Energy from Tidal, River, and Ocean Currents and from Ocean Waves

EESI Briefing on

“The Role of Advanced Hydropower and Ocean Energy in Upcoming Energy Legislation”

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Two Basic Forms of 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

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)*

General types of conversion technology

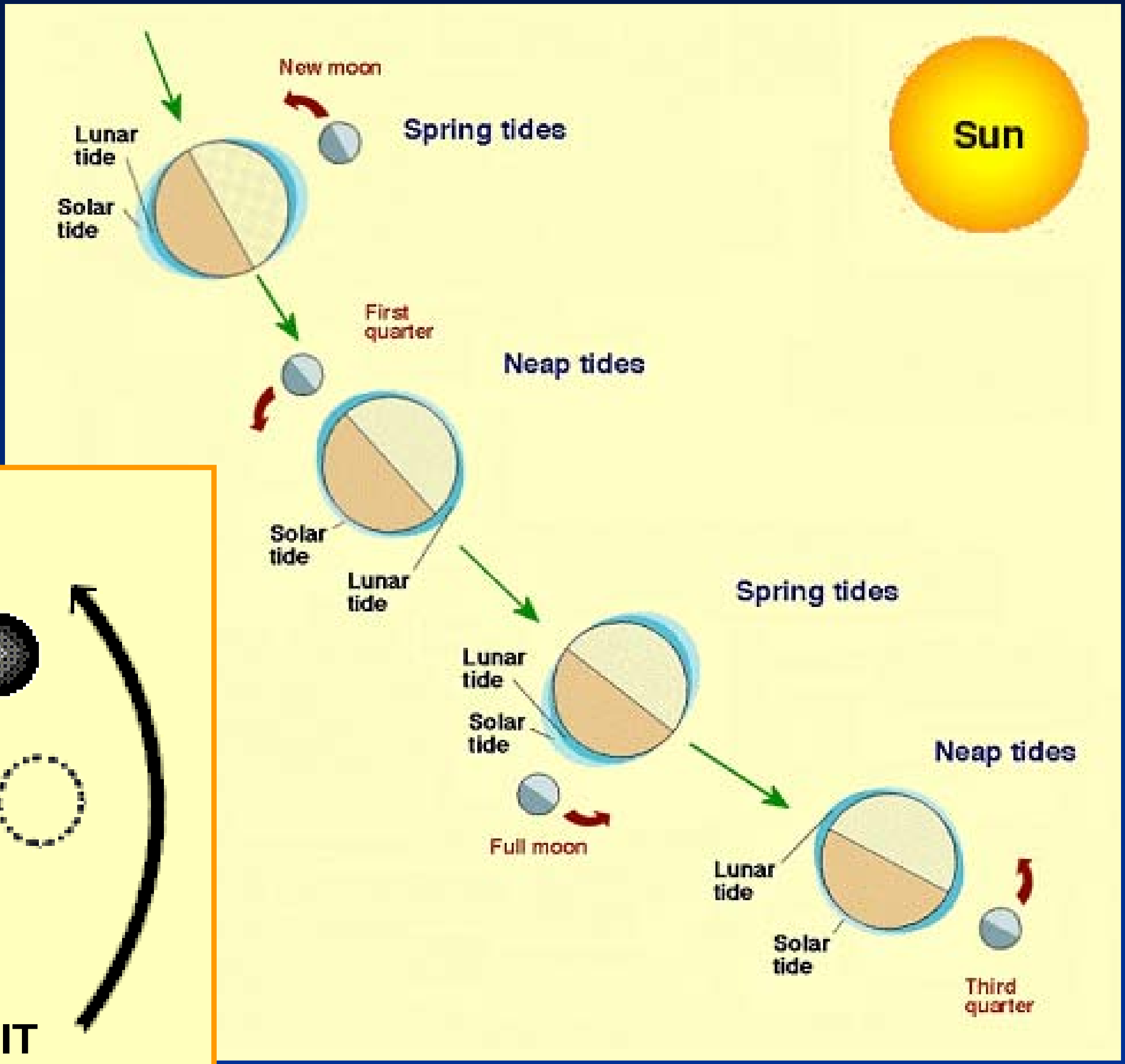
- *Underwater turbines in various configurations*

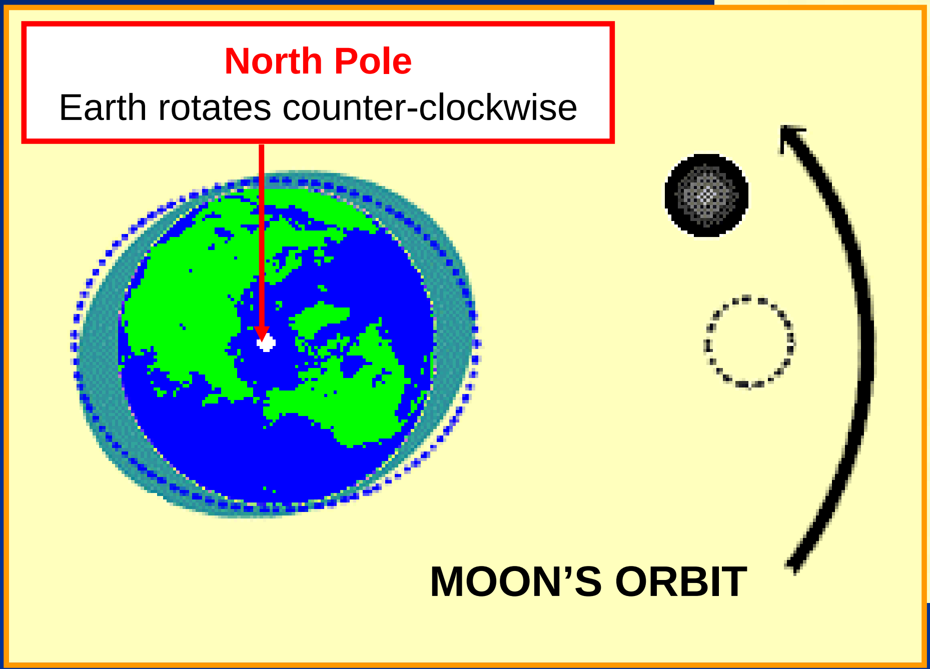
Conversion technology status

- *Less diversity in technical approach than with wave devices*

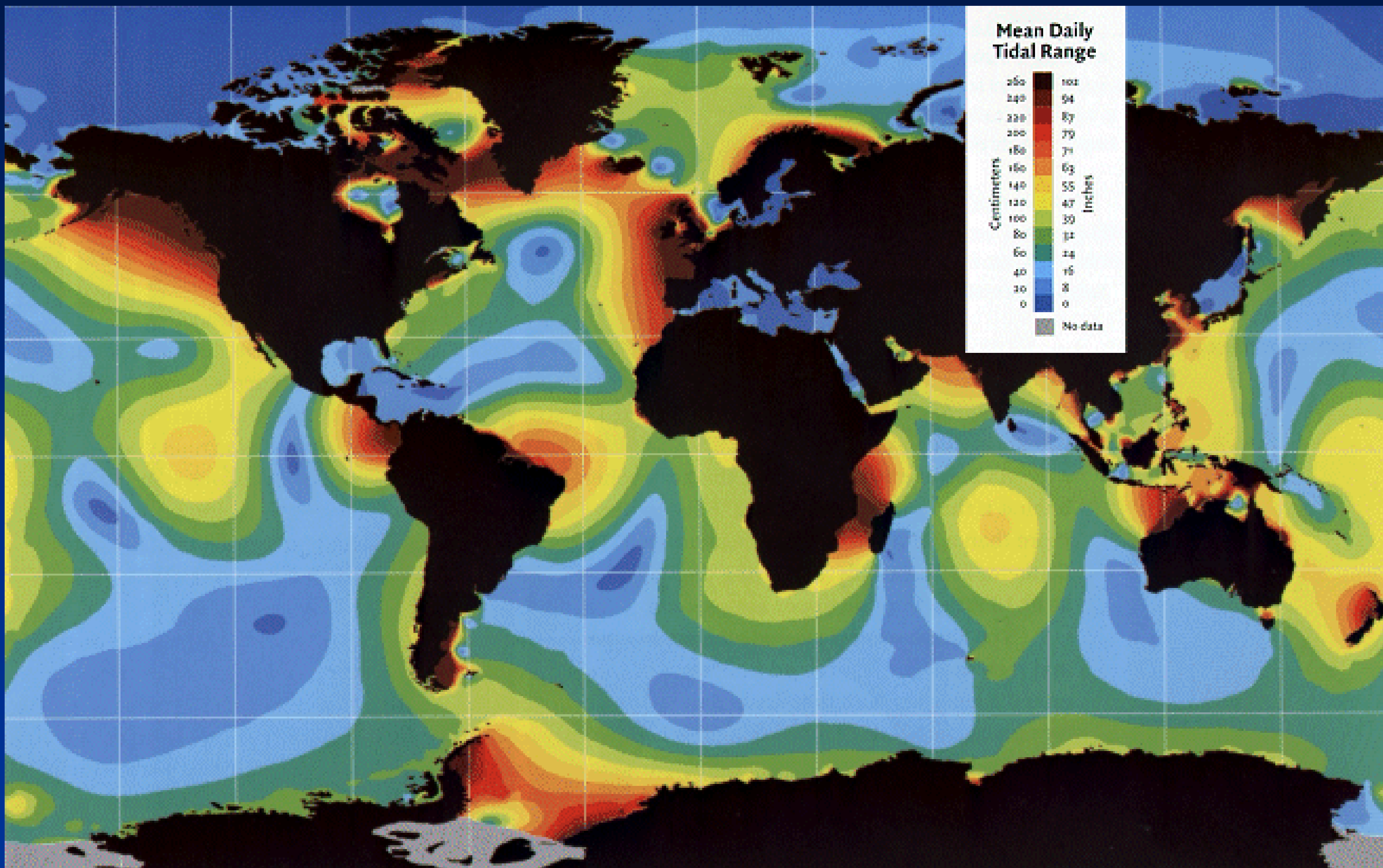
Tides Governed by Earth-Moon-Sun

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

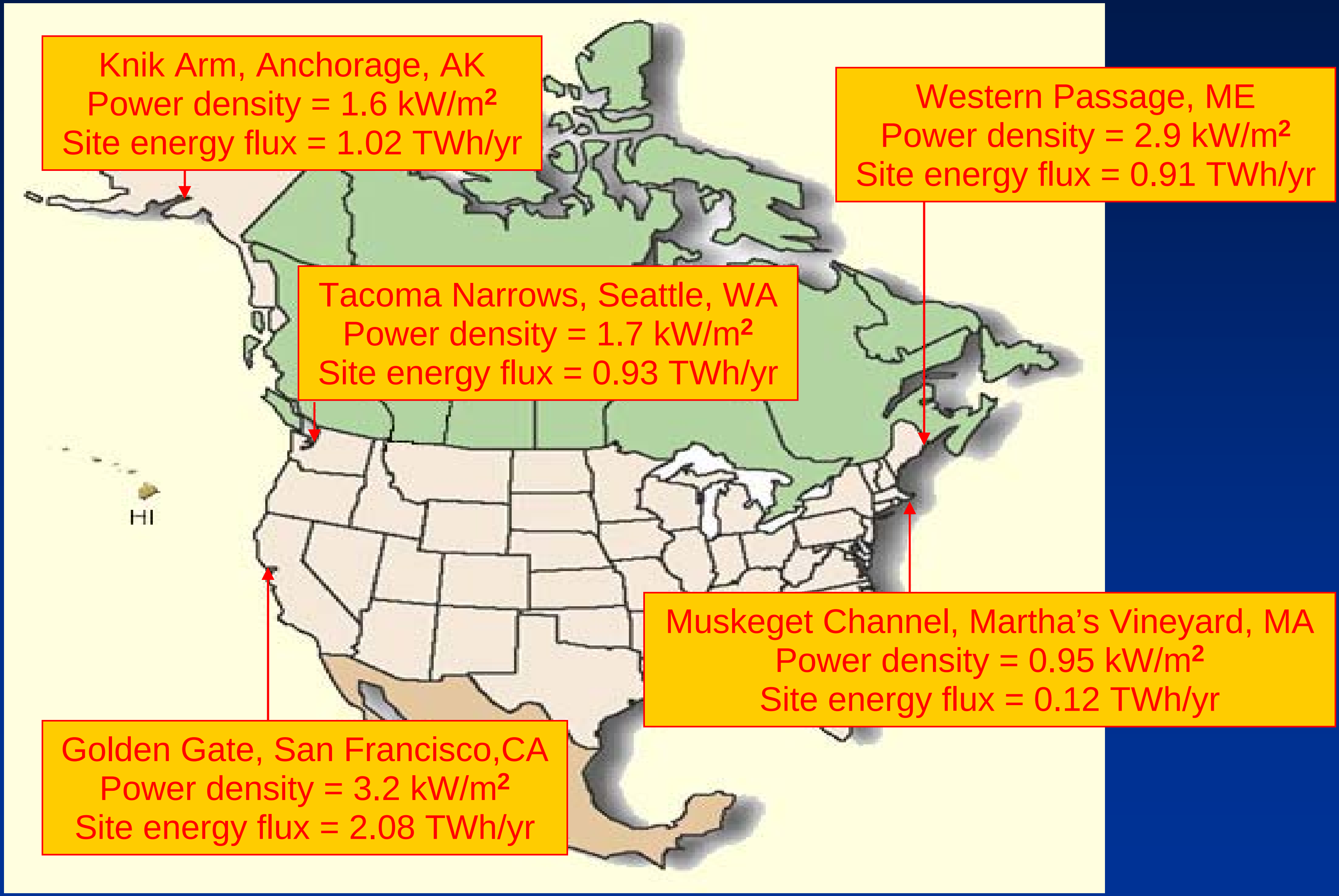




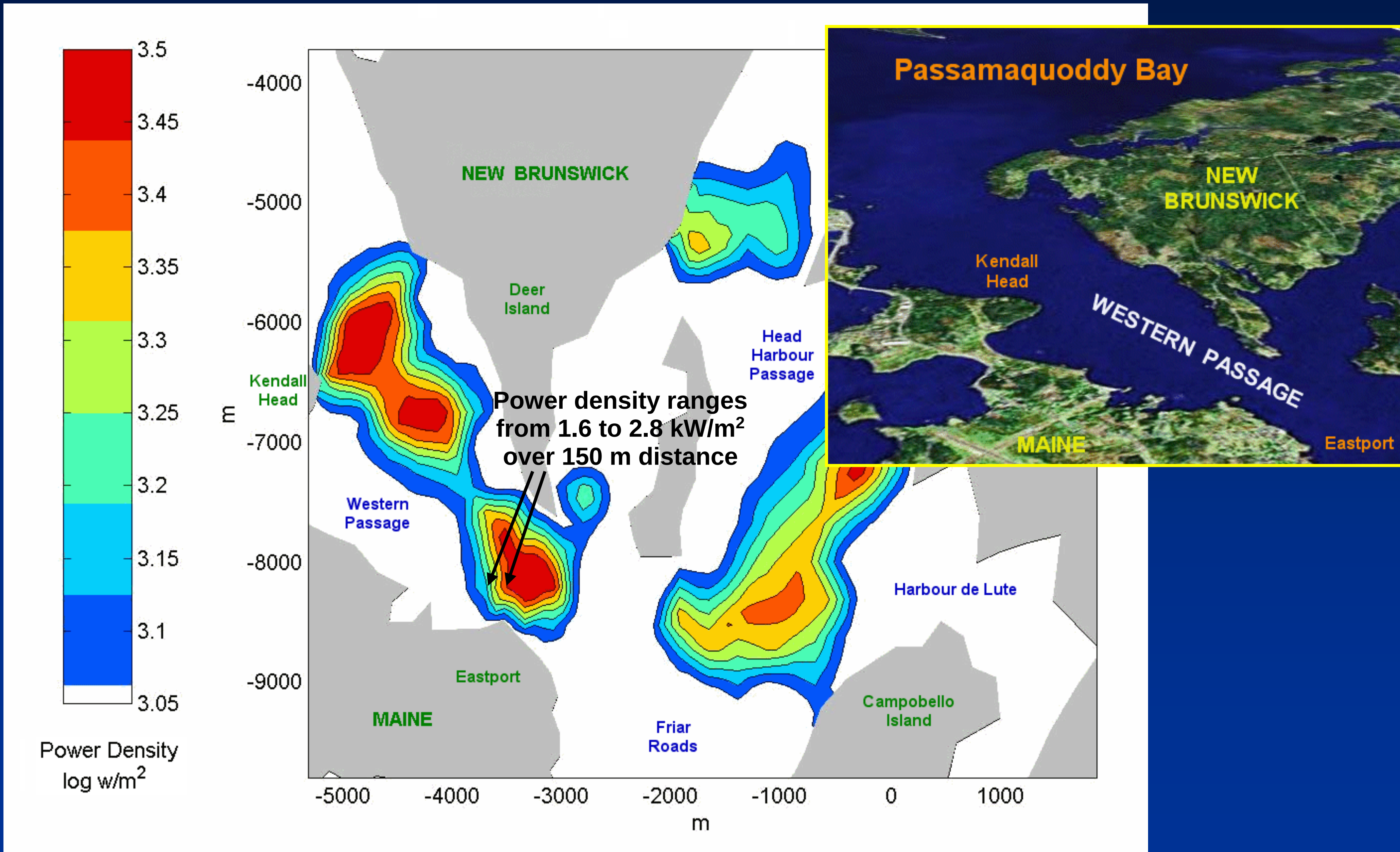
Global Distribution of Tidal Range



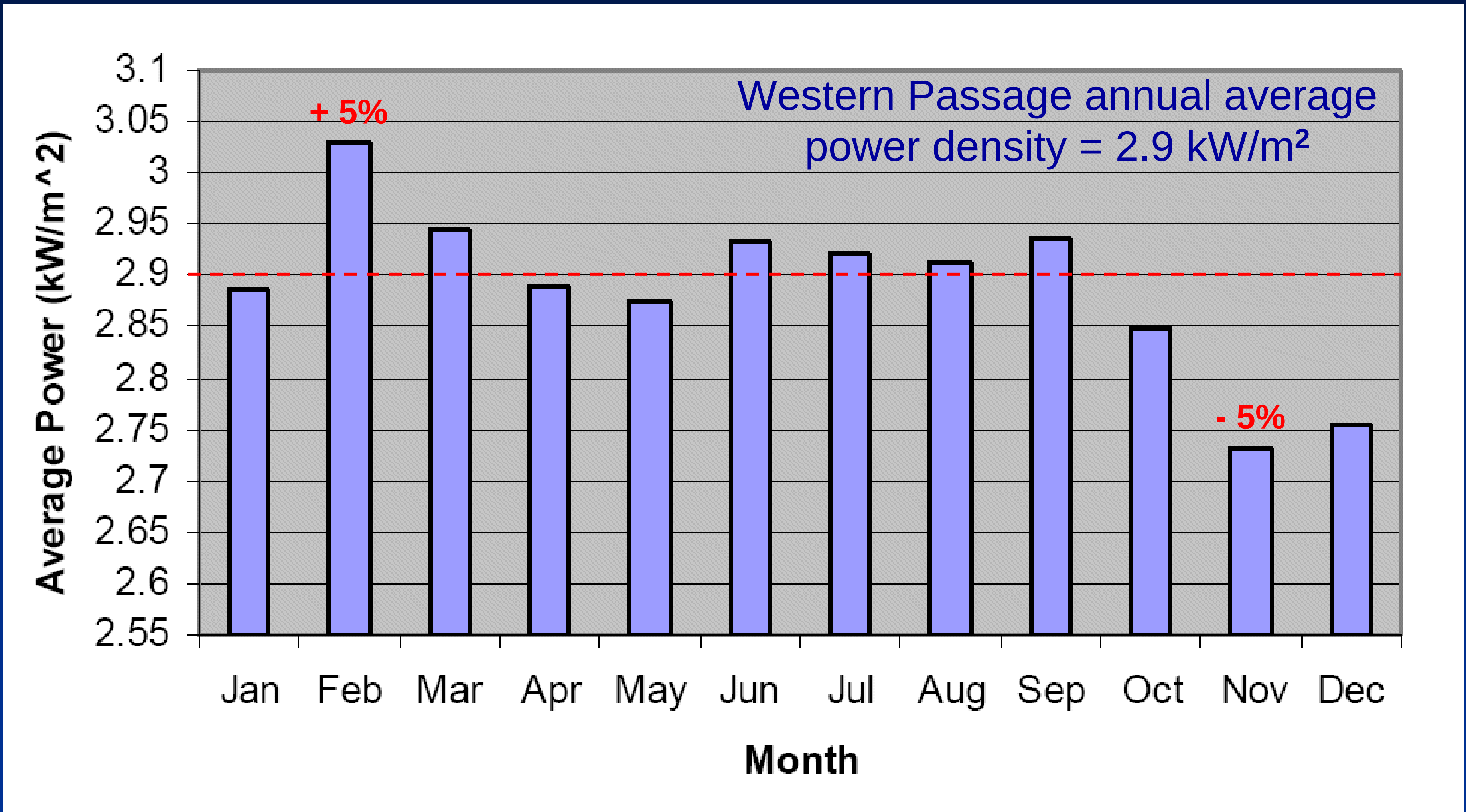
Tidal Stream Resources at EPRI Study Sites



Power Densities Highly Localized



Negligible Seasonal Variability



Apparent seasonal pattern actually shifts forward by 48 days each year

UK-Based Marine Current Turbines

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

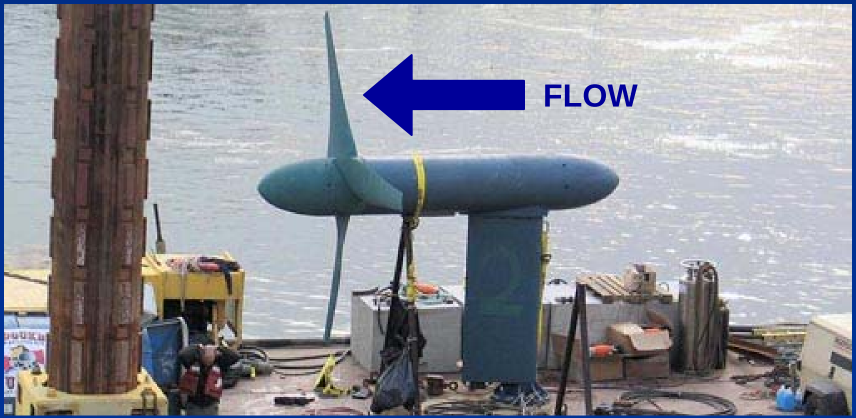
www.marineturbines.com

Upstream, two-blade rotor; blades pitch 180° to accommodate reversing flow

Commercial array would consist of 1.2 MW, twin-rotor units, with individual rotor diameter of 16 m

US-Based Verdant Power

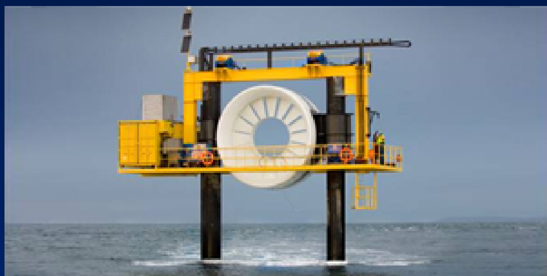
Six-turbine, 200 kW array installed May 2007 in east channel of East River, New York City



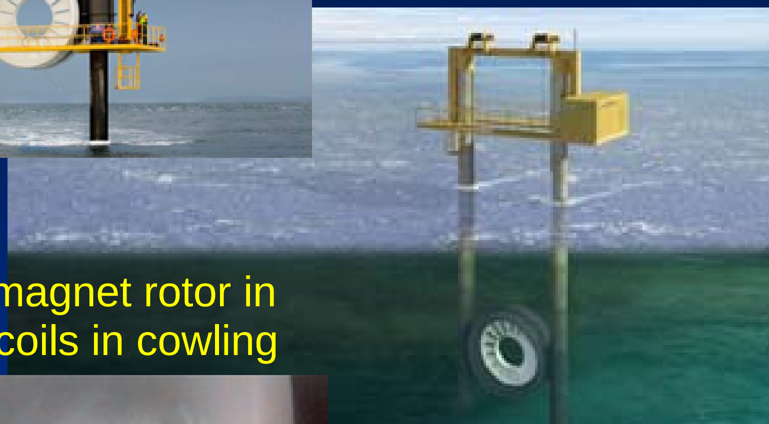
www.verdantpower.com

35 kW turbine with downstream rotor, 5-m in diameter, which yaws to accommodate reversing flow

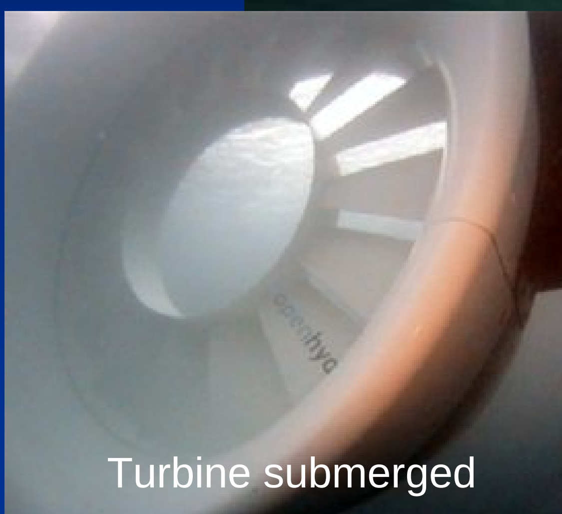
Ireland-Based OpenHydro



Rotor reverses rotation direction when tide turns



Permanent magnet rotor in rim – stator coils in cowling



Turbine submerged

First developer to use the European Marine Energy Centre tidal stream field test site in the Orkney Islands. Photos show EMEC field test rig with 6-m diameter turbine rated at 250 kW capacity.

www.openhydro.com

Turbine raised

River Current Energy

Resource characteristics

- *Stochastic (% probability forecasts) – governed by precipitation*

U.S. production potential

- *~110 TWh per year (NY University, 1986)*

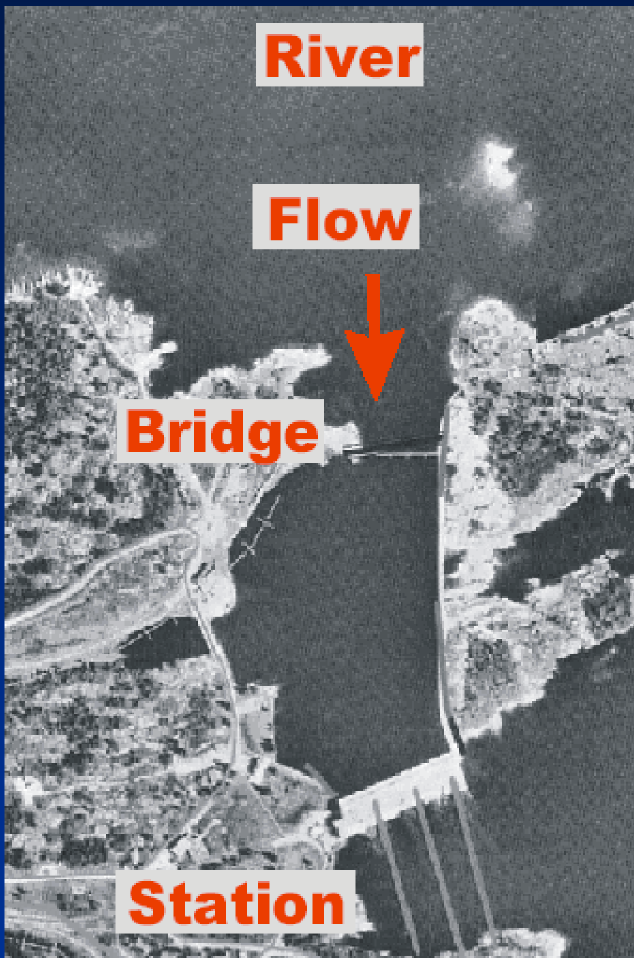
General types of conversion technology

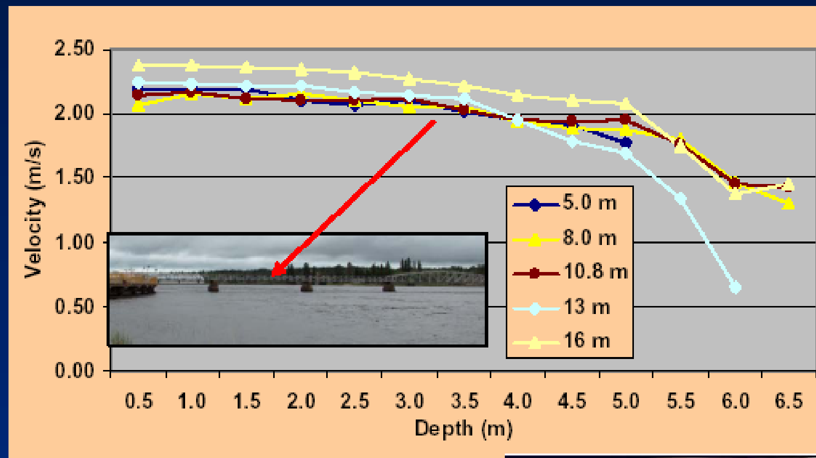
- *Underwater turbines in various configurations*

Conversion technology status

- *Same turbine technology as tidal in-stream, but <u>more difficult</u>, because there is no predictable slack water for scheduled maintenance, and there are higher suspended sediment loads, as well as greater probability of drift wood and ice*
- *<u>Advantage</u>: no flow reversal (simpler turbine & anchoring)*

US-Based Underwater Electric Kite





www.uekus.com

Demonstration project 300 m upstream of Pointe du Bois station on Winnipeg River

3-m diameter, 60 kW turbine

Ocean Current Energy

Resource characteristics

- *Gulf Stream relatively steady – stochastic variability governed by ocean-basin-scale climate changes*

U.S. production potential

- *Perhaps 3-5 TWh/yr at 10-15% utilization (DOE, 1980)*

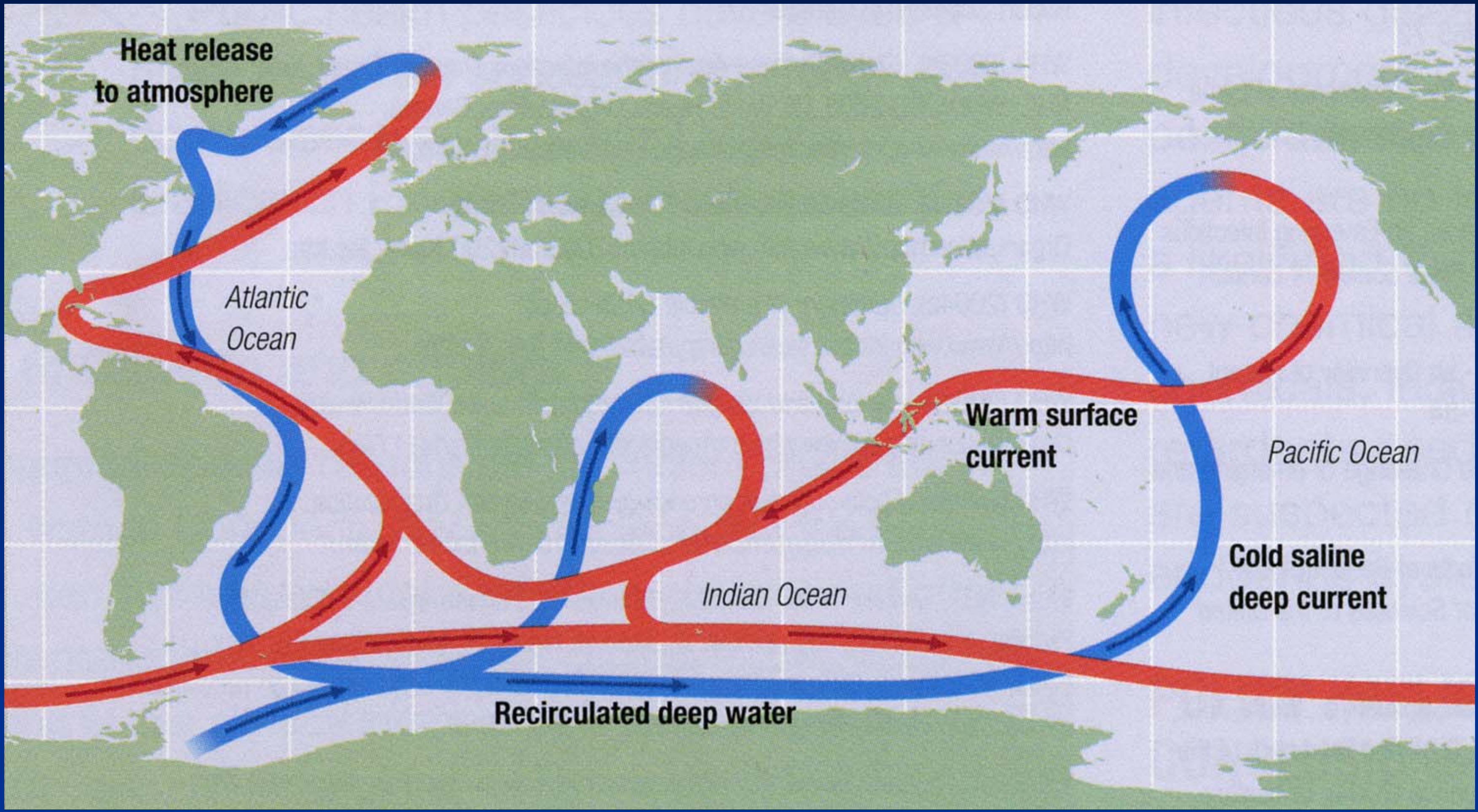
General types of conversion technology

- *Underwater turbines in various configurations*

Conversion technology status

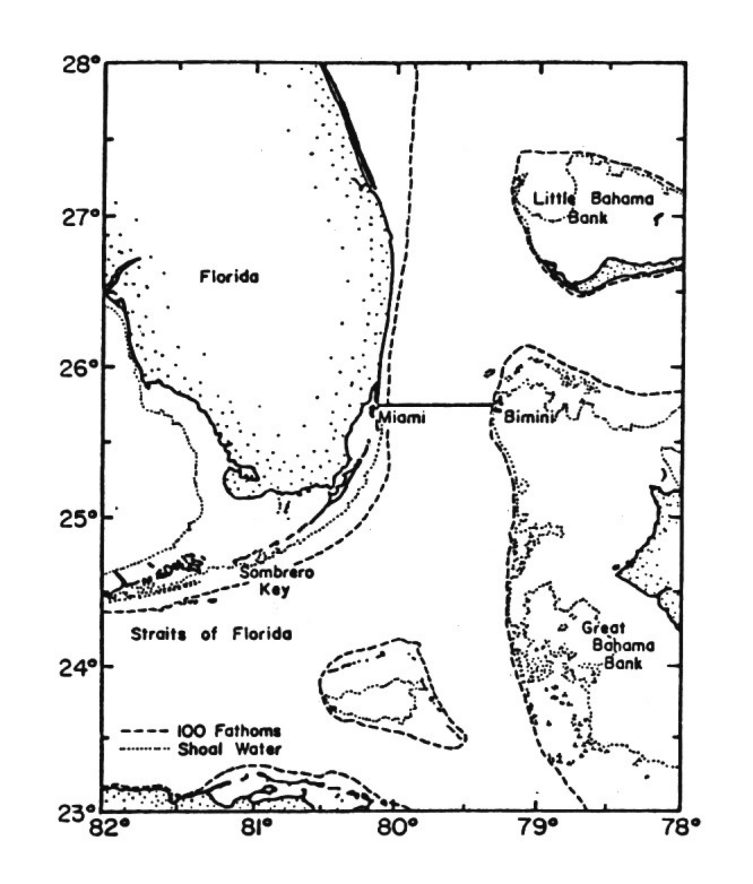
- *Challenges: potential climate impacts, no slack water, large water depths (350-450 m), long submarine cable transmission distances (20-35 km)*

Ocean Currents Move Solar Energy from Equator to Poles



Interaction with global warming could be substantial; still being researched

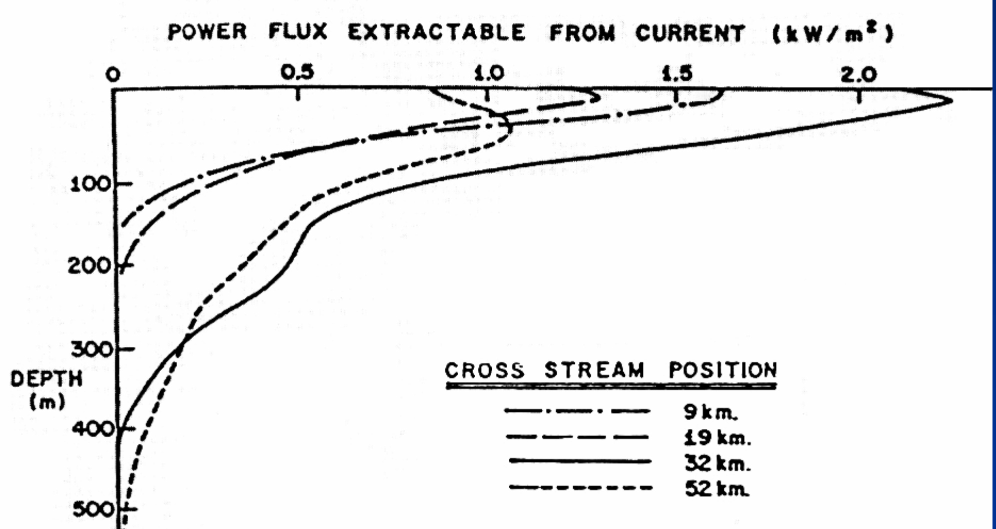
Florida Current Resource



Engineering challenges:

- No slack water
- 300-500 m mooring depths
- 20-25 km offshore

Resource utilization may be constrained by climate change concerns



Average Florida Current power density profiles from ~1980 studies funded by U.S. DOE for *Coriolis* Project

Ocean Wave Energy

Resource characteristics

- *Stochastic – governed by local winds and offshore storms*

U.S. production potential

- *250-260 TWh per year (EPRI, 2004)*

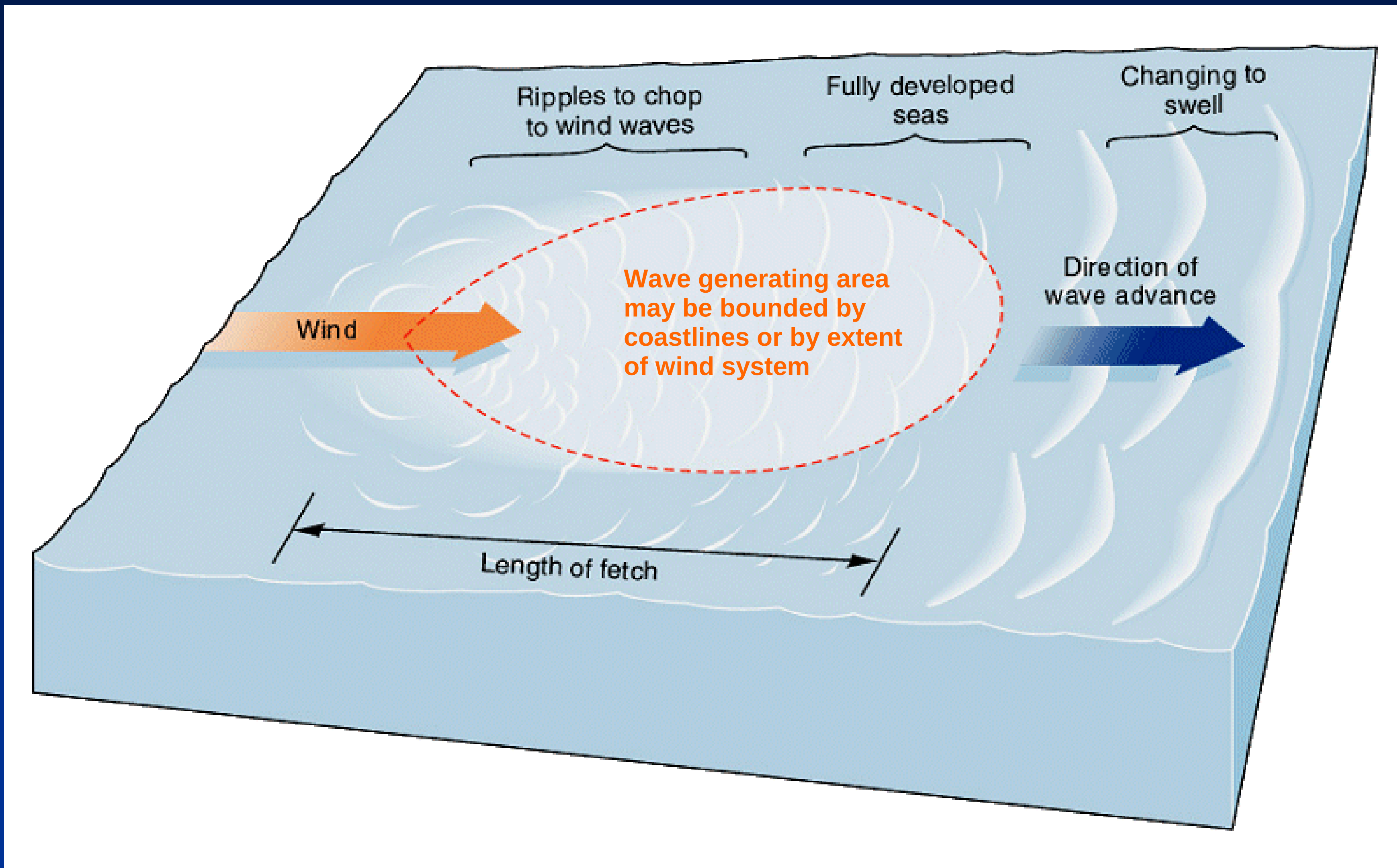
General types of conversion technology

- *Highly diverse alternatives; classified into Terminators, Attenuators, and Point Absorbers*

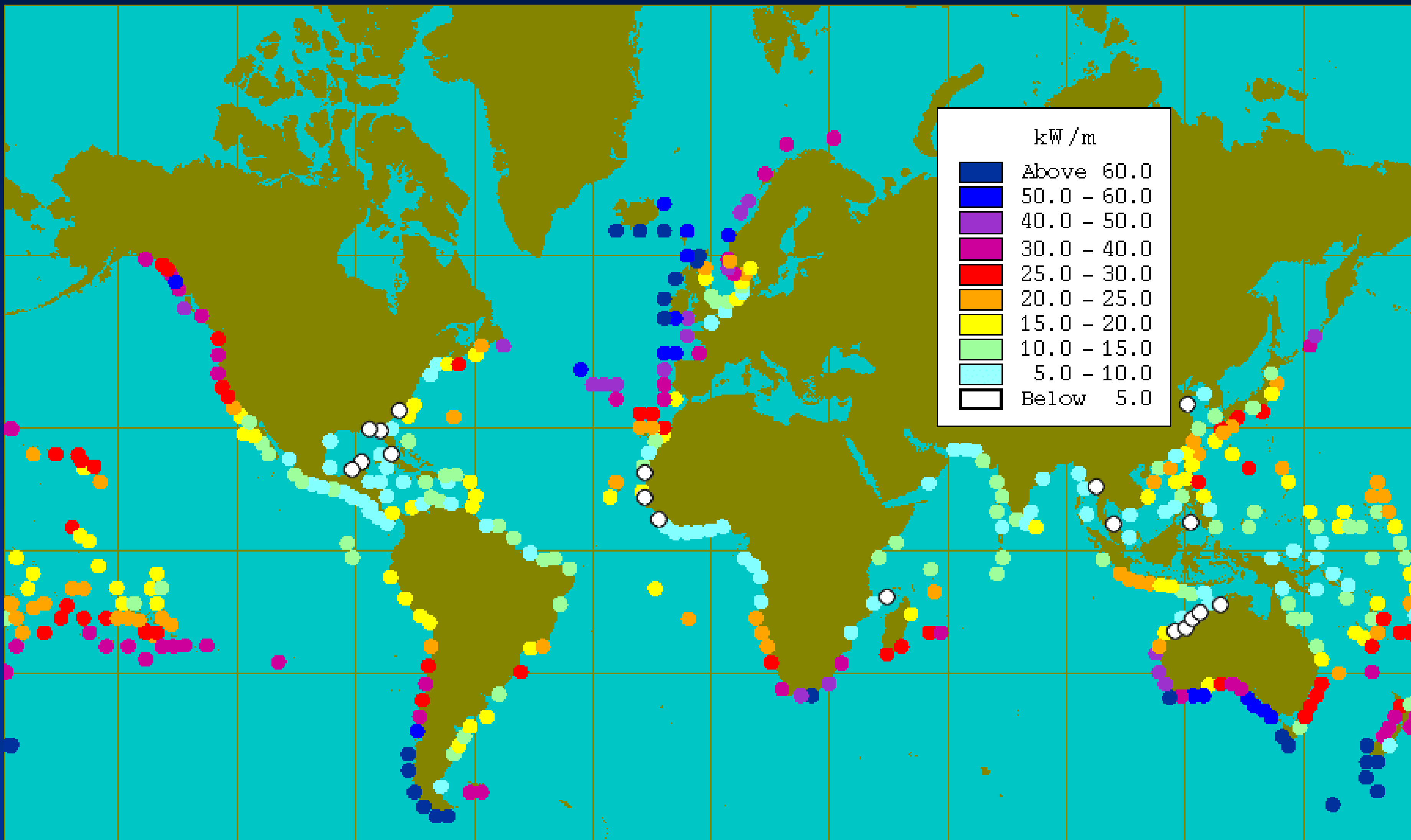
Conversion technology status

- *Has yet to converge on single best technical approach (if such exists)*

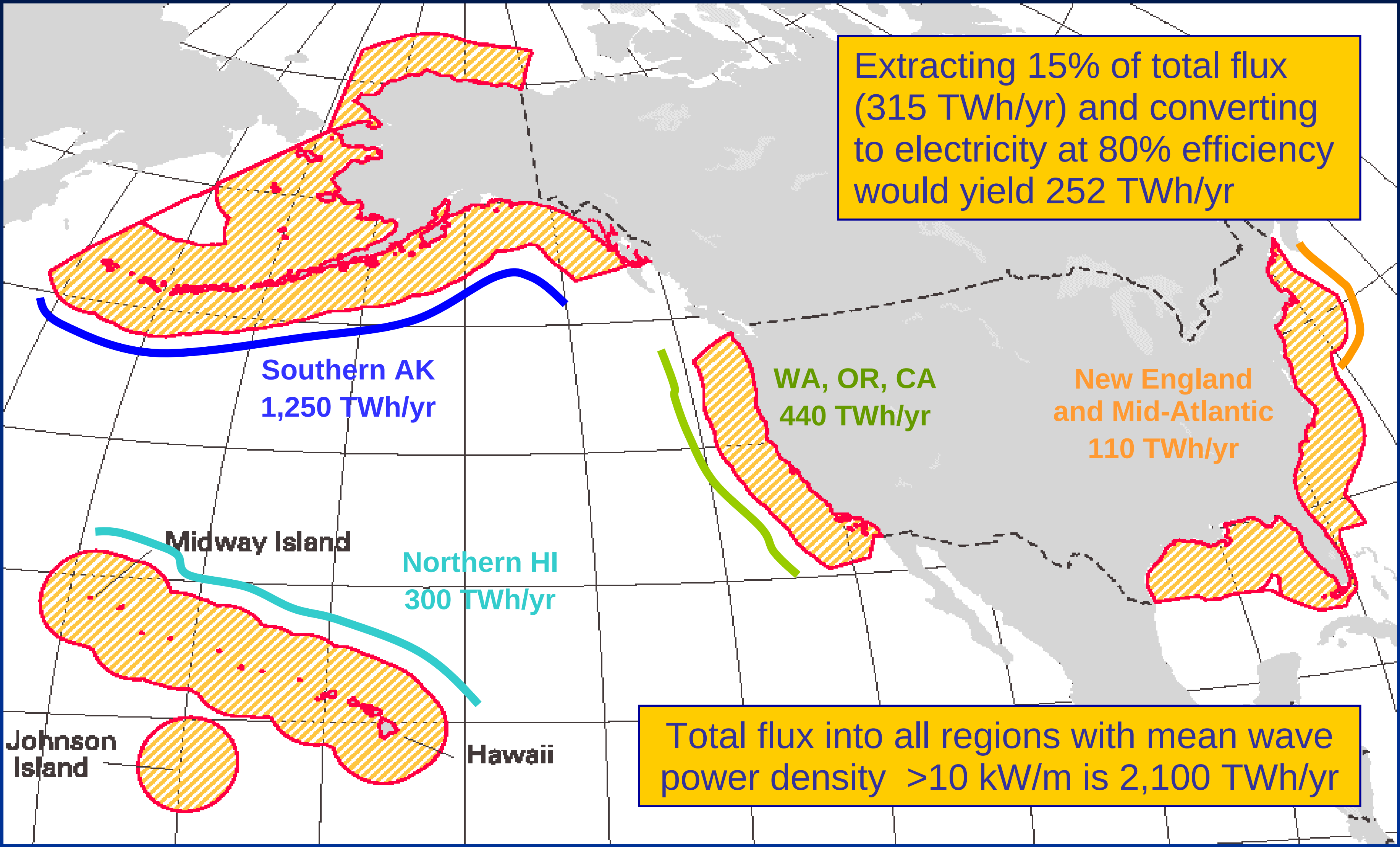
Waves Governed by Wind Over Water



Global Wave Energy Flux Distribution



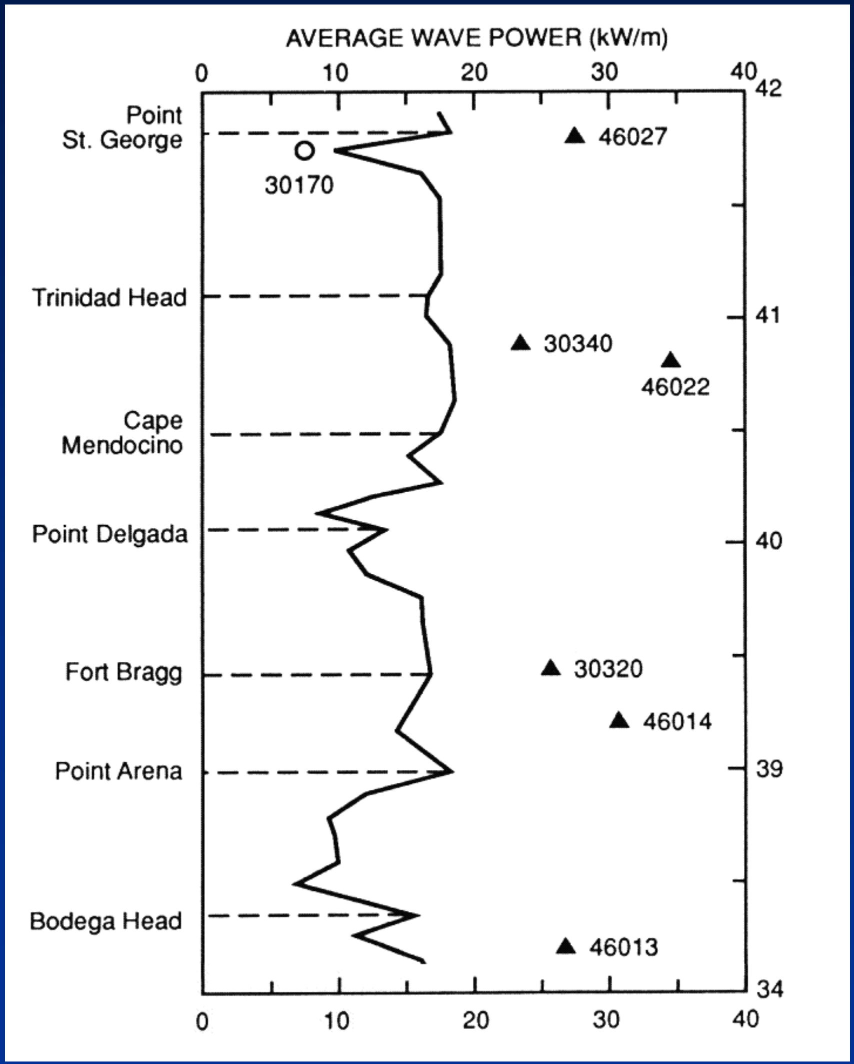
U.S. Offshore Wave Energy Resources

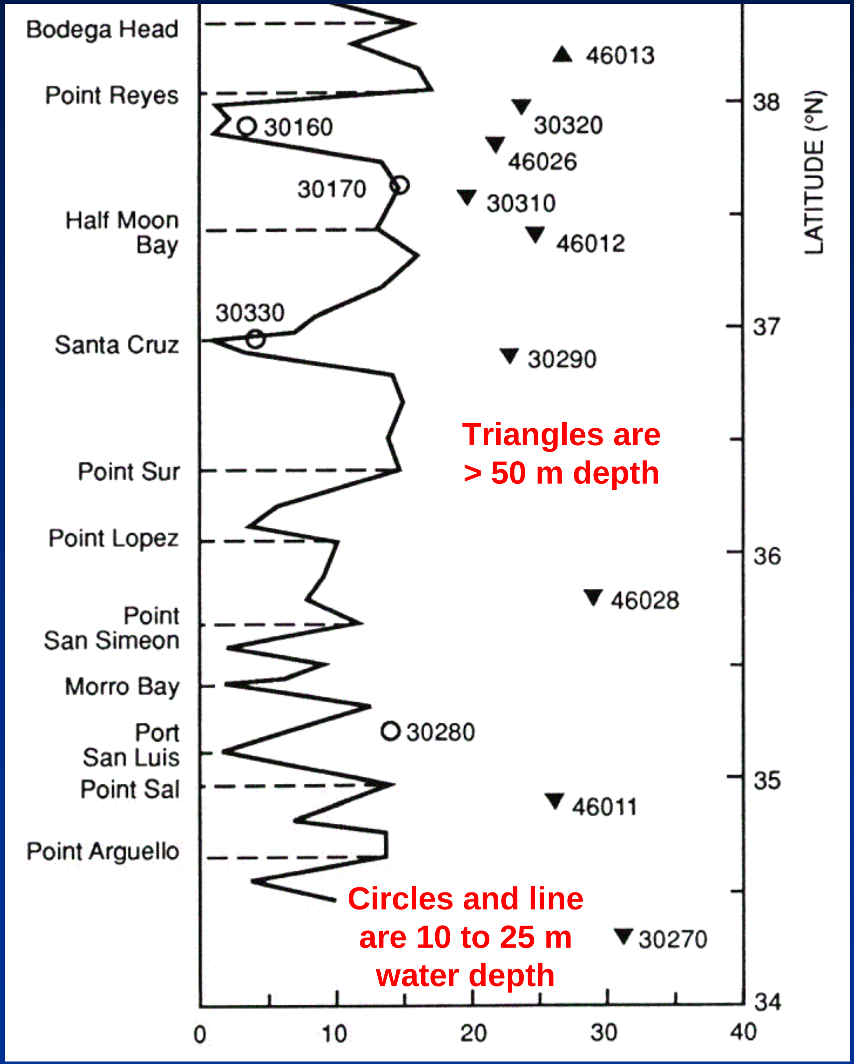


Extracting 15% of total flux (315 TWh/yr) and converting to electricity at 80% efficiency would yield 252 TWh/yr

Total flux into all regions with mean wave power density >10 kW/m is 2,100 TWh/yr

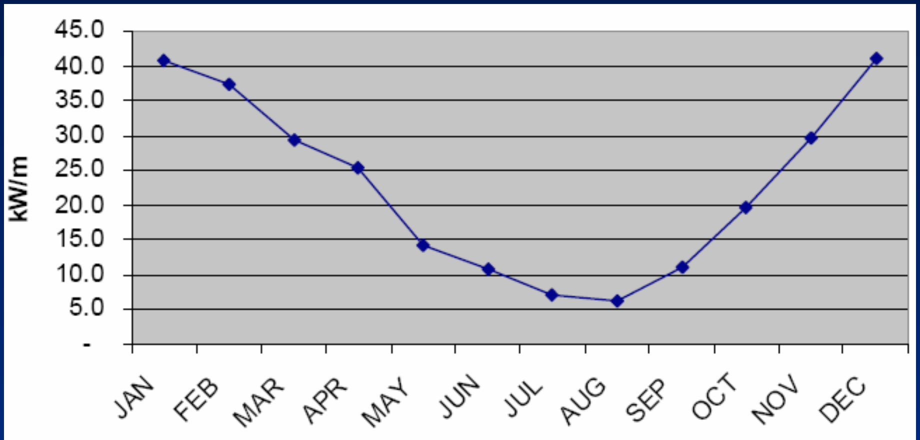
Power Densities Less Variable Offshore, More Variable Near Shore



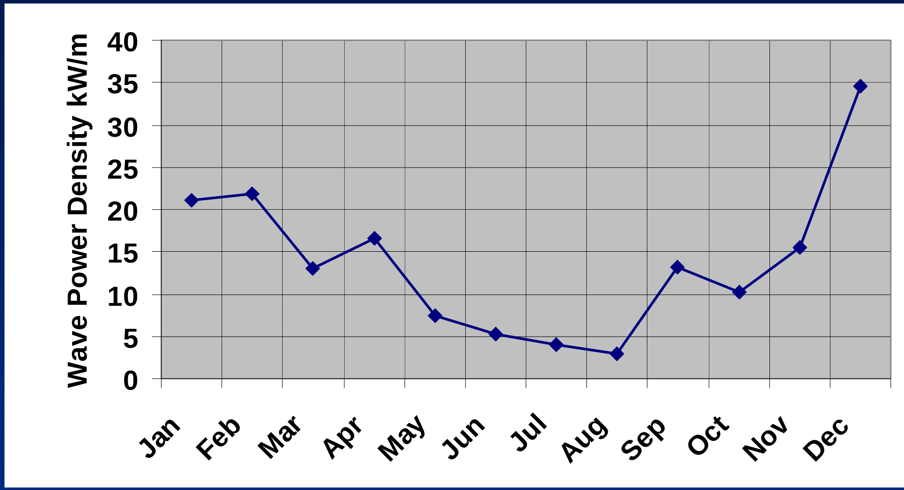


Substantial Seasonal Variability

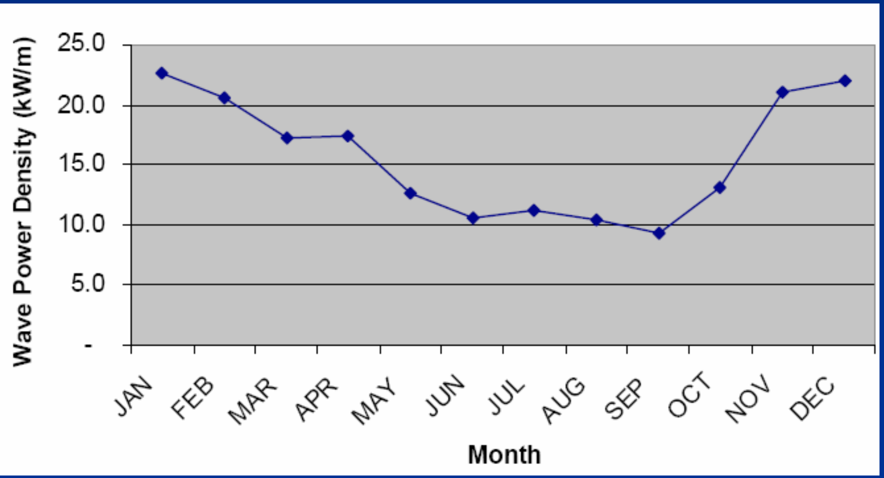
West Coast (Oregon)



East Coast (Massachusetts)



Hawaii



Wave Energy Devices Highly Diverse

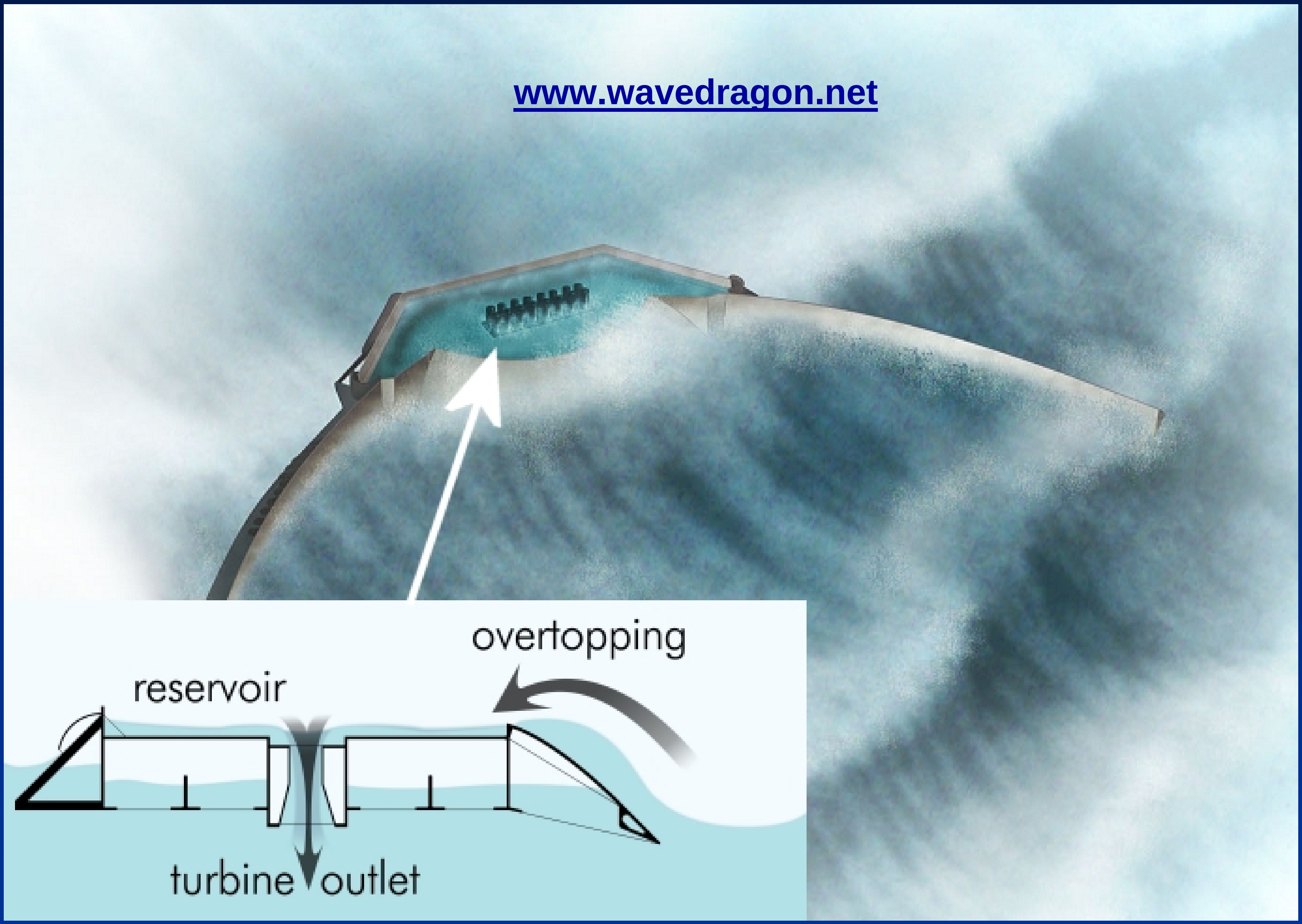
Fixed Oscillating Water Column
Terminator (Oceanlinx)

Floating **Attenuator** (*Pelamis*)

Floating Overtopping
Terminator (*Wave Dragon*)

Floating
Point Absorber
(*AquaBuOY*)

Overtopping Terminator: *Wave Dragon*



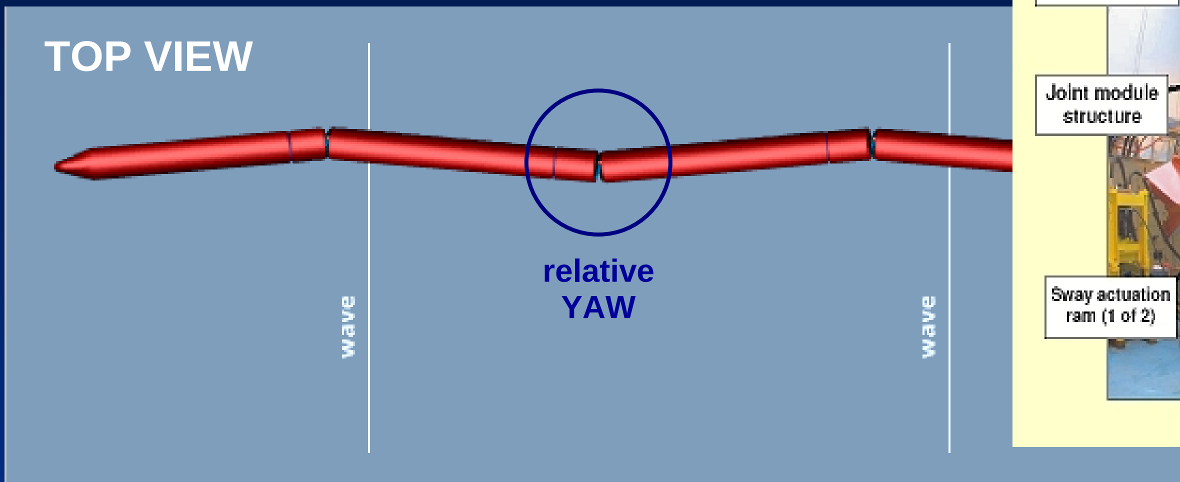
Wave Dragon Prototype Trials

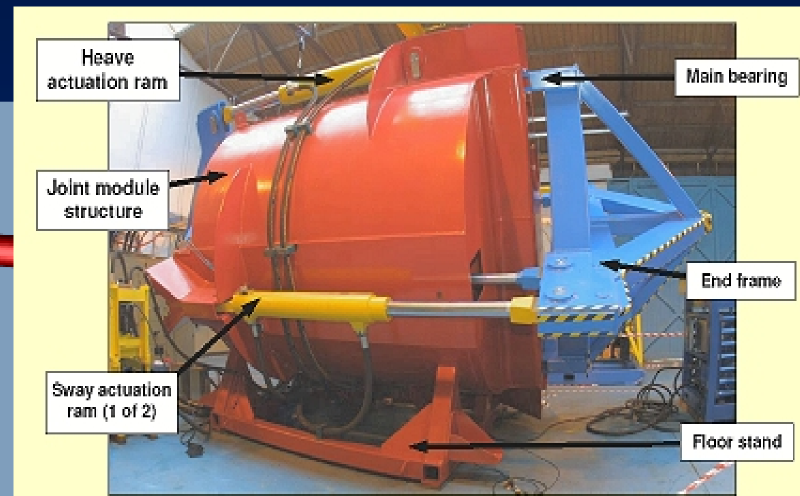
Prototype is 58 m wide (between tips of funneling side walls) and 33 m long, with a reservoir volume of 55 m^3 and a displacement of 237 metric tons. Total rated capacity is 17.5 kWe.

Funneling side walls are moored separately from central floating reservoir.

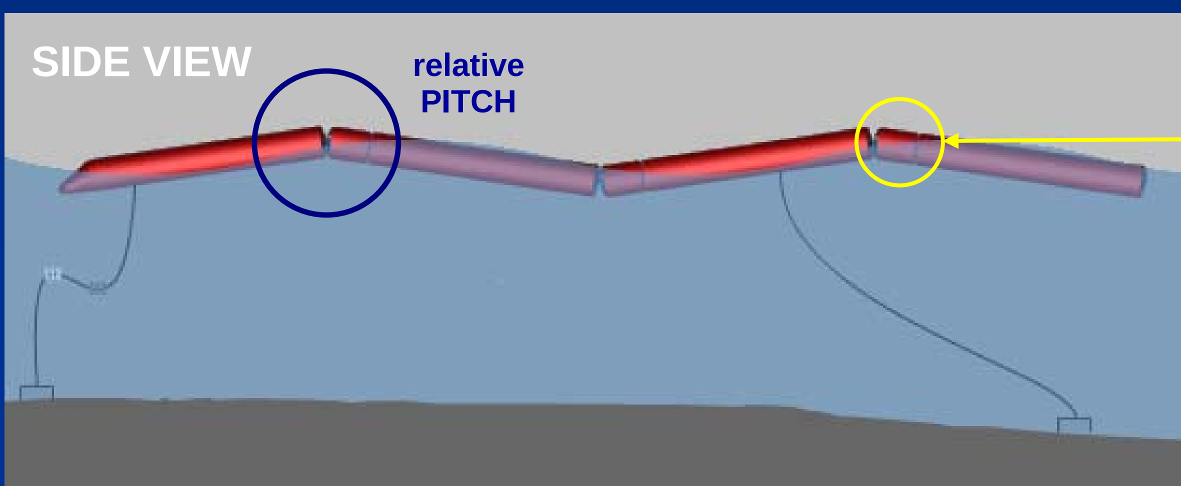
Floating Attenuator: *Pelamis*

www.oceanpd.com





Full-scale joint test rig at Edinburgh facility.



Power module at front of each tube section contains two hydraulic cylinders that are stroked by relative pitch and yaw between adjacent sections

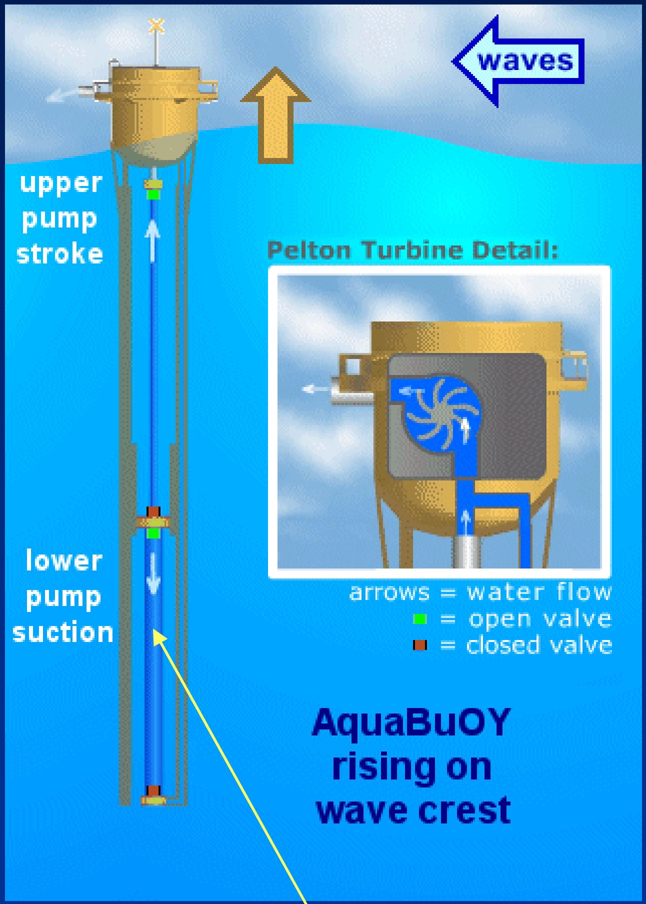
Pelamis Sea Trials and Pilot Plant

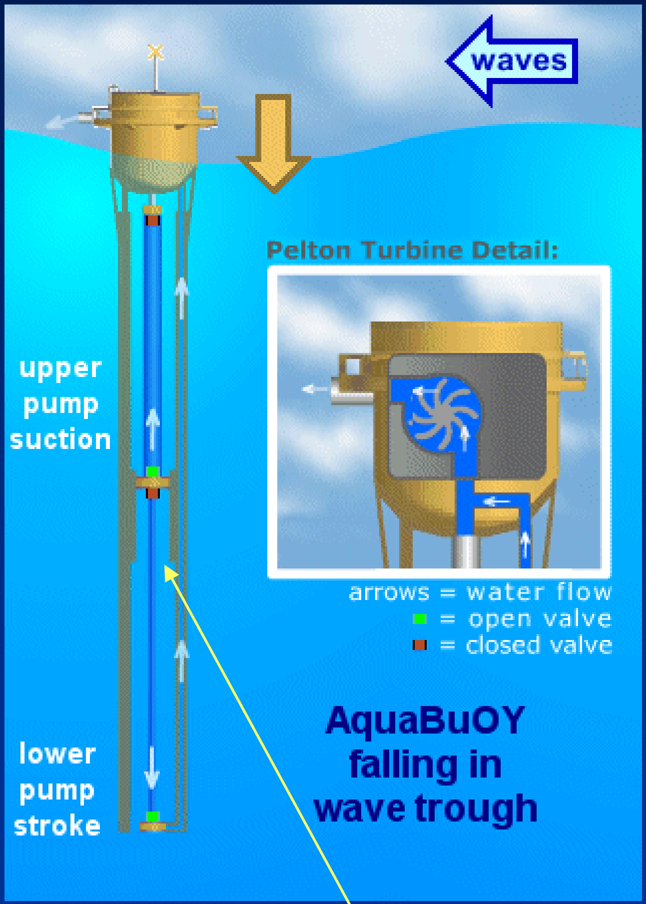
Three 750 kW modules to be installed summer 2007 in 2.25 MW pilot plant off northern Portugal

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

Point Absorber: *AquaBuOY*

http://finavera.com/en/wavetech

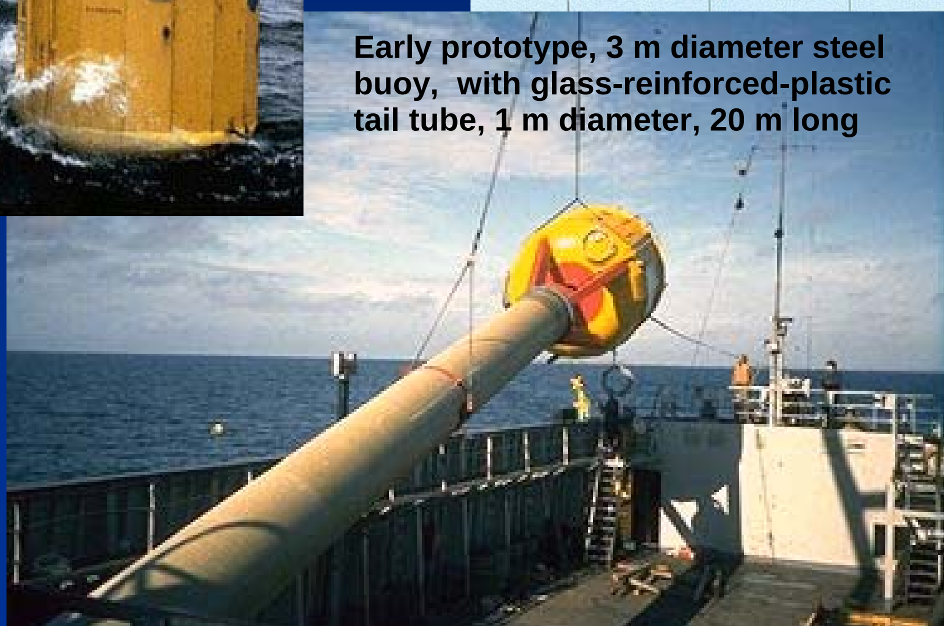




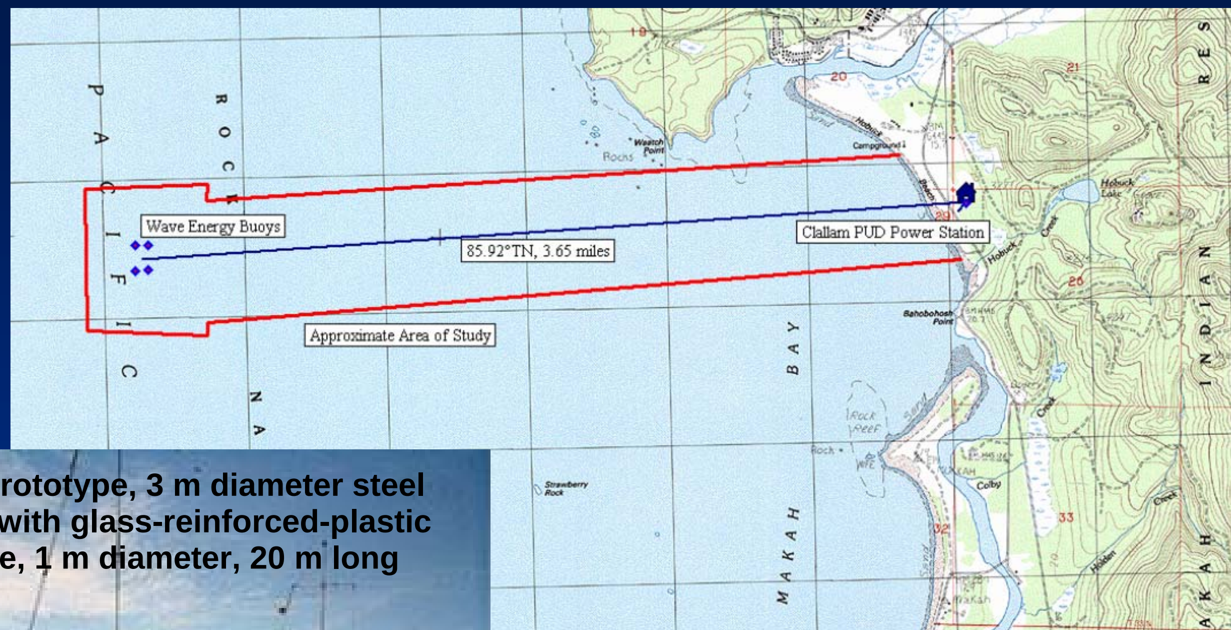
Hose pump inner diameter contracts when stretched, expands when relaxed

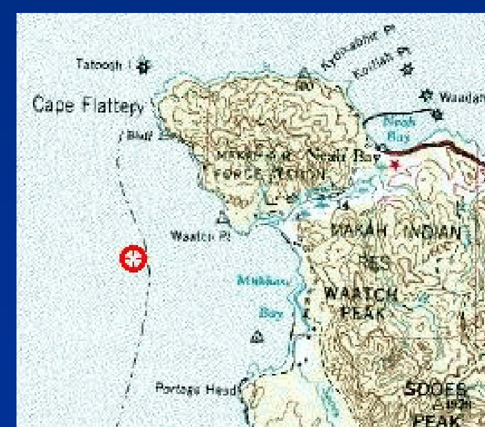
Inertia of seawater trapped above or below piston in tube provides reaction point for hose to stretch as buoy heaves up or down

AquaBuOY 1 MW Project to be Installed off Makah Bay, Washington



Early prototype, 3 m diameter steel buoy, with glass-reinforced-plastic tail tube, 1 m diameter, 20 m long



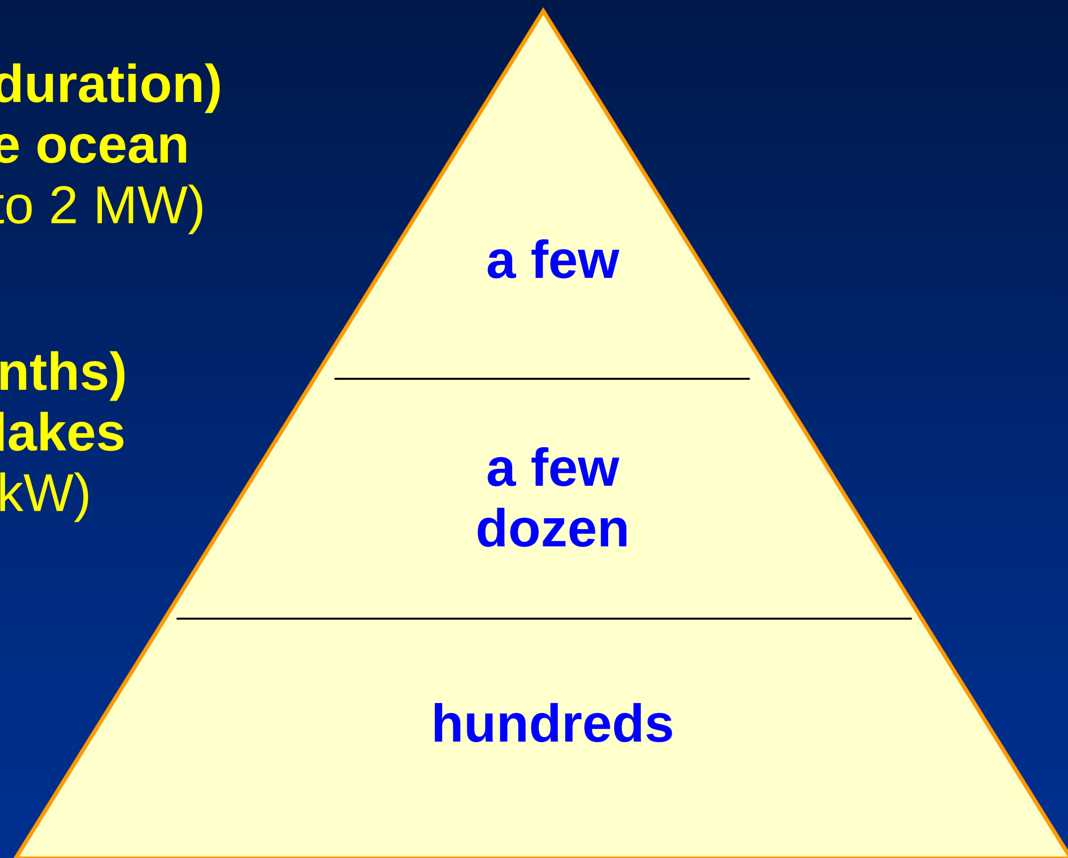


Technology Development Pyramid

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

Short-term (days to months) tests in rivers, bays or lakes
(typically 10 kW to 100 kW)

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



It typically takes 5 to 10 years for a technology to progress from concept-only (not in pyramid) to deployment of a long-term prototype

Summary Points

Basic oceanography is well understood, but detailed mapping remains to be done, and “extractable” resource (percent that can be utilized) requires further research

Harnessing of currents by underwater turbines is most advanced in tidal stream applications due to the highly predictable nature of tides, including slack water

Gulf Stream presents much greater engineering challenges and possible climate change concerns

Ocean wave energy technology is less mature, but many prototype and full-scale units are now operating at sea

Wave energy devices have yet to converge on single best approach (if such exists), with wide variety of designs among terminators, attenuators, and point absorbers

Thank You!

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