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Overview of Wave and Current Energy: Resource, Technology, Environmental and Business Issues

January 25, 2007

Roger Bedard
Ocean Energy Leader

Two of the Basic Forms of Ocean Energy

CURRENTS

- Activating force flows in same direction for at least a few hours
- Tidal, river, and ocean variants
- Conversion technology is some sort of submerged turbine

WAVES

- Activating force reverses direction every 5 to 20 seconds
- Conversion technology can be floating or submerged, with a wide variety of devices still being invented and developed

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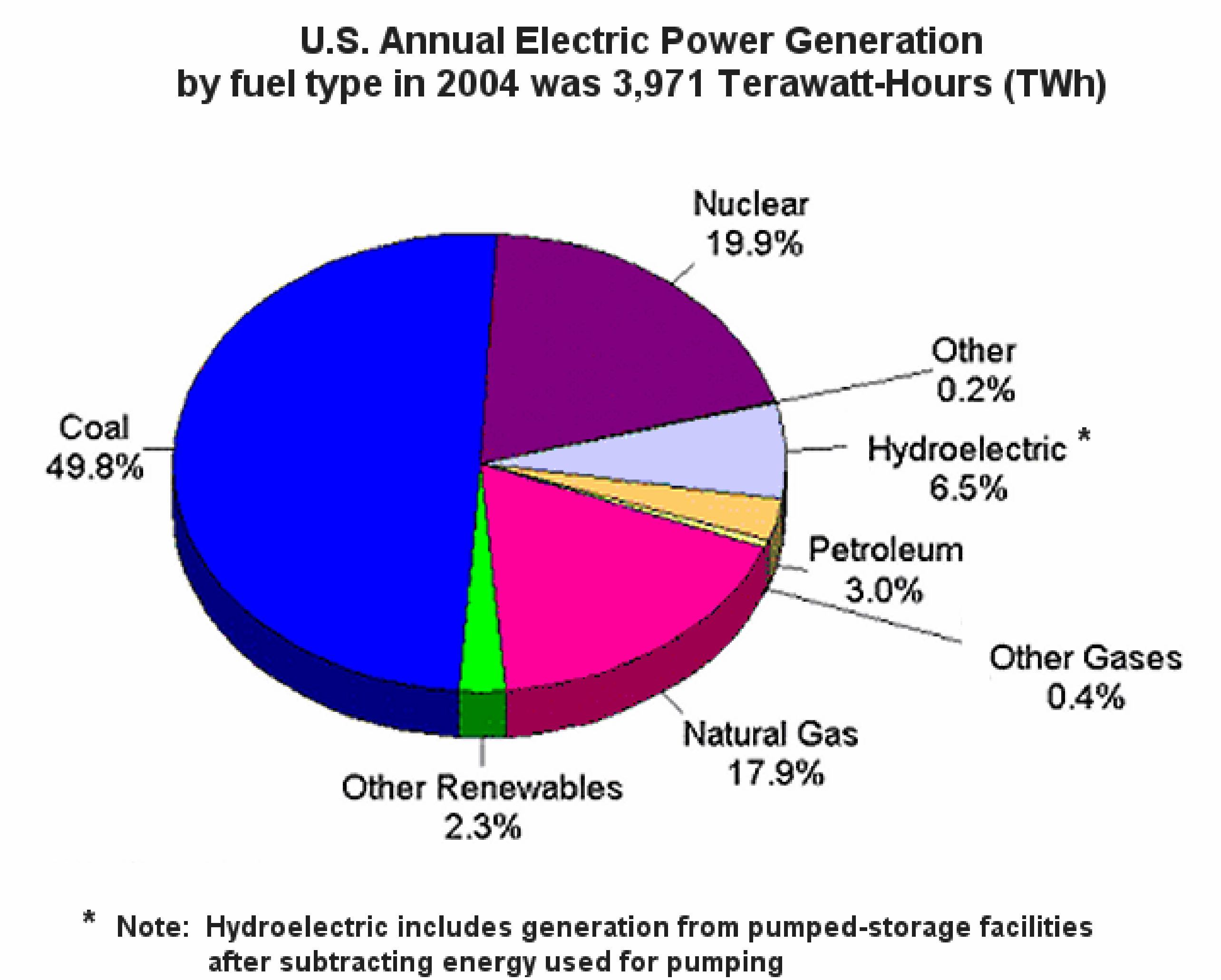
U.S. Wave and Current Energy Potential



U.S. conventional hydro-electric generation in 2004 was ~260 TWh/yr

Wave and current generation potential

- Offshore wave 250-260 TWh/yr if 15% utilized
- Tidal, river, and ocean currents TBD but maybe half of wave

Credible potential to meet nearly 10% of national demand

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Advantages of Wave and Current Energy

- High power density as compared to most renewable resources – translates to lower installed cost
- With proper siting, installation, O&M and decommissioning, could be one of the more environmentally benign of electricity generation technologies
- Minimizes NIMBY – submerged or barely visible
- No emissions – including CO_2
- Job creation and economic development for maritime communities
- Decrease national dependence on foreign fuel suppliers and risk of future fuel price volatility
- Increases diversity and robustness of electricity energy supply portfolio

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EPRI Pilot Demonstration Projects

2004 | 2005 | 2006 | 2007 | 2008

Wave Energy Conversion (WEC)

Phase 1
Project Definition Study

OR Phase 1.5 Pre-Implementation Planning

Phase 2
Design, Permitting and Financing
Many in Oregon

WEC

CA Phase 1.5 Pre-Implementation Planning

Phase 2
Design, Permitting and Financing
One in Ca, many more to come

Phase 1 – Study It
Phase 2 – Permit It
Phase 3 – Build It
Phase 4 – Test It

Tidal In-Stream Energy Conversion (TISEC)

Phase 1
Project Definition Study

Phase 2
Design, Permitting and Financing
NS, Tacoma Power, SnoPUD, ME and SF

Completed
In-progress
Future

River In-Stream Energy Conversion (RISEC)

Phase 1
Project Definition Study

Phase 2
Design, Permitting, & Financing

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EPRI Feasibility Studies are Having an Impact

- Private investors have filed >40 applications for ocean energy preliminary permits with FERC
- In May, 2006, NSPI announced a multi million dollar pilot tidal plant project based on our study
- In June 2006, OPT filed with FERC for the 1st US commercial wave plant; a 50 MW plant at Reedsport OR, the site we selected in 2004; Coos Bay and Newport filings followed
- In July 2006, Lincoln and Douglas County OR applied for FERC preliminary permit for multiple wave plants
- In December 2006, Finevera AquaEnergy filed for plants in southern Oregon and northern California
- Forecasting a very wet 2007

The Chronicle

Volume 58 Number 116

EAGLE TO LAND

Ex-president Bill Clinton to speak in Halifax on July 26. / B3

Ralph Tedesco, president of Nova Scotia Power, responds to the release of an international study on potential tidal power project sites at the Bedford Institute of Oceanography in Dartmouth on Monday afternoon. Nova Scotia was identified as the best location in North America to develop tid power, with possible commercial implications. (ERIC WYNNE / Sta

Turning the tides of power

NSP boss 'bullish' on alternative energy source, N.S. vows go-slow approach on tidal potential

By JUDY MYRDEN
Business Reporter

Nova Scotia is going to take a go-slow approach to developing its tidal power potential, Energy Minister Bill Dooks says, after an international study found it to be the most promising loca-

needs to be protected."

The $400,000 study, conducted by the Electric Power Research Institute of California over the past 15 months, identified eight potential sites for tidal power projects on the Nova Scotia side of the Bay of Fundy, which has among the most powerful tides

288-megawatt project would be roughly $485 million.

Ralph Tedesco, Nova Scotia Power's president and chief executive officer, said he is "bullish" on tidal power and is keen to undertake a demonstration project in the Bay of Fundy with other partners to pay for the

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Currents

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Tidal Current Energy

- **Resource characteristics**
  - Deterministic (precise forecasts) – governed by astronomy
- **U.S. production potential**
  - Not mapped – EPRI was first to study representative sites (five U.S. sites total ~5 TWh/yr; additional good sites exist in Maine, New York, San Francisco Bay, Puget Sound, and Alaska, all of which remain to be quantified and mapped)
  - Southeast Alaska tidal resource mapped by EPRI in late 2006
- **General types of conversion technology**
  - Underwater turbines in various configurations
- **Conversion technology status**
  - Many tank and pull tests, a few devices in the sea

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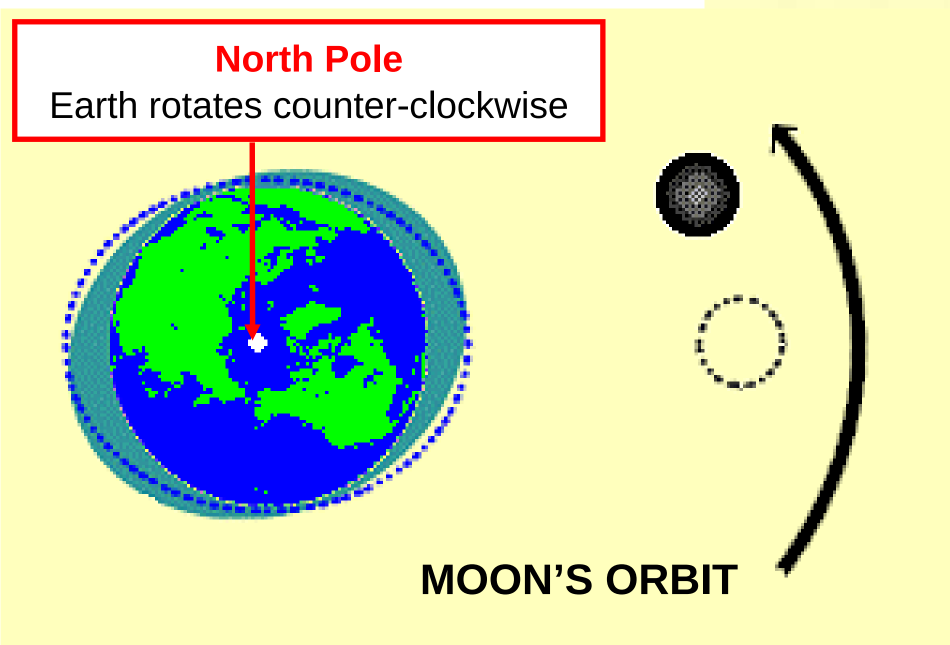
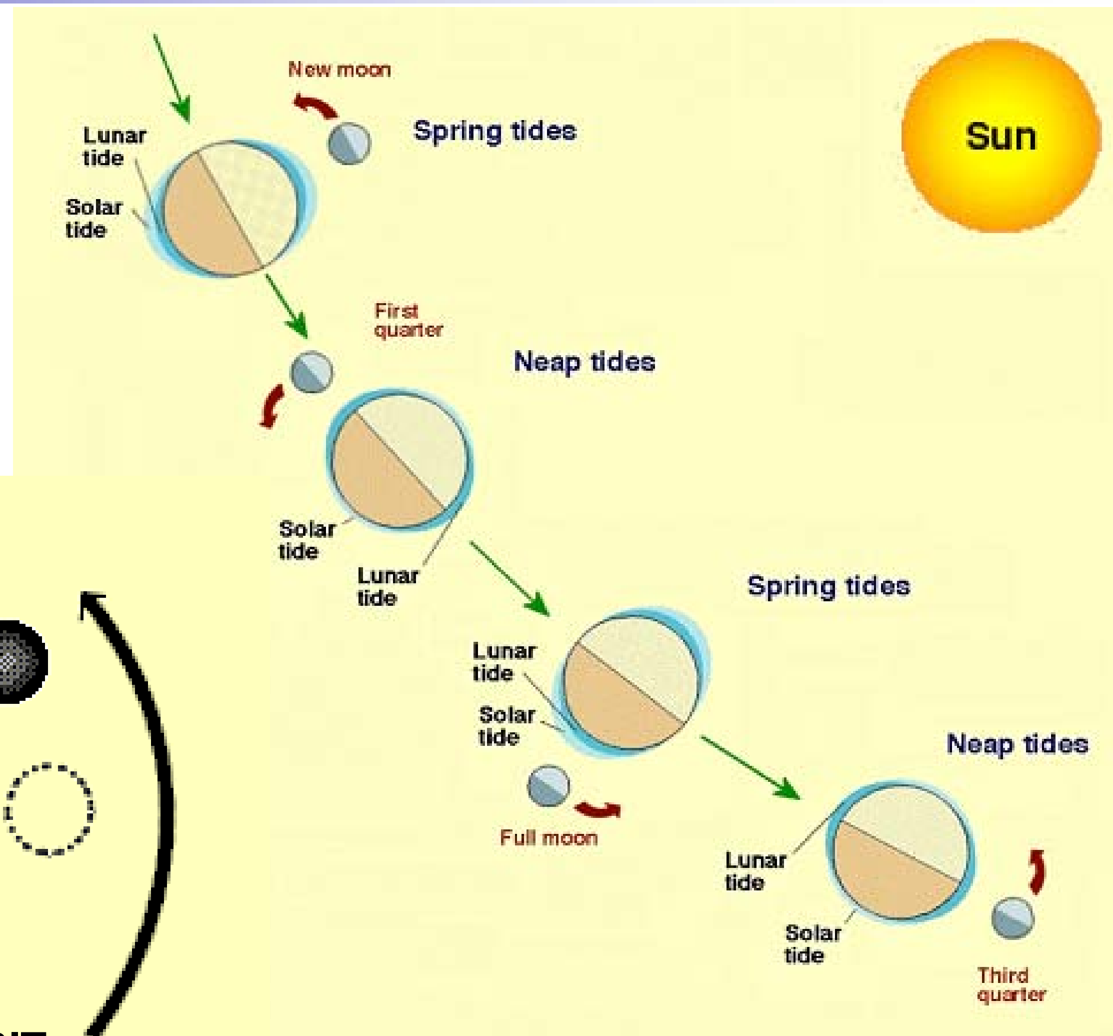
Tides Governed by Earth-Moon-Sun

Tidal changes in sea level occur as Earth rotates beneath bulges in ocean envelope, which are produced by solar and lunar gravitational forces.





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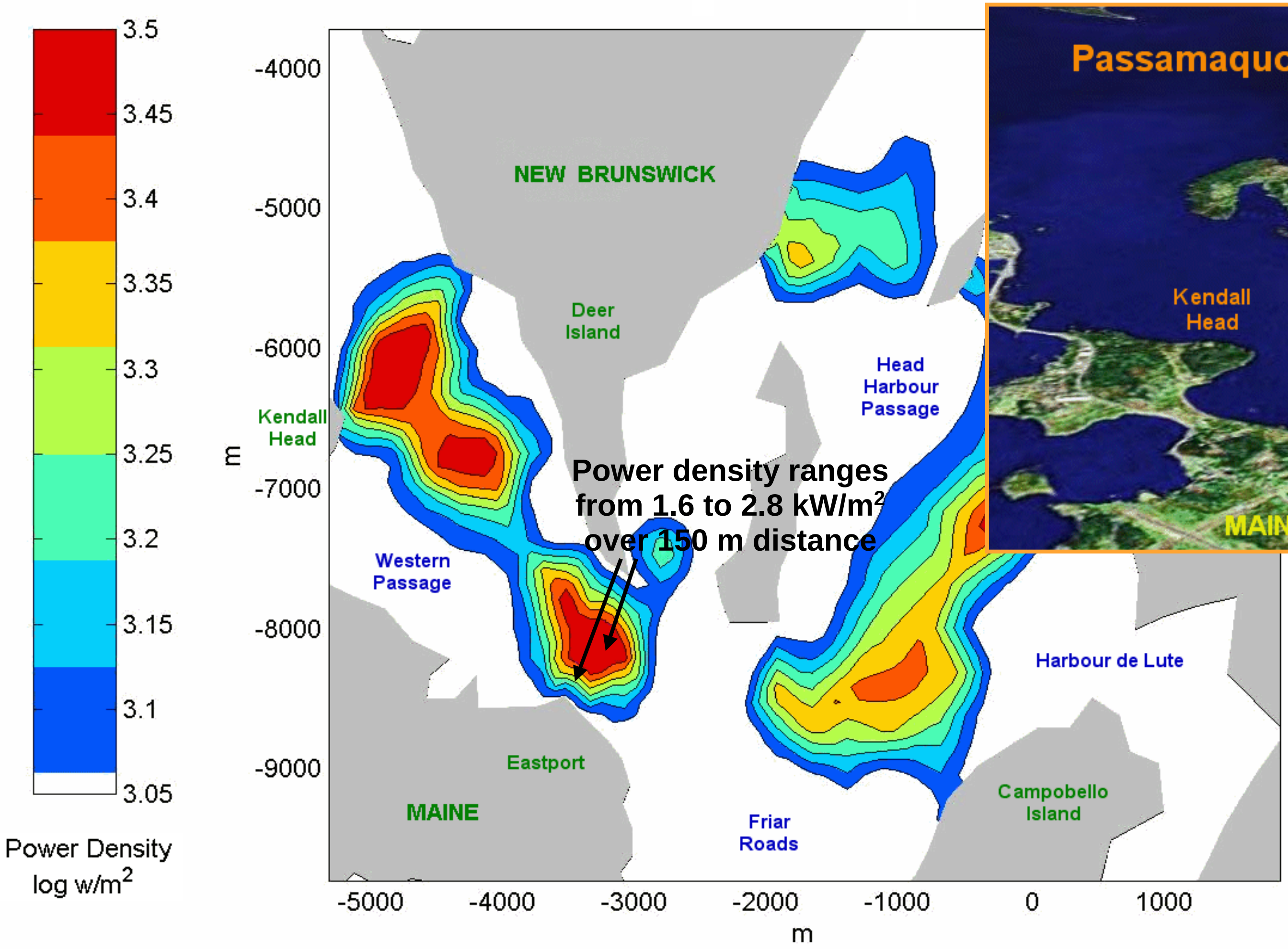
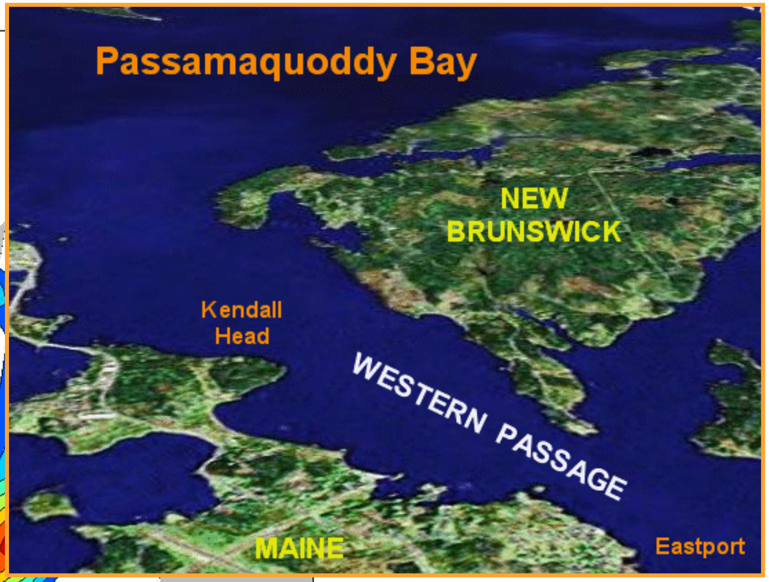
Power Densities Highly Localized





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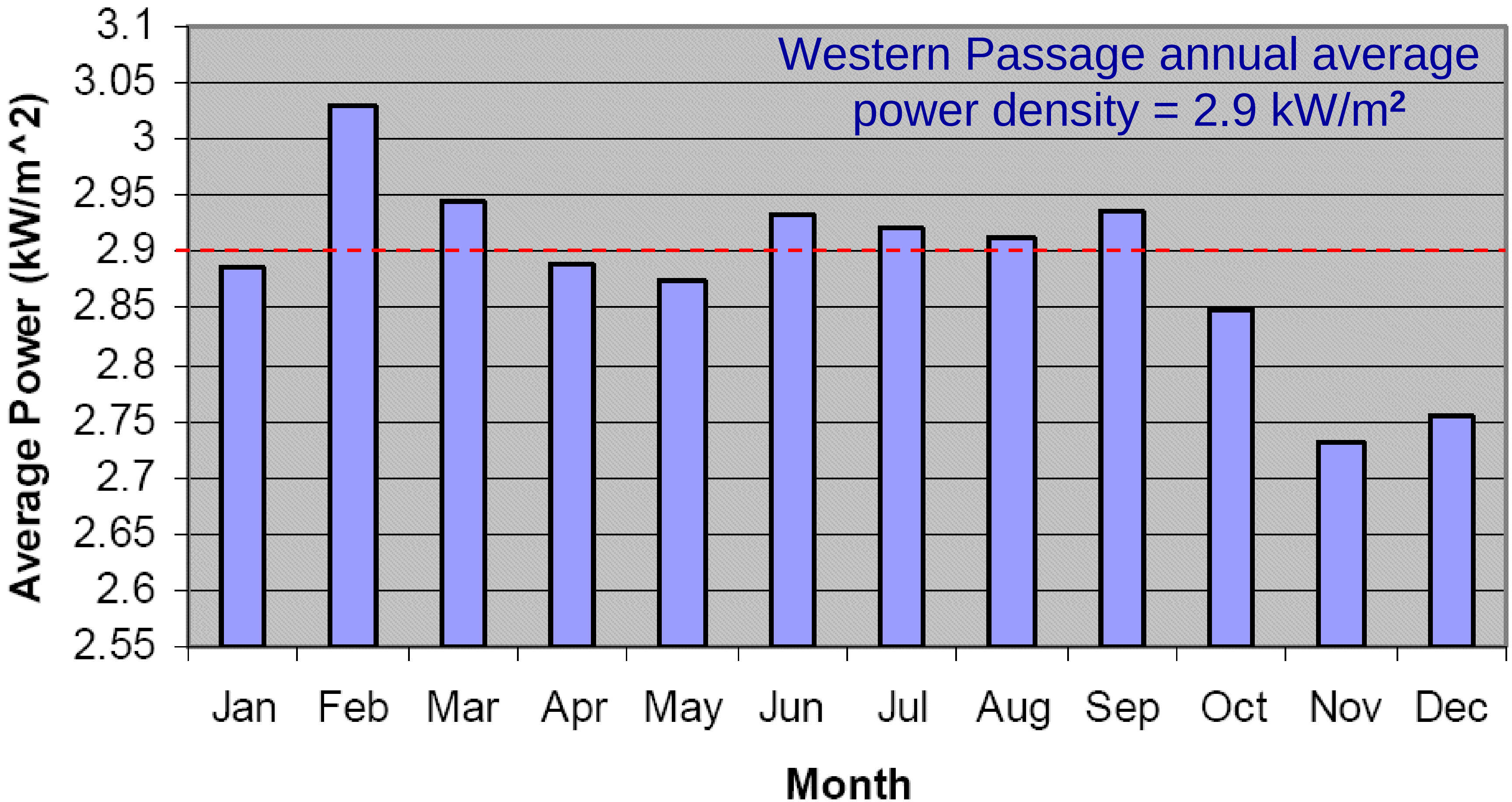
No Significant Seasonal Trend



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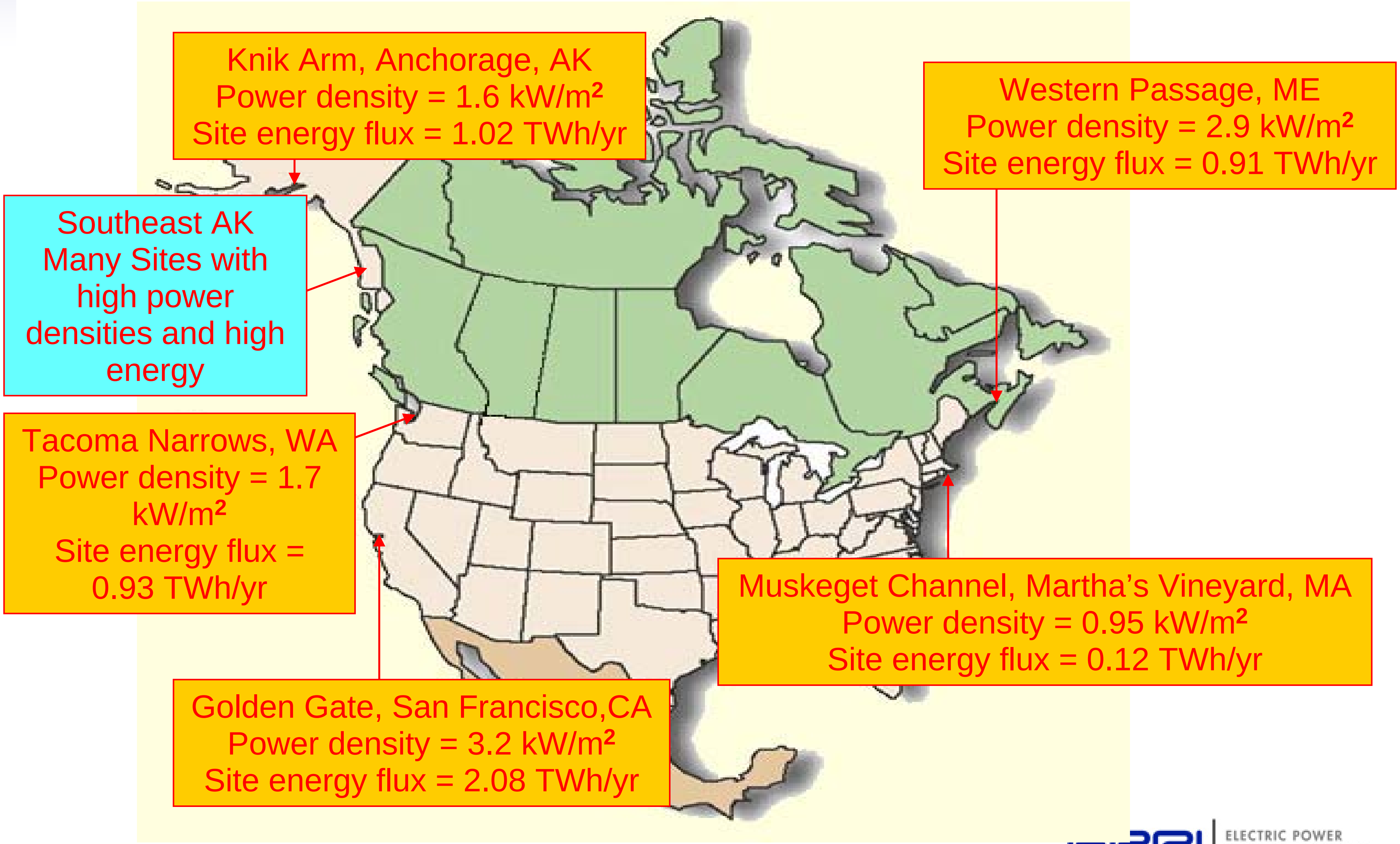
Tidal Resources at EPRI Study Sites



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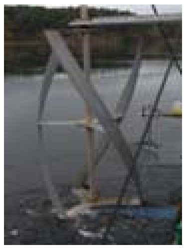
Tidal Current Turbines

EPRI state and provincial Advisory Groups selected turbines in **bold** font for more detailed study



- GCK (vertical-axis, Gorlov helical rotor)
- **Lunar Energy (h-axis, shrouded rotor)**
- **Marine Current Turbines (h-axis, open rotor)**
- Open Hydro (h-axis, open rotor, rim-drive)
- SeaPower (vertical axis, Savonius rotor)
- SMD Hydrovision (h-axis, open rotor)
- UEK (h-axis, shrouded rotor)
- **Verdant Power (h-axis, open rotor)**

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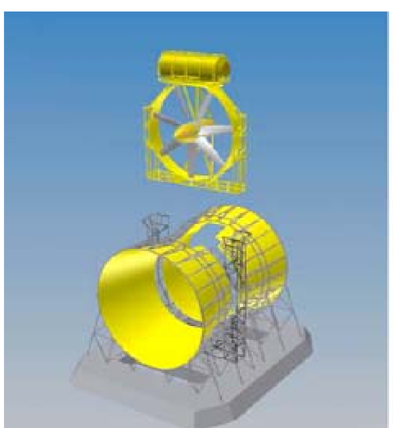
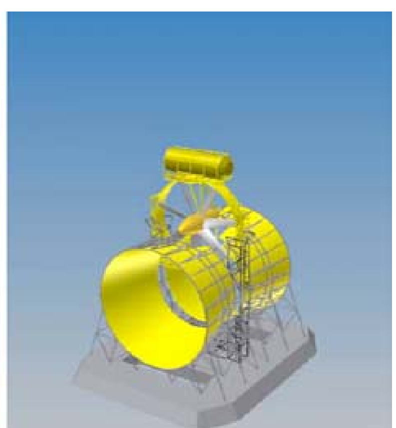
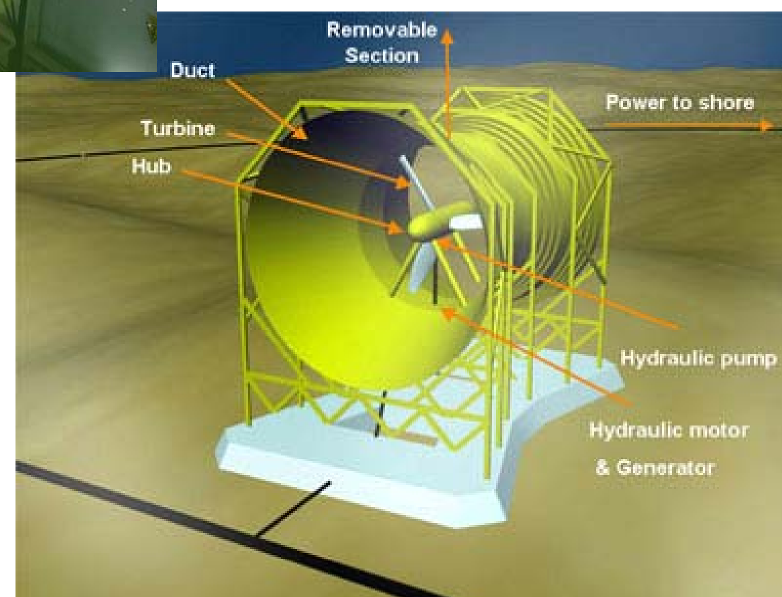
UK-Based Lunar Energy

Design and fabrication of 1 MW prototype now underway for installation at European Marine Energy Center in 2007

Duct inlet diameter for 2 MW unit is 25 m







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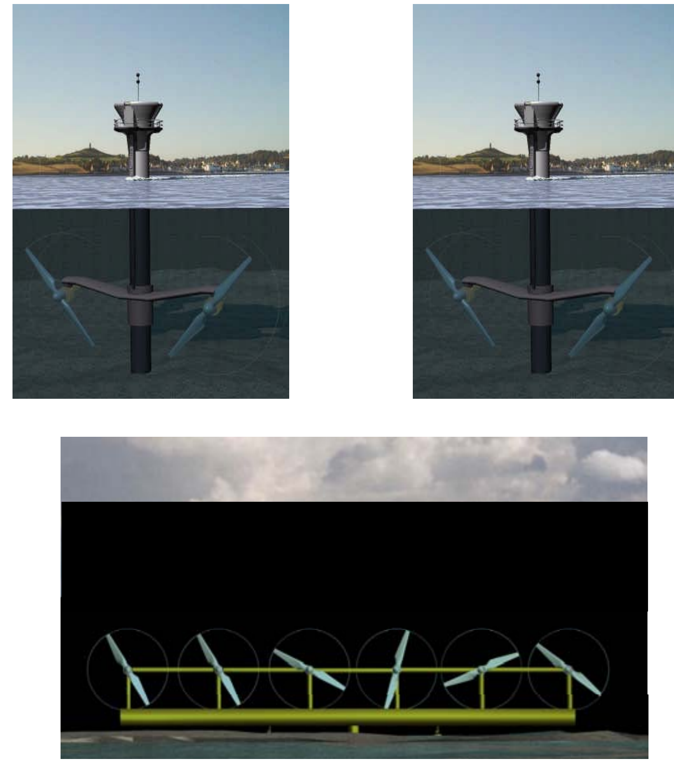
UK-Based Marine Current Turbines

SeaFlow experimental 300 kW prototype (11-m rotor diameter) operating in Bristol Channel since May 2003; not connected to grid)



SeaGen commercial 1.2 MW prototype consists of dual 16-m rotor diameter unit being installed at Strangford Lough, No Ireland

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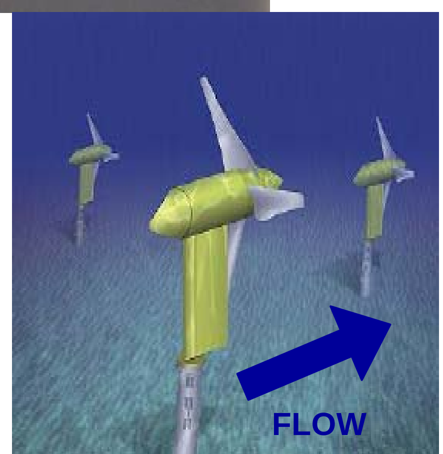
US-Based Verdant Power

Six-turbine, 200 kW array being installed Dec 2006 – Jan 2007 for 18 months in East River, New York City for environmental monitoring pursuant to FERC commercial project licensing



Downstream, 3-blade rotor 5-m in diameter, yaws to accommodate reversing flow

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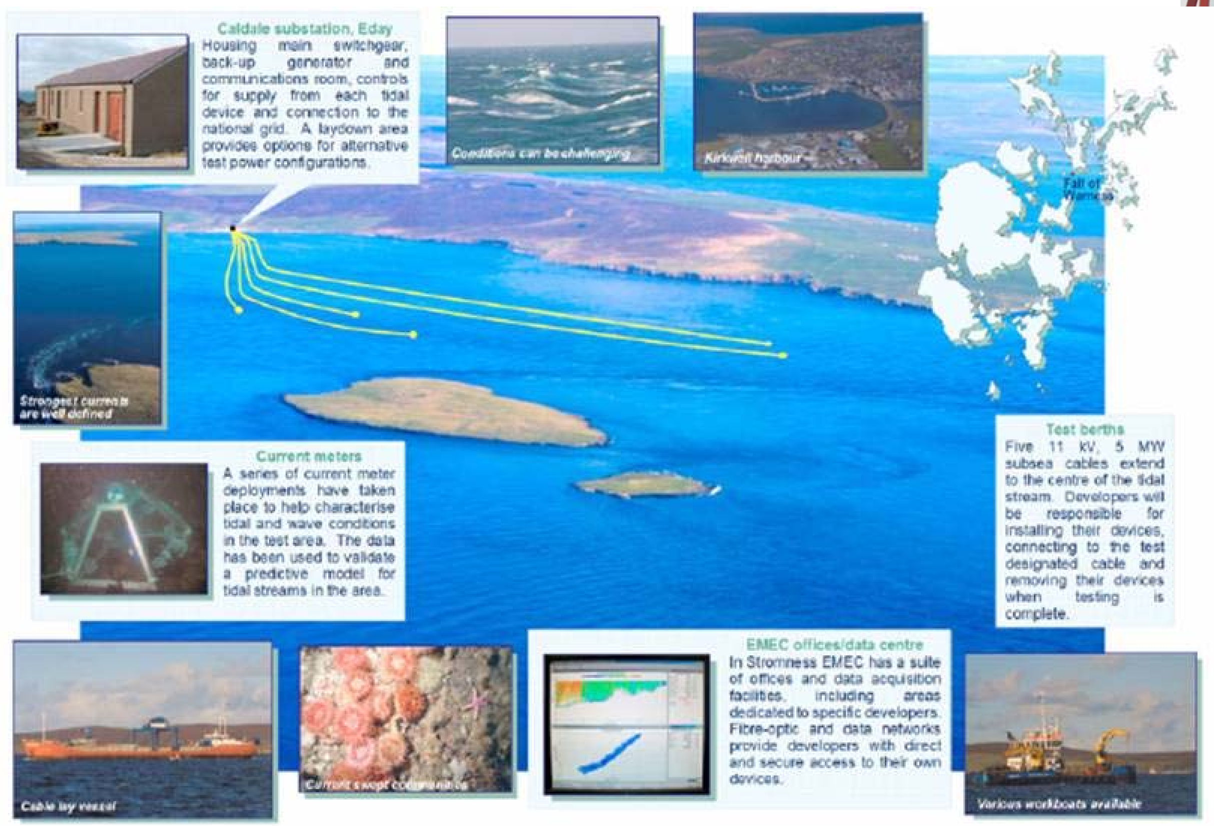
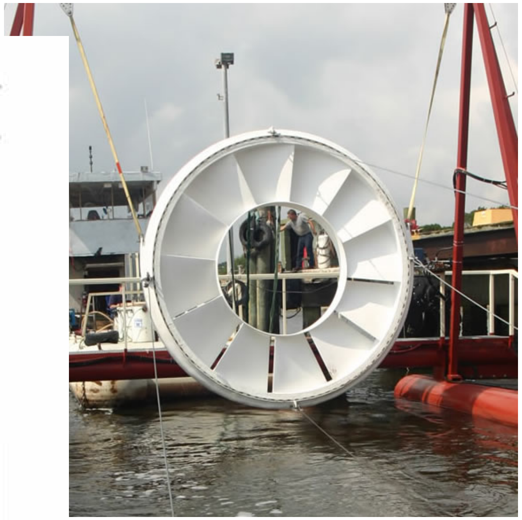
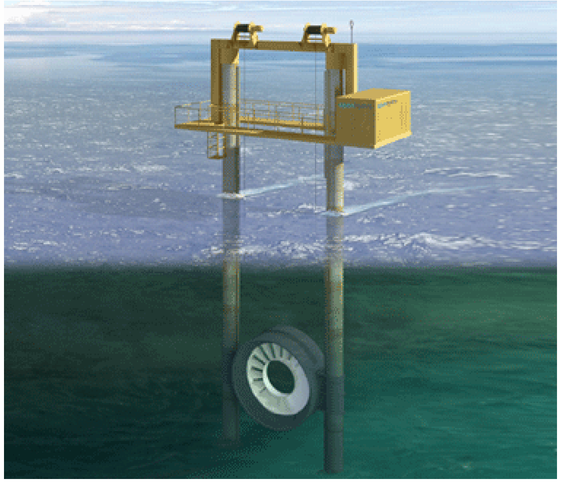
Open Hydro – 1st in EMEC – Dec 2006







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River Current Energy

- **Resource characteristics**
  - Stochastic (% probability forecasts) – governed by precipitation
- **U.S. production potential**
  - ~110 TWh per year (NY University, 1986
  - EPRI proposing to study in 2007
- **General types of conversion technology**
  - Underwater turbines in various configurations

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Ocean Current (Florida Gulf Stream) Energy

- **Resource characteristics**
  - Gulf Stream relatively steady
- **U.S. production potential**
  - EPRI not engaged in ocean current
- **General types of conversion technology**
  - Underwater turbines in various configurations
- **Conversion technology status**
  - Challenges: potential climate impacts, no slack water, large water depths (350-450 m), long submarine cable transmission distances (20-35 km), single US state resource

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Waves

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Ocean Wave Energy

- **Resource characteristics**
  - Stochastic – governed by remote and local winds
- **U.S. production potential**
  - 250-260 TWh per year (EPRI, 2004)
- **General types of conversion technology**
  - Highly diverse alternatives
- **Conversion technology status**
  - Many devices with at-sea testing; early commercial plants

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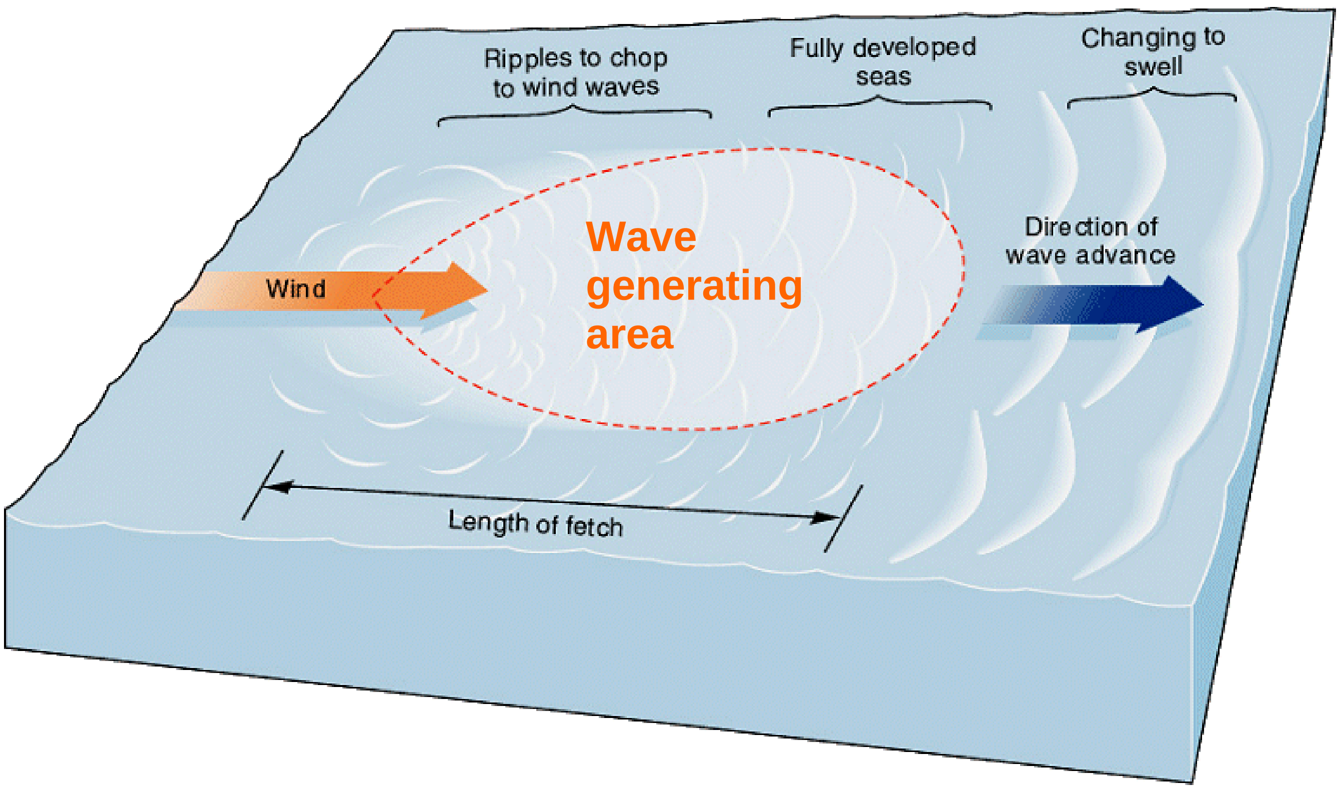
Waves Governed by Wind Over Water



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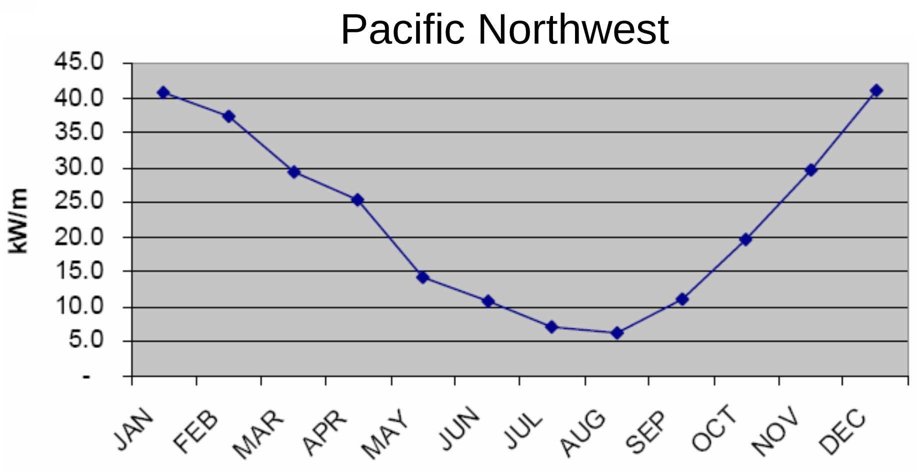
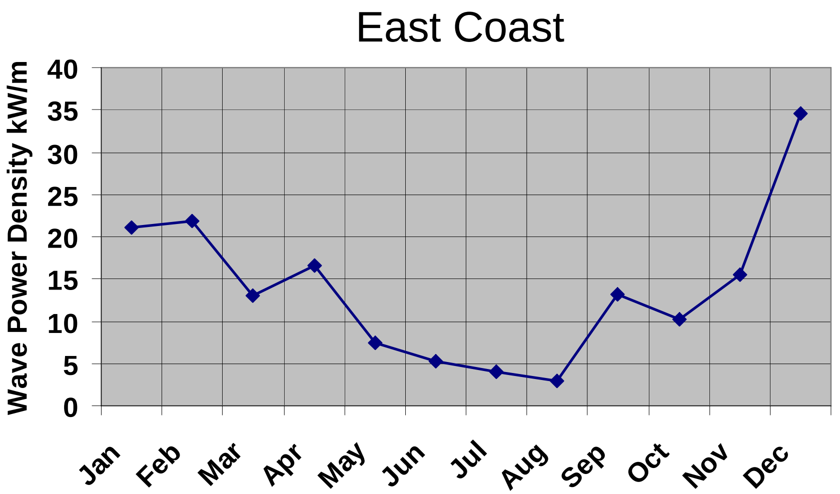
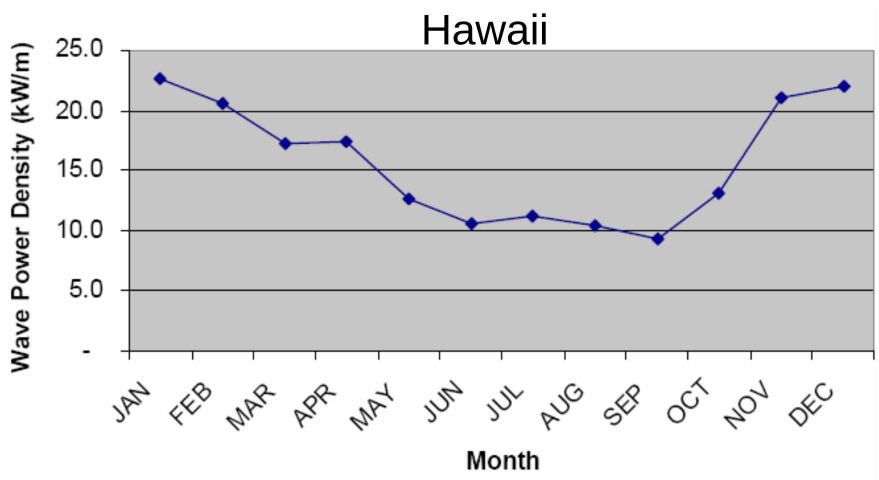
Substantial Seasonal Differences







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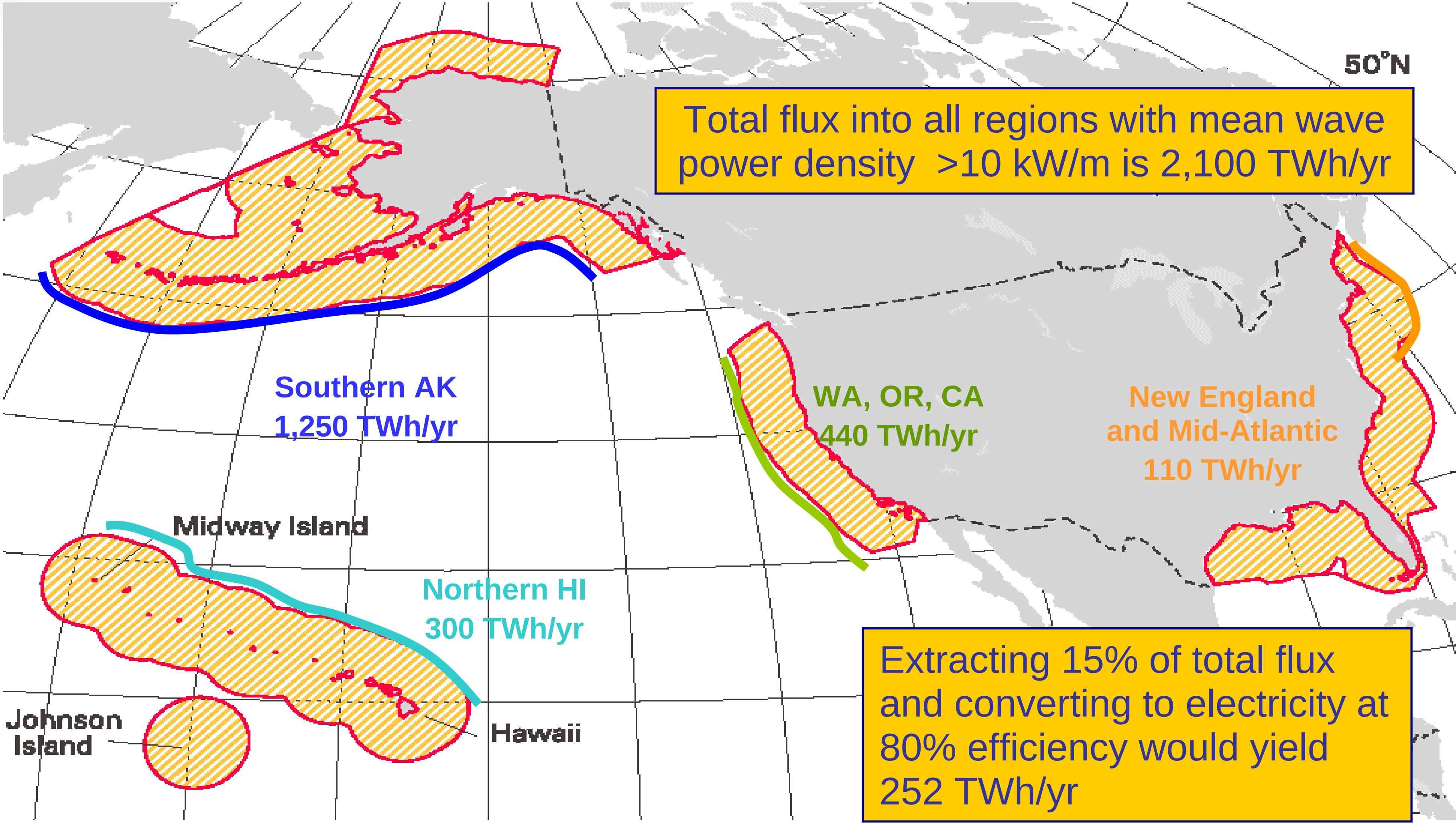
U.S. Offshore Wave Energy Resources



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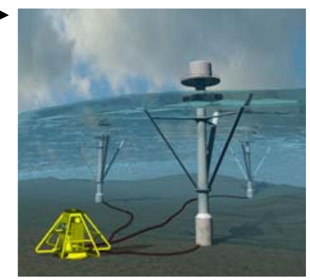
Wave Energy Conversion Devices

EPRI December 2006 WEC Device Survey – 14 Respondents

The two in bold were used in 2004 Feasibility Studies

- Able Technologies - Electricity Generation Wave Pump
- AquaEnergy Group, Finevera - AquaBuOY
- AWS Energy - Archimedes Wave Swing
- Ecofys - Wave Rotor
- **Energetech - Uiscebeathe**
- Fred Olsen - FO Research Rig “Buldra”
- Independent Natural Resources Inc - SeaDog™
- **Ocean Power Delivery - Pelamis**
- Ocean Power Technologies - PowerBuoy®
- Renewable Energy Holdings - Cylindrical Energy Transfer Oscillator (CETO)
- Wavebob Ltd - Wavebob WEC
- Wave Dragon Ltd - Wave Dragon
- Wave Energy AS - Sea Wave Slot-Cone Generator (SSG)
- Wave Star Energy - Wave Star



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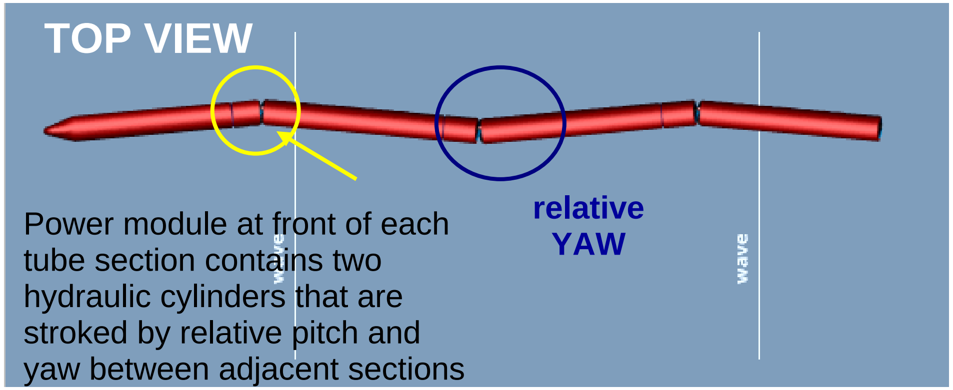
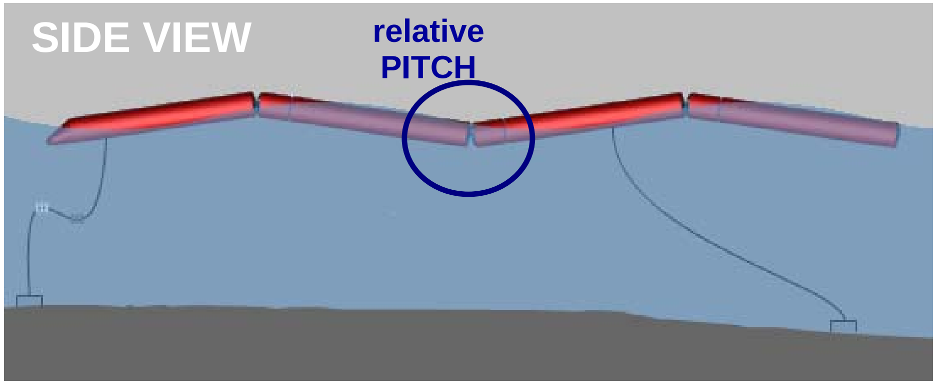
UK Based Ocean Power Delivery Pelamis





Pelamis 750 kW prototype installed in August of 2004 in 50 m water depth, 2 km offshore the European Marine Energy Centre, Orkney, UK

Pelamis 1st commercial sale occurred 2005 – OPD Pelamis in Portugal – contains an early 3 unit qualification

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Energetech

Port Kembla Prototype

Size:	25 x 35 m
Average power:	500 kW @ avg wave resource of 35 kW/m
Max rated power:	1.5 MW
Structural Steel Wt:	150 ton
Deployed Water Depth:	9 m

Milestones

2005 - Completed installation of a 500 kW prototype at Port Kembla Australia

2006 - Energetech begins development of a slack moored floating version of the PK prototype with an expected completion of the first project using the floating technology in Q1 2008.

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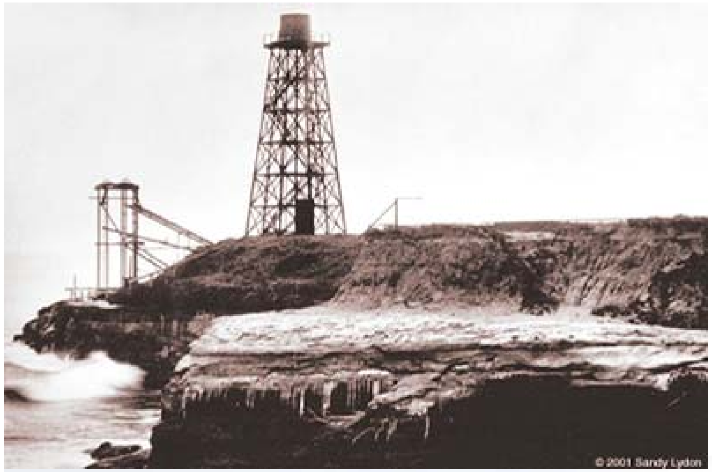
Santa Cruz Wave Pump - 1898



Operated 1898 – 1910
Solved a need – how to water local wagon roads to keep dust down
A ‘new 1910” technology put the Armstrong Brothers out of business

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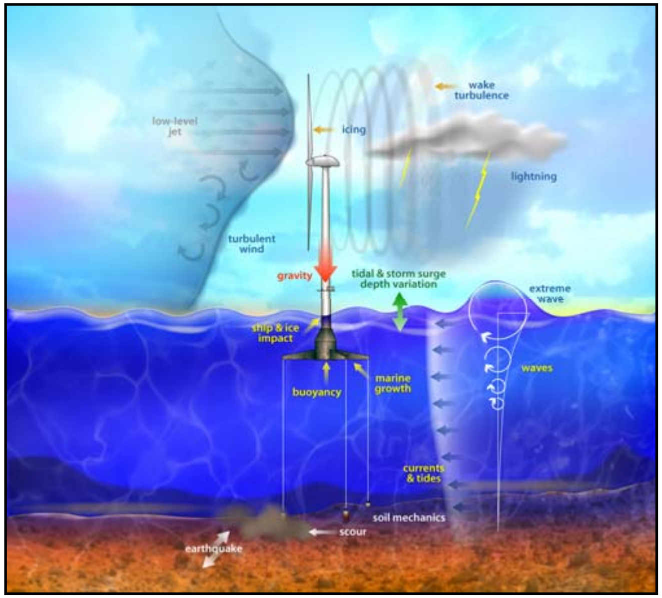
Hybrid Wind-Wave – 2098!



- Common Engineering & Design Considerations
- Maximize Grid I/C Potential Through Dual Tech
- Improve Intermittency & Total Energy Output
- Increase System Reliability
- Reduce Maintenance Cost

EPRI Building A Coalition of Developers, Universities and Other Stakeholders to Explore the Wind / Wave Development Potential

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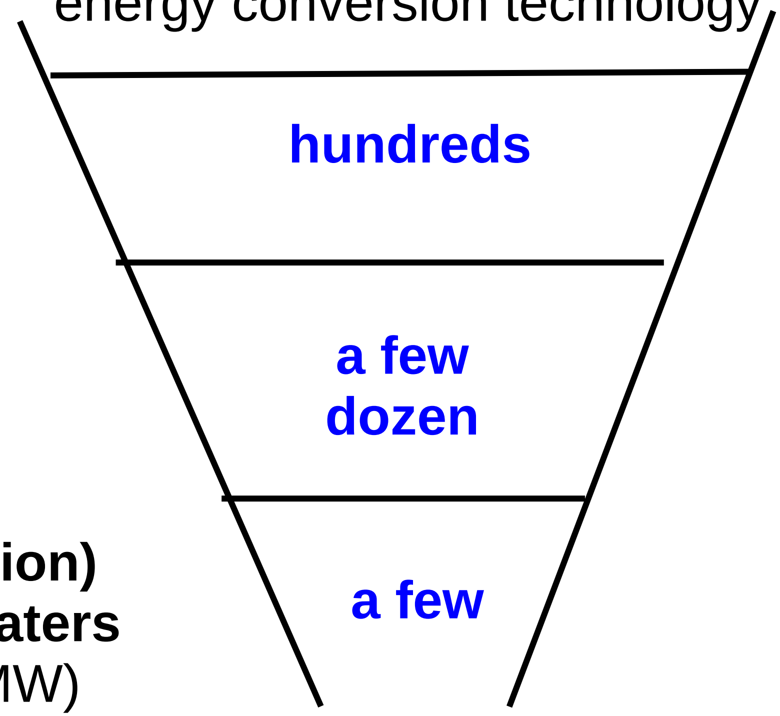
Technology Development Status

Thousand of concepts and patents on ocean energy conversion technology



Rigorous laboratory tow- or wave-tank physical model tests
(1/50- to 1/5-scale)

Short-term (days to months) tests in natural waters
(typically 10 kW to 100 kW)

Long-term (>1 yr duration) prototypes in natural waters
(typically 100 kW to 2 MW)

It typically takes 5 to 10 years for a technology to progress from concept-only to deployment of a long-term prototype

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Will these devices affect the environment?

Ocean power may be one of the more environmentally benign of the known electricity generation technologies.

The Environmental Issues

- Withdrawal of wave and tidal flow energy on the ecology
- Interactions with marine life (fish and mammals)
- Atmospheric and oceanic emissions
- Visual appearances
- Conflicts with other uses of sea space (fishing, boating, shipping, clamming, crabbing, etc)
- Installation and decommissioning

Wave Energy Environmental Impact Statements (EIS)

- Belt Collins EIS for Navy Hawaii WEC Project - FONSI[#]
- Devine Tarbell EIS for AquaEnergy Makah Bay WA Project – FONSI[#]
- Many European EIS - FONSI[#]

- Finding of No Significant Impact

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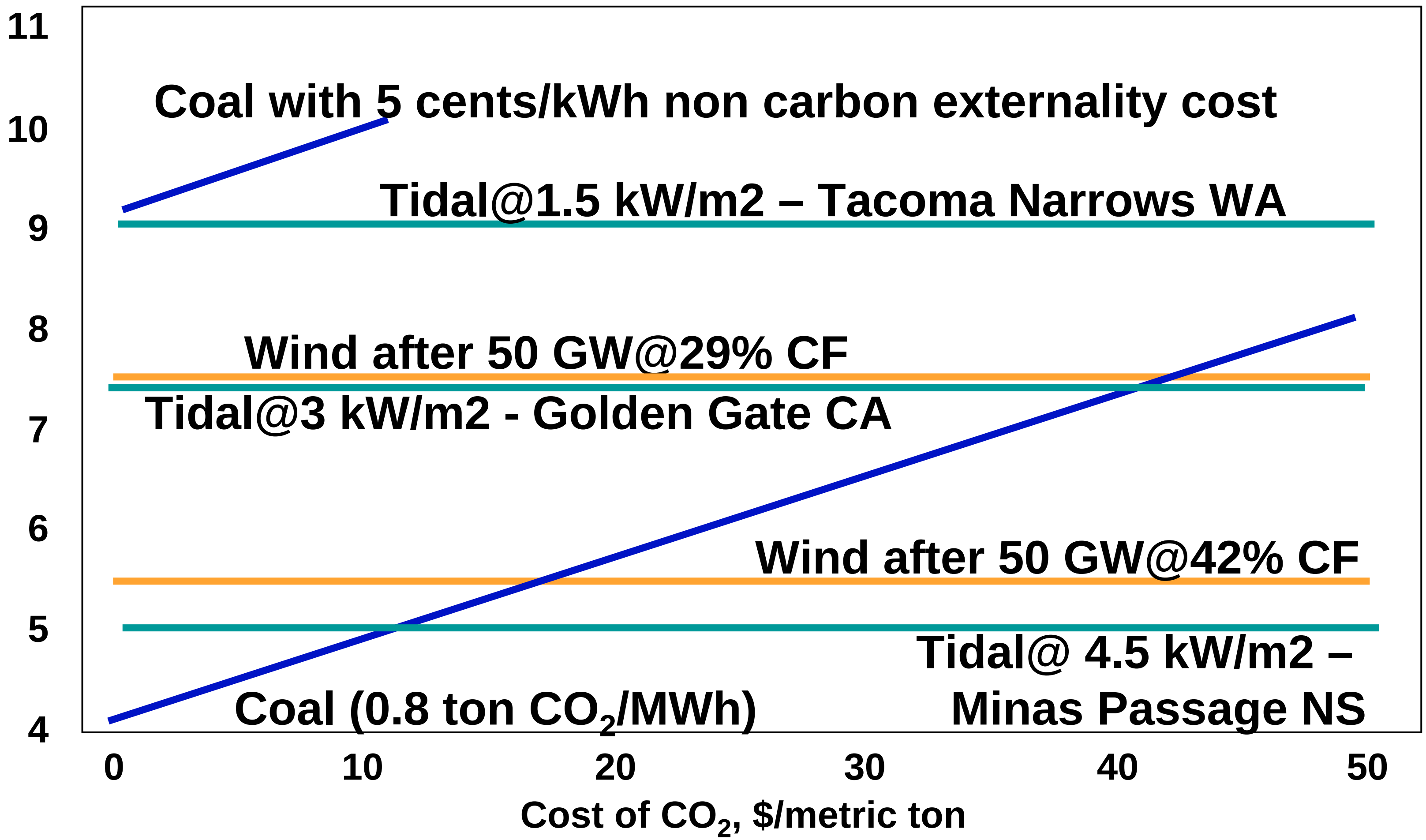
Cost of Electricity, cents/kWh, 2005$, w/o Incentives



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Key Points and Concerns

- Basic oceanography and hydrology are well understood, but “extractable” resource (percent utilization) is not
- Energy conversion technology is well understood and continues to evolve
- Environmental effects of commercial projects uncertain – commercial-scale units must be deployed in “pilot” arrays before full build-out
- The regulatory situation in the US could spell doom

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The Barriers

The primary barriers to wave and current energy applications are :

- **U.S. Government regulatory uncertainty**
- **No U.S. Government Incentives to Allow Ocean Energy to Compete on a Level Playing Field with:**
  - **Fossil fuel generation with its externalities**
  - **Other Renewables such as Wind and Solar Tax Credits**
- **No U.S. Government RD&D Funding Support**

PogoPossum.jpg

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And Now, Let's All Work Together to Move Ocean Energy Technology Forward

EPRI Reports available at: www.epri.com/oceanenergy

Email: rbedard@epri.com

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Participants

State/City Agencies (11)

Maine Tech Initiative

Mass Tech Collaborative

New Brunswick DOE

Nova Scotia Ministry

Alaska Energy Authority

Washington CTED

Oregon DOE & OECDD

CEC, San Francisco & Oakland CA

Institutes (4)

Bedford Oceanography

Univ of Maine, Orono

Virginia Tech

Univ of Washington

Technology Companies (>30)

Wave & Tidal Power Developers

EPRI PROJECT

EPRI
M. Previsic
Devine Tarbell
Global Energy Partners
DOE/NREL
Va Tech
Univ of WA

Federal (4)

U.S. DOE and NREL

BPA and ACOA

Utilities (22)

Bangor HydroCentral

Central Maine Power

National Grid & NSTAR

NB Power

Saint John Electric

NS Power

Chugach & Anchorage

Tacoma Power

Puget Sound Energy

Seattle City and Light

Snohomish PUD

Central Lincoln PUD

Douglas Electric Co-op

Portland General

Pacificorp

HECO and KIUC

PG&E and Idaho Power

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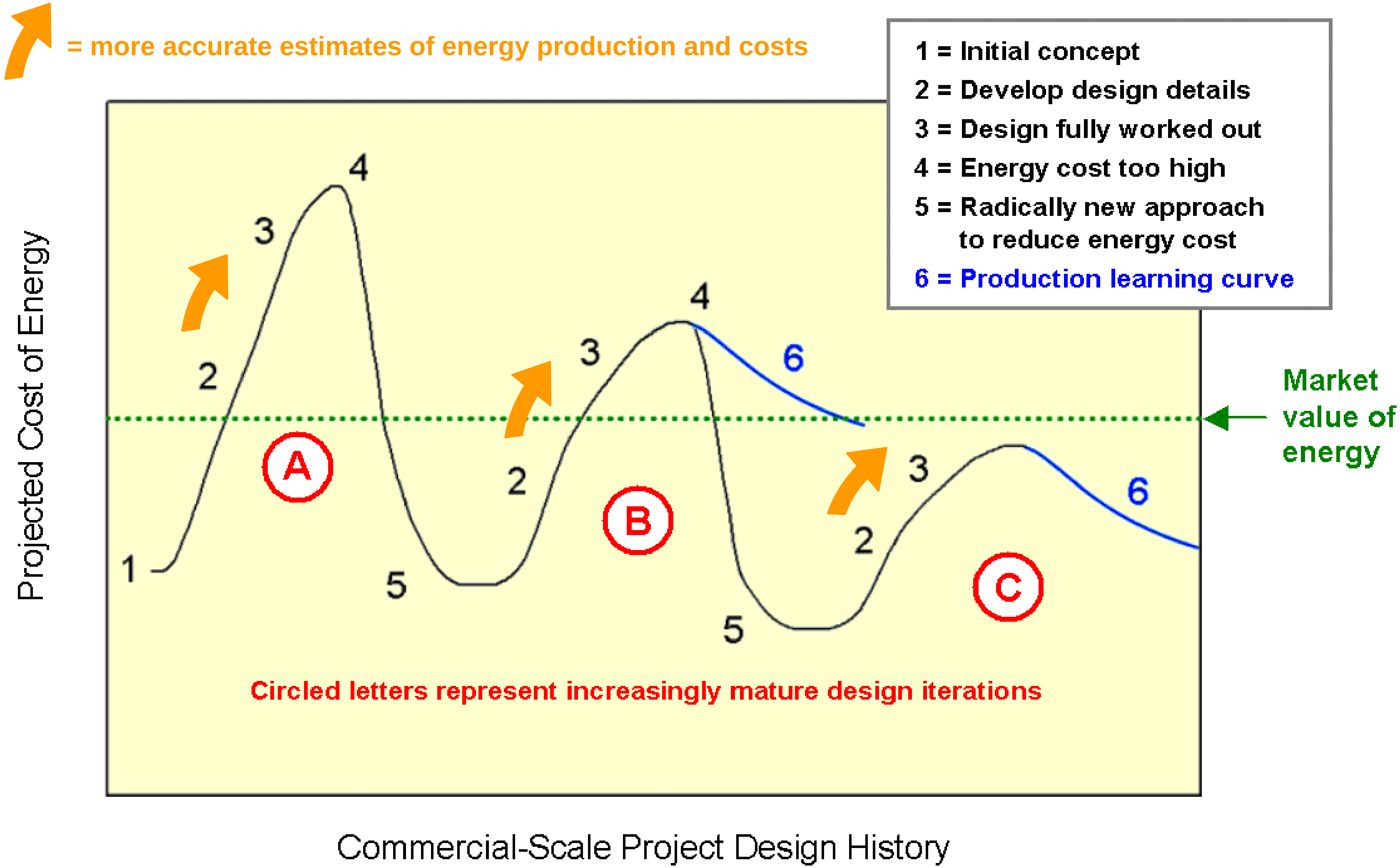
Where is the Project Business Case?



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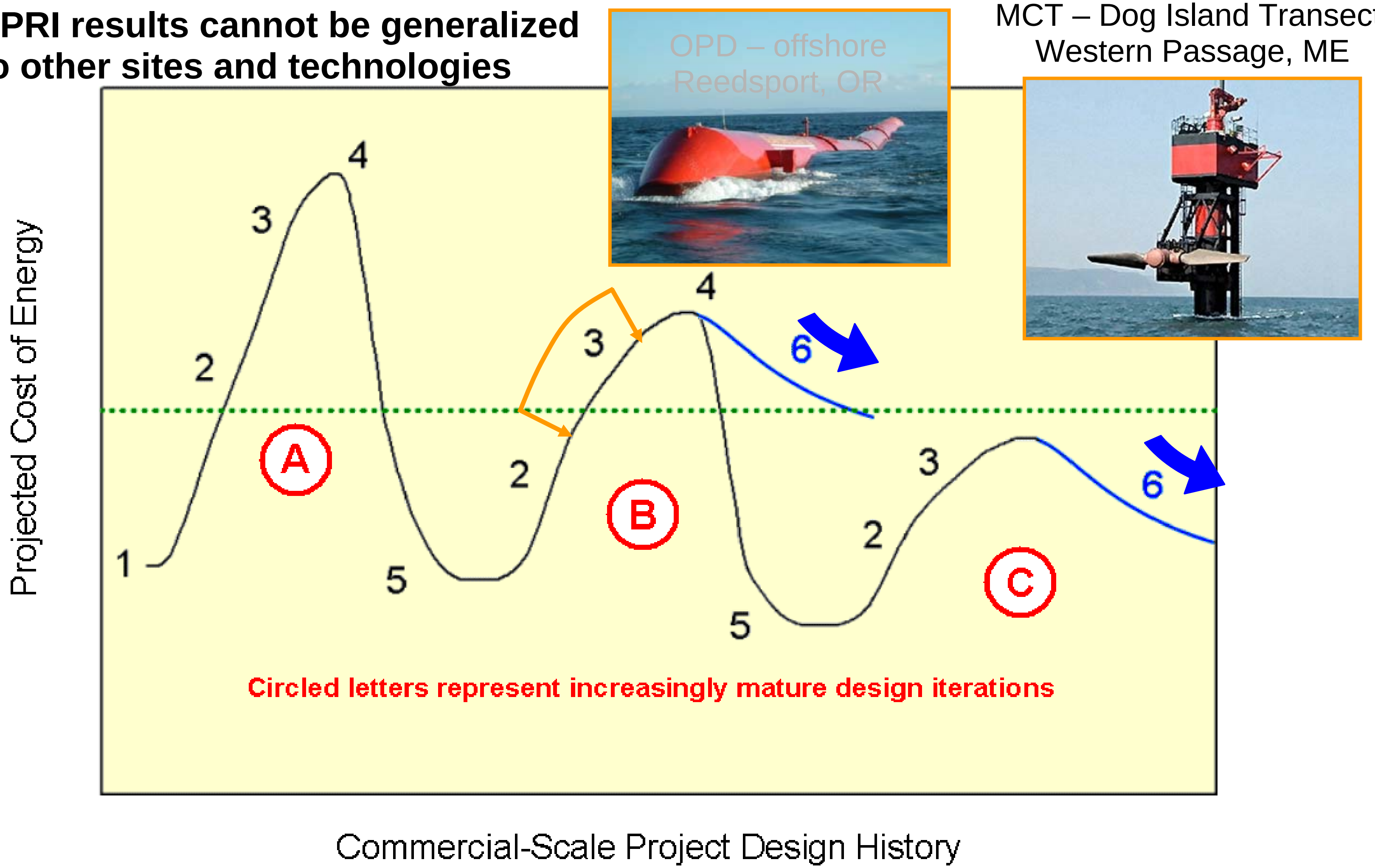
Where are the EPRI Case Studies?

EPRI results cannot be generalized to other sites and technologies



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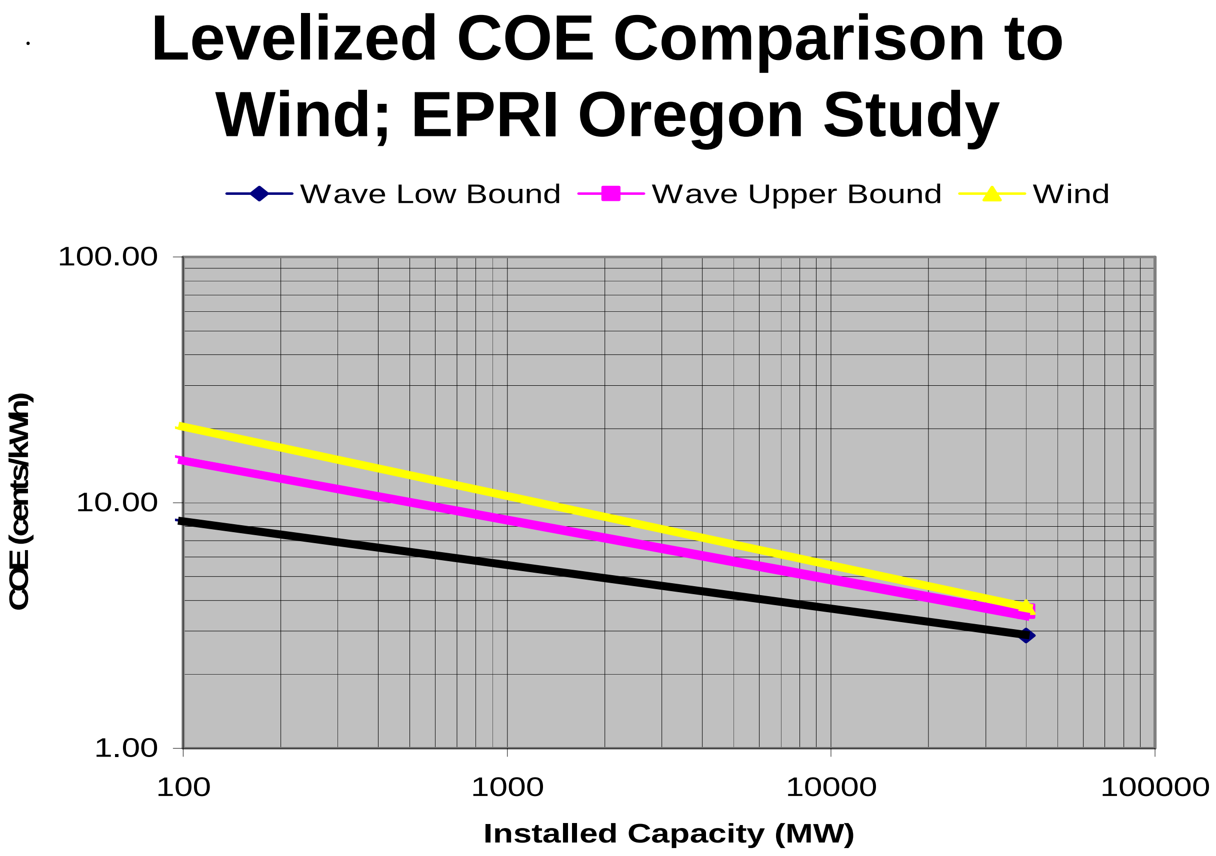
Wave Energy CoE



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Ocean Energy and Power Relationships

<u>ENERGY IS THE ABILITY TO DO WORK</u>

Work (W) = Force (F) x Distance (d)

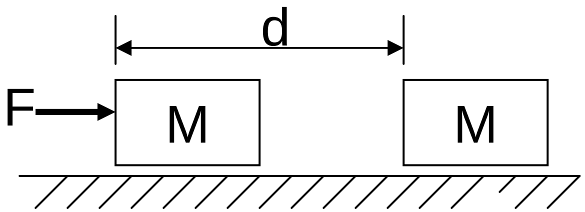
(lbs – ft) or (newton – meter)

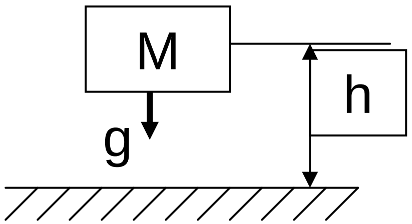
Potential Energy - energy stored in an object

= Mgh = (lbs – ft) or (newton – meter)

Kinetic Energy - energy associated with moving object

= ½ MV^2 (lbs – ft) or (newton – meter)

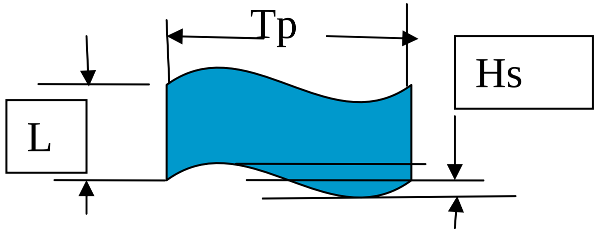




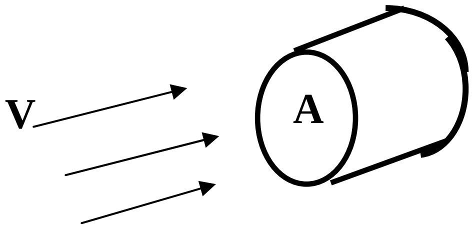
<u>POWER IS THE RATE OF WORK</u>

Power (P) = Energy / Time) (lbs-ft)/sec or (newton-meter)/sec

$(P/L)_{wave} = 0.42\ Hs^2\ Tp$



$(P/A)_{flow} = 0.5\ density\ V^3$



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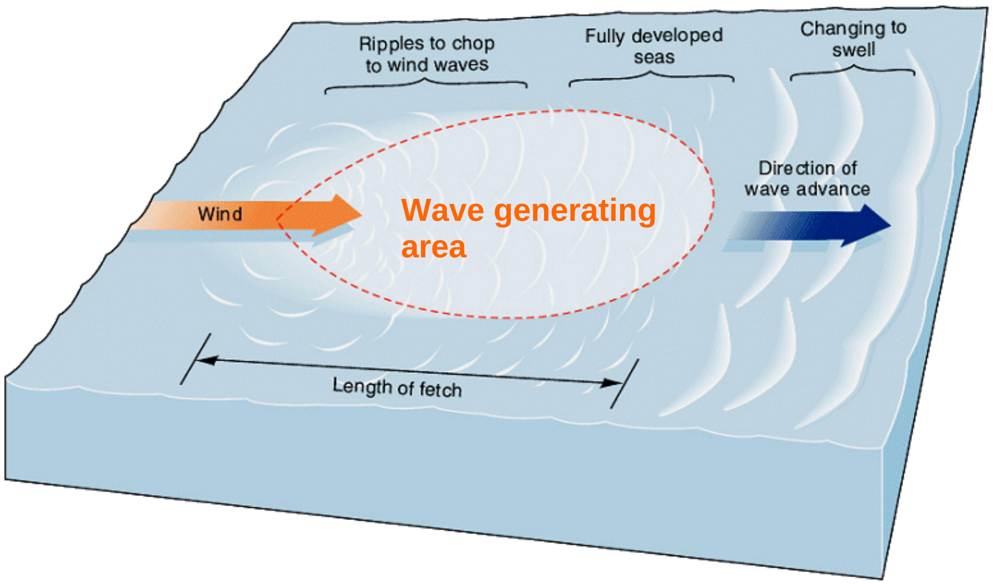
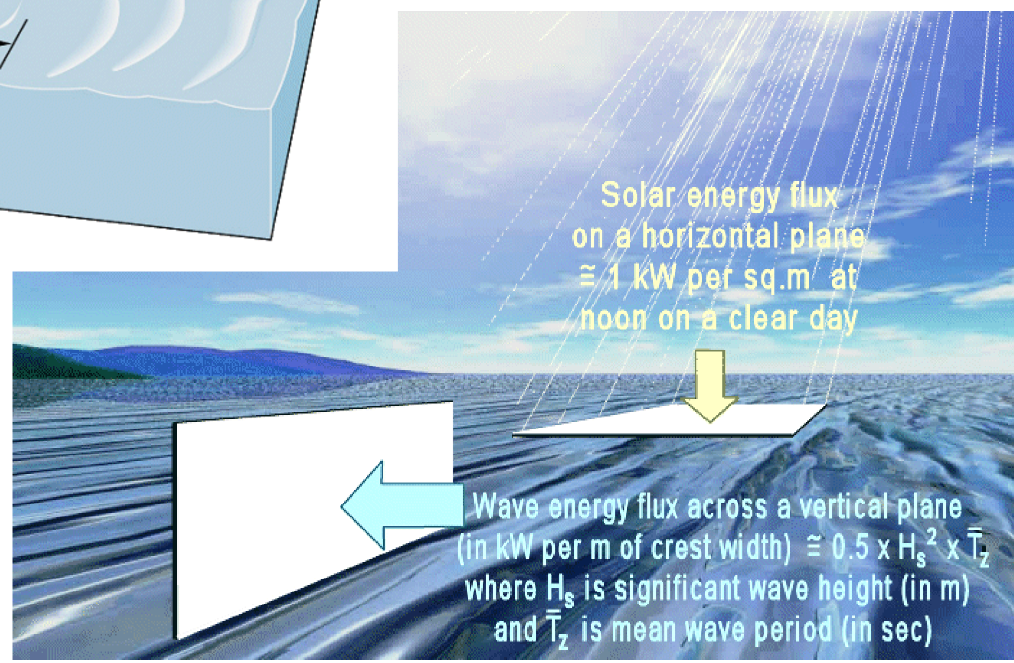
Waves Governed by Wind Over Water





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Wave Energy Devices Highly Diverse

- Fixed Oscillating Water Column Terminator (Energetech)

- Floating Attenuator (*Pelamis*)

- Floating Overtopping Terminator (Wave Dragon)

- Floating Point Absorber (*AquaBuOY*)

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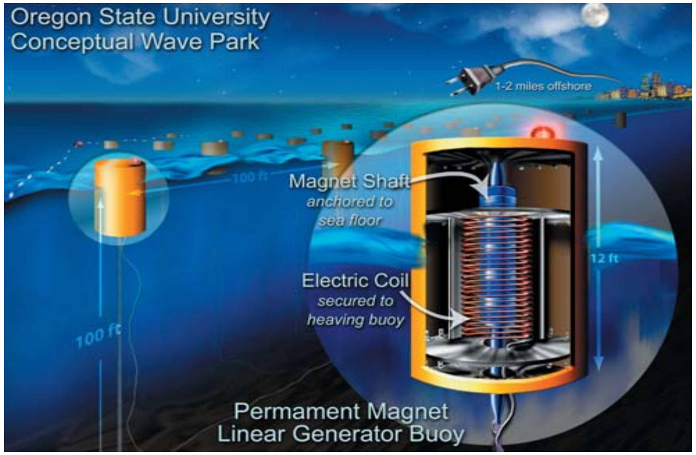
More Examples of WECs

Point Absorber TeamWork Archimedes Wave Swing Before Deployment

After Deployment

Point Absorber Wavebob

Point Absorber OSU PM Direct Drive



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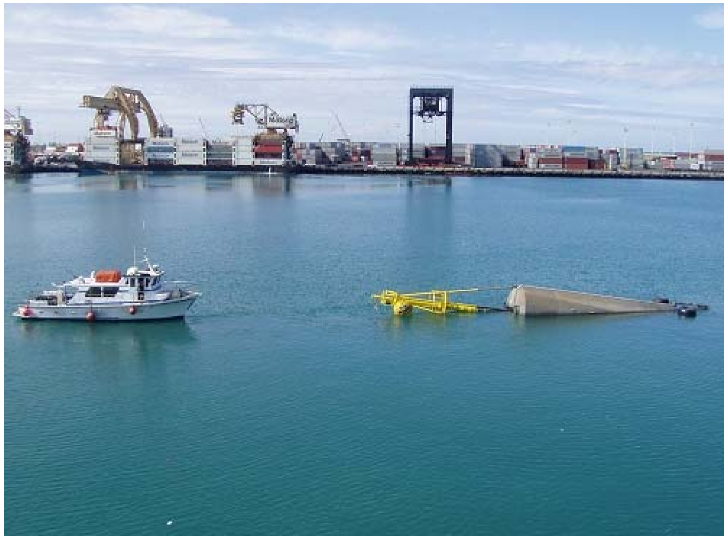
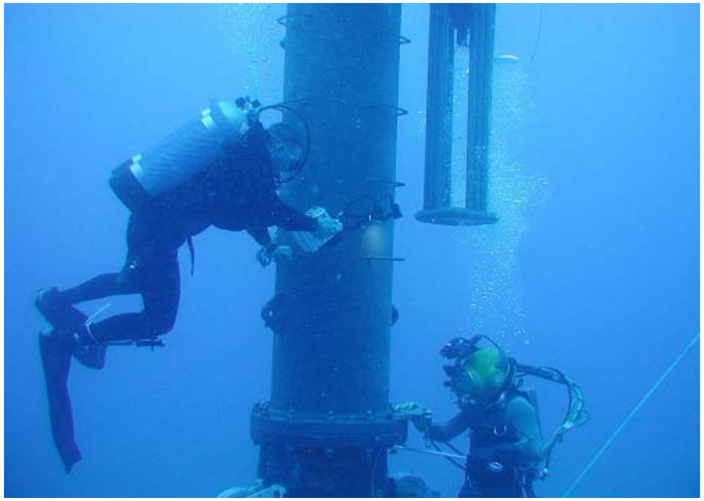
North America Wave Energy Projects
Kaneohe HI – OPT PowerBuoy





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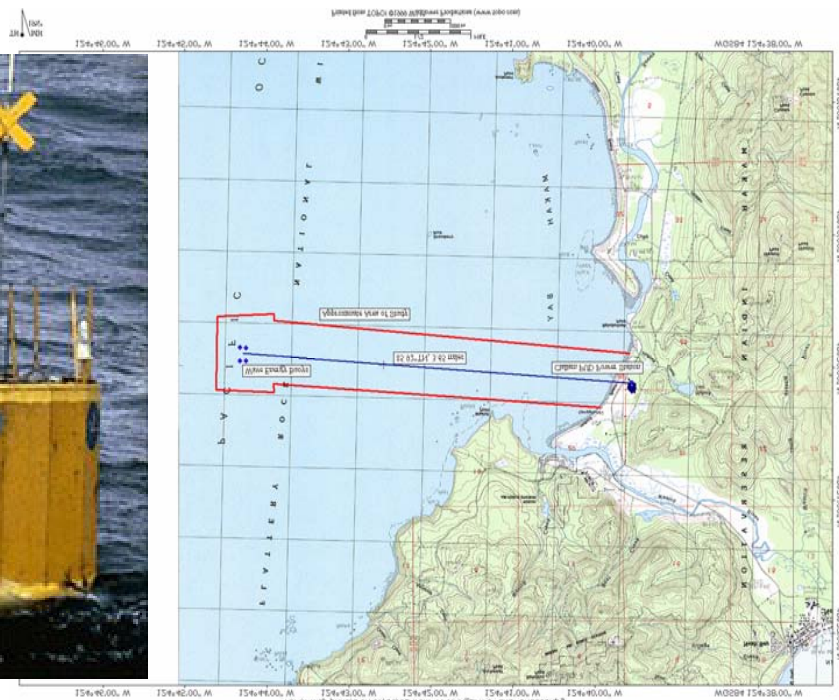
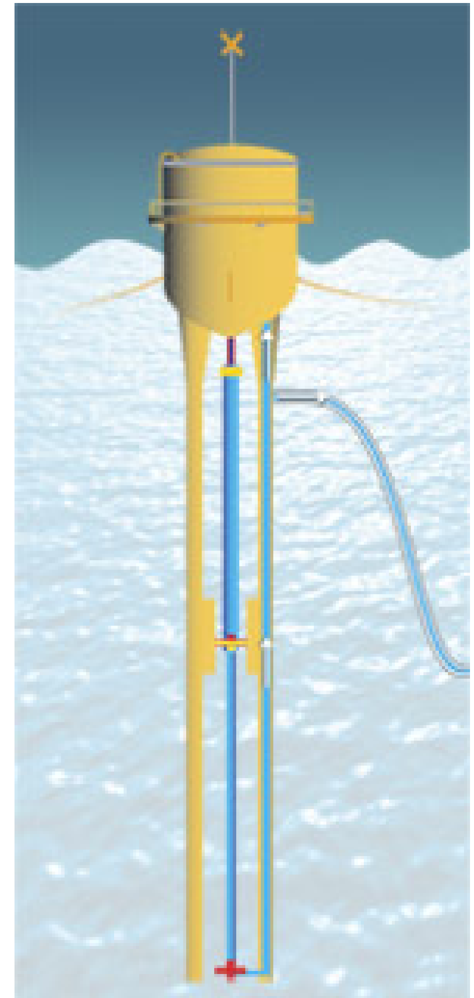
North America Wave Energy Projects
Makah Bay, WA – AquaEnergy AquaBuOY





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