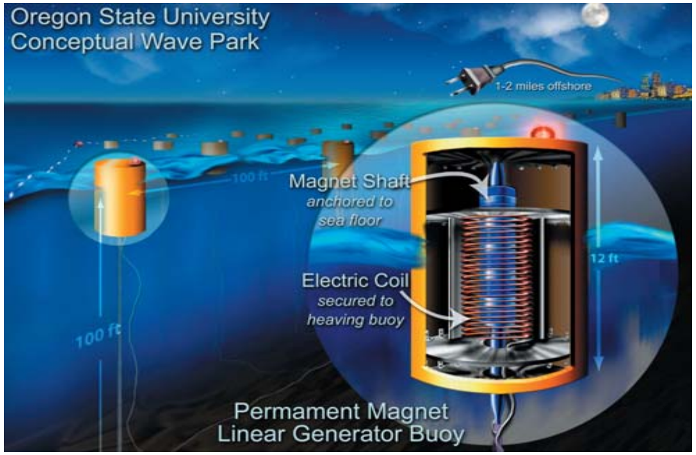
Before Deployment



After Deployment

Point Absorber Ocean Power Delivery PowerBuoy

Point Absorber OSU PM Direct Drive



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Three US Tidal Flow Demonstrations

East River, New York, NY

Golden Gate Bridge, SF, Ca

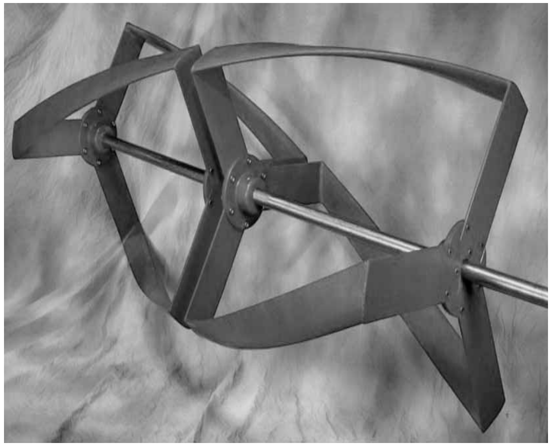
Verdant Horizontal Axial Turbine

Tacoma Narrows

Other US Tidal Flow Devices

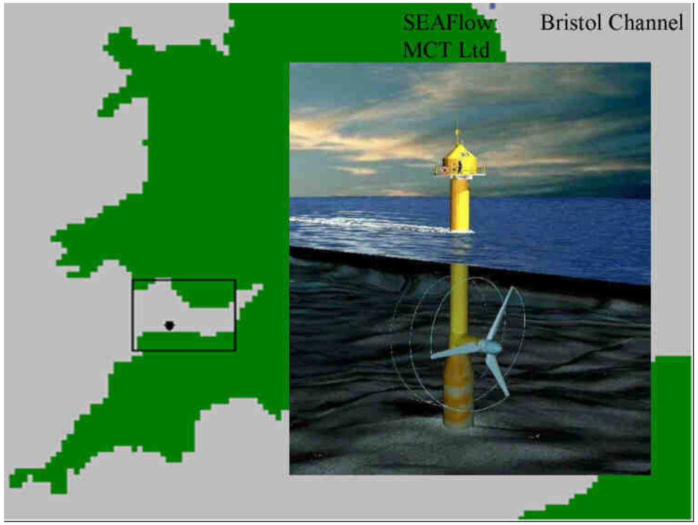
- Underwater Electric Kite (UEK) Test Unit

* Gorlov Turbine

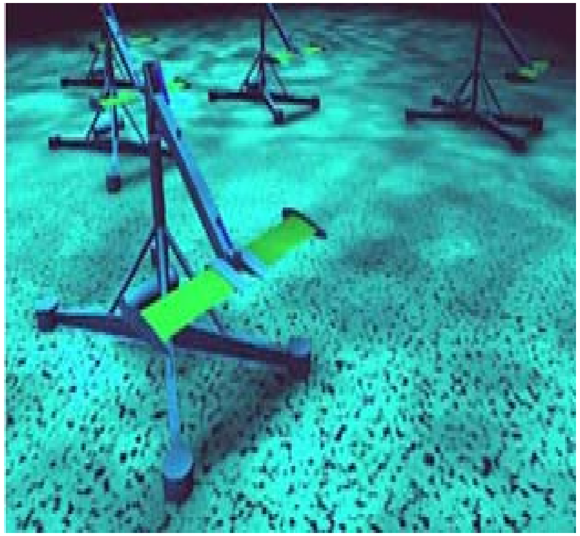


Two UK Tidal Flow Demonstrations

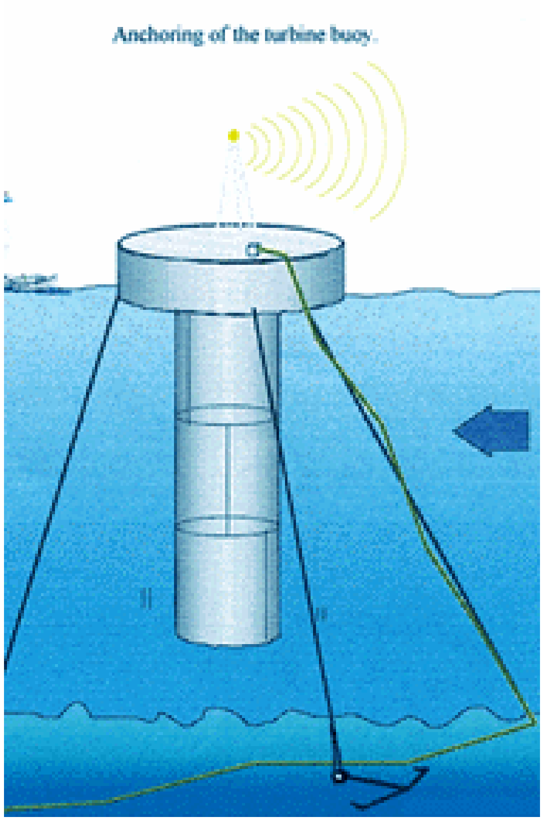
Marine Current Turbines



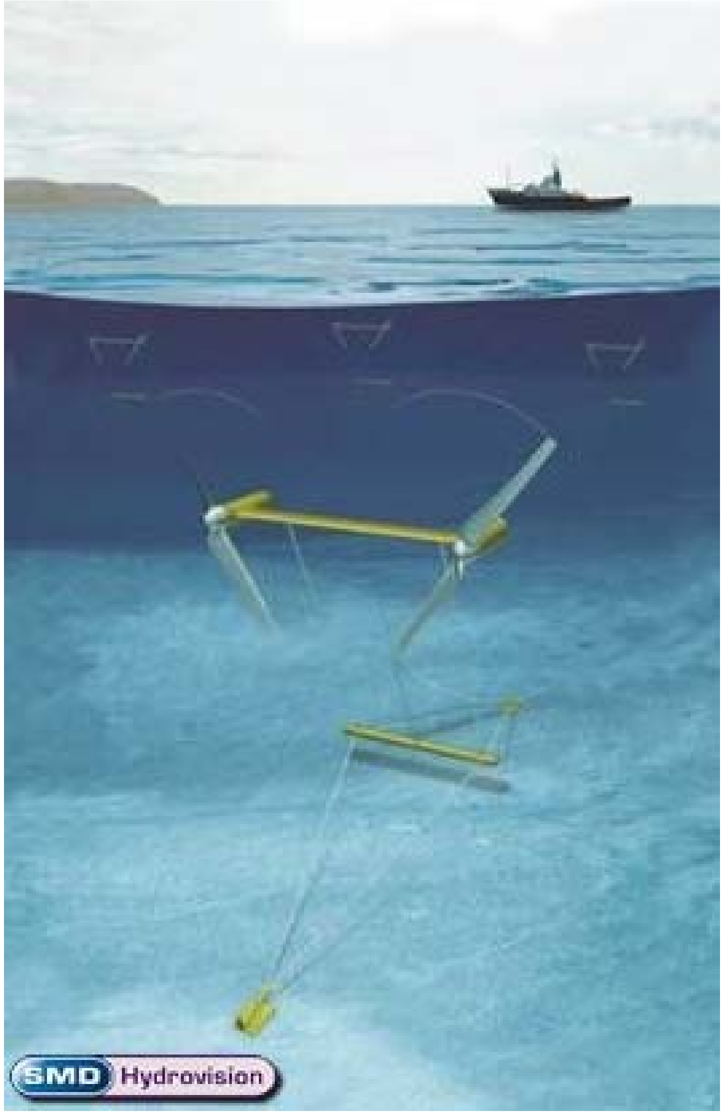
Engineering Business Stingray



Swedish Vertical Axis Device - Seapower



UK In-Stream Device - SMD Hydrovision



UK In-Stream Device – Lunar Energy