
FERC TECHNICAL CONFERENCE
Hydroelectric Generation from
Ocean Waves, Tides & Currents
and from Free-Flowing Rivers
Wednesday, December 6, 2006
1:00 pm– 5:00 pm
Commission Meeting Room

Energy from Waves, Tides, Ocean Currents, and Free-Flowing Rivers:

An Overview of Resource, Technology, and Business Issues

Federal Energy Regulatory Commission
Washington, DC

06 Dec 2006

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Oceanographer, EPRI Ocean Energy Team

Two Basic Forms of Energy

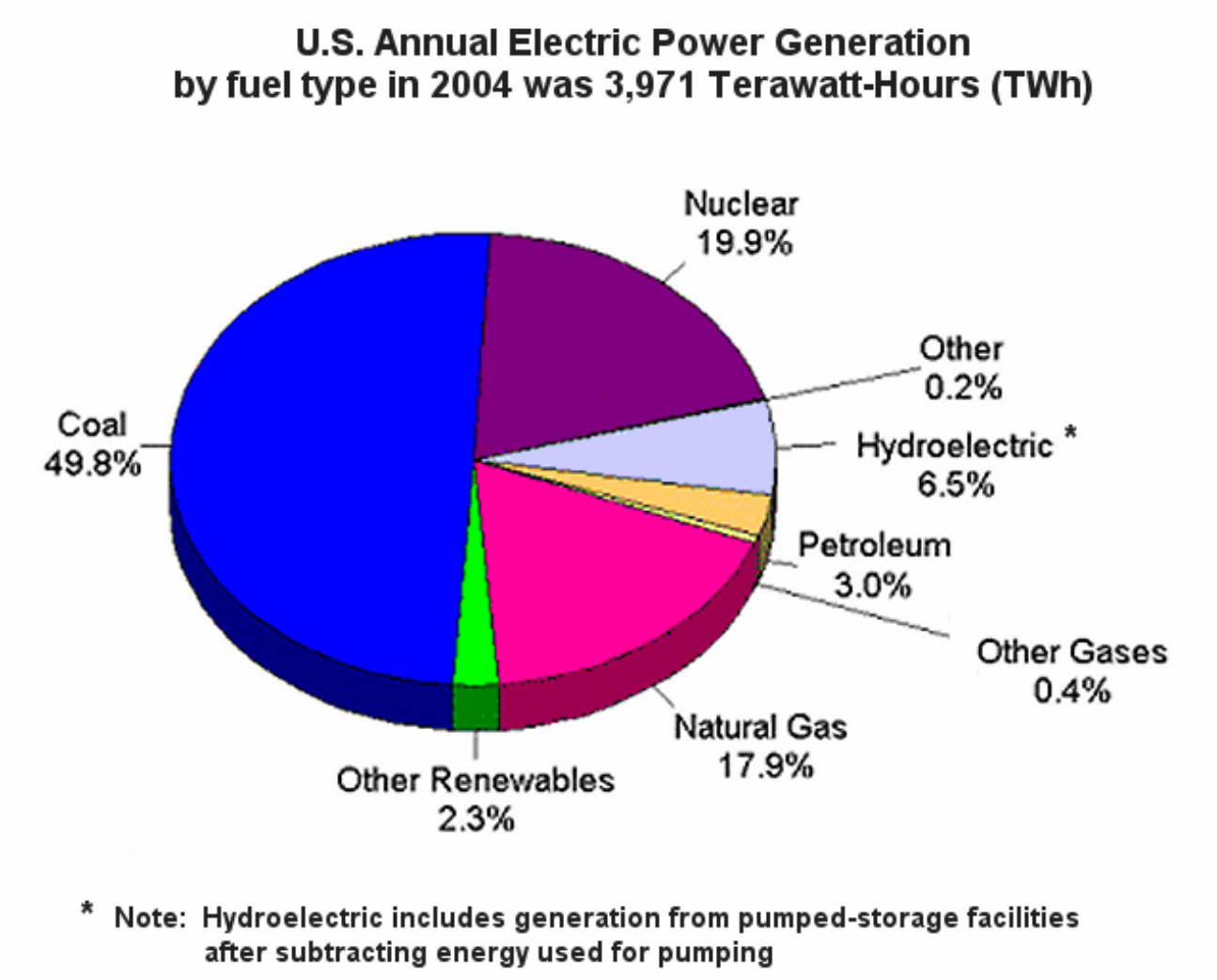
CURRENTS

- 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

Wave and Current Energy Potential



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

Wave and current generation potential

- *Offshore wave energy 250-260 TWh/yr if 15% utilized*
- *Tidal, river, and ocean currents >110 TWh/yr*

Credible potential to meet nearly 10% of national demand

Advantages of Wave and Current Energy

With proper siting and early stakeholder involvement, among the most environmentally benign of known electricity generation technologies

Minimizes NIMBY – submerged or barely visible

No emissions – including CO_2

Sustainable job creation and new business opportunities for maritime communities

Decrease national dependence on foreign fuel suppliers and reduce risk of future fuel price volatility

Increases diversity of electricity energy supply portfolio

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

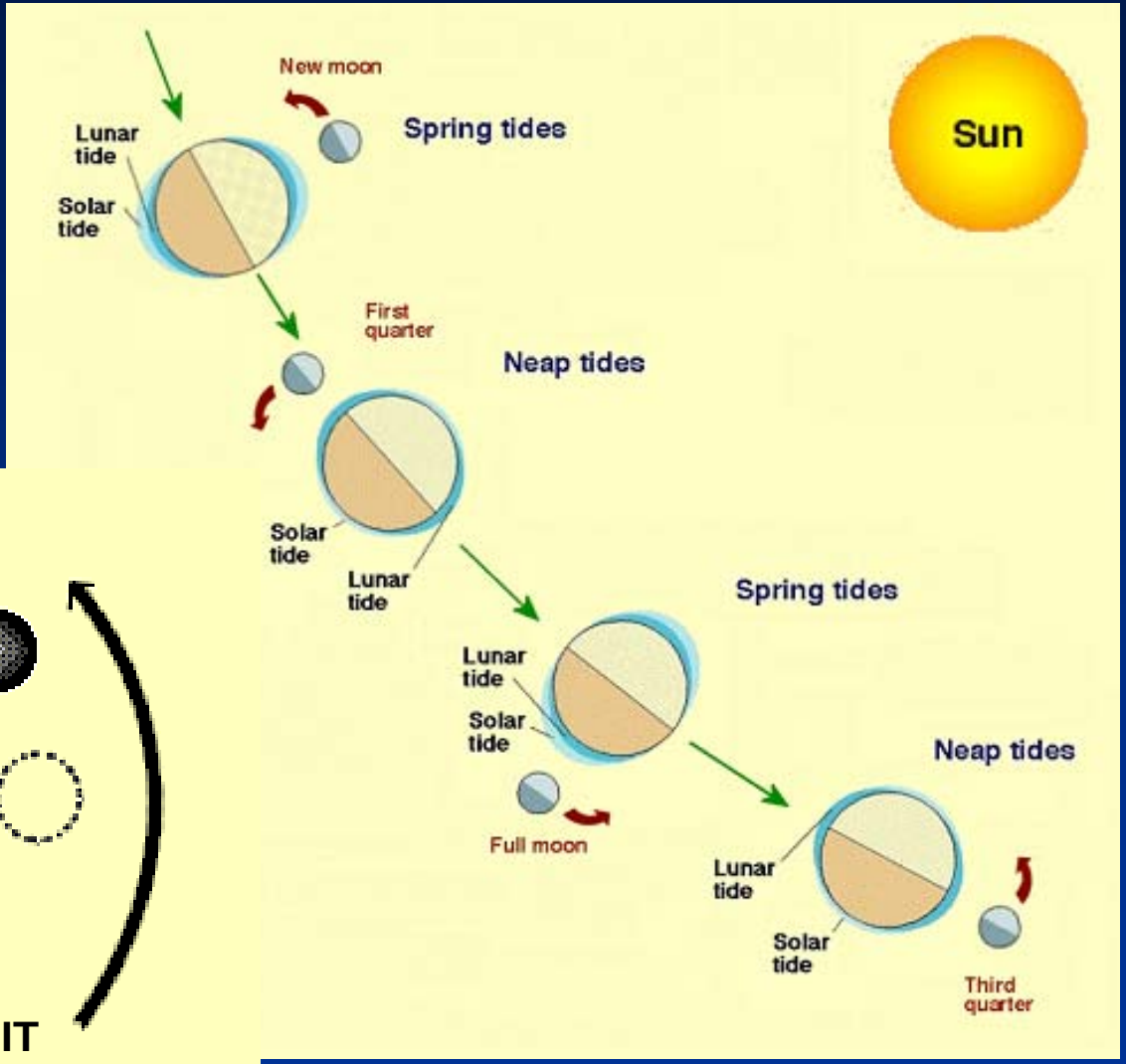
- *Underwater turbines in various configurations*

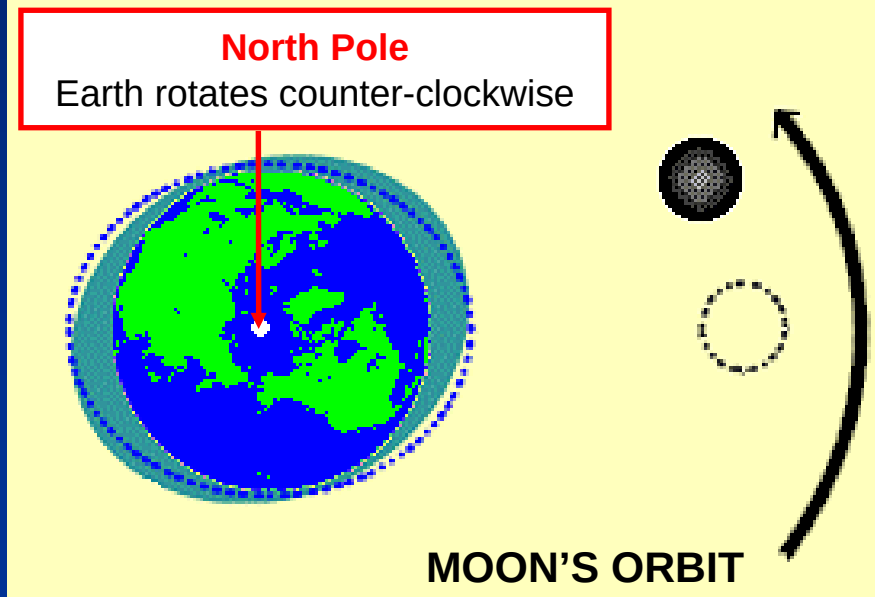
Conversion technology status

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

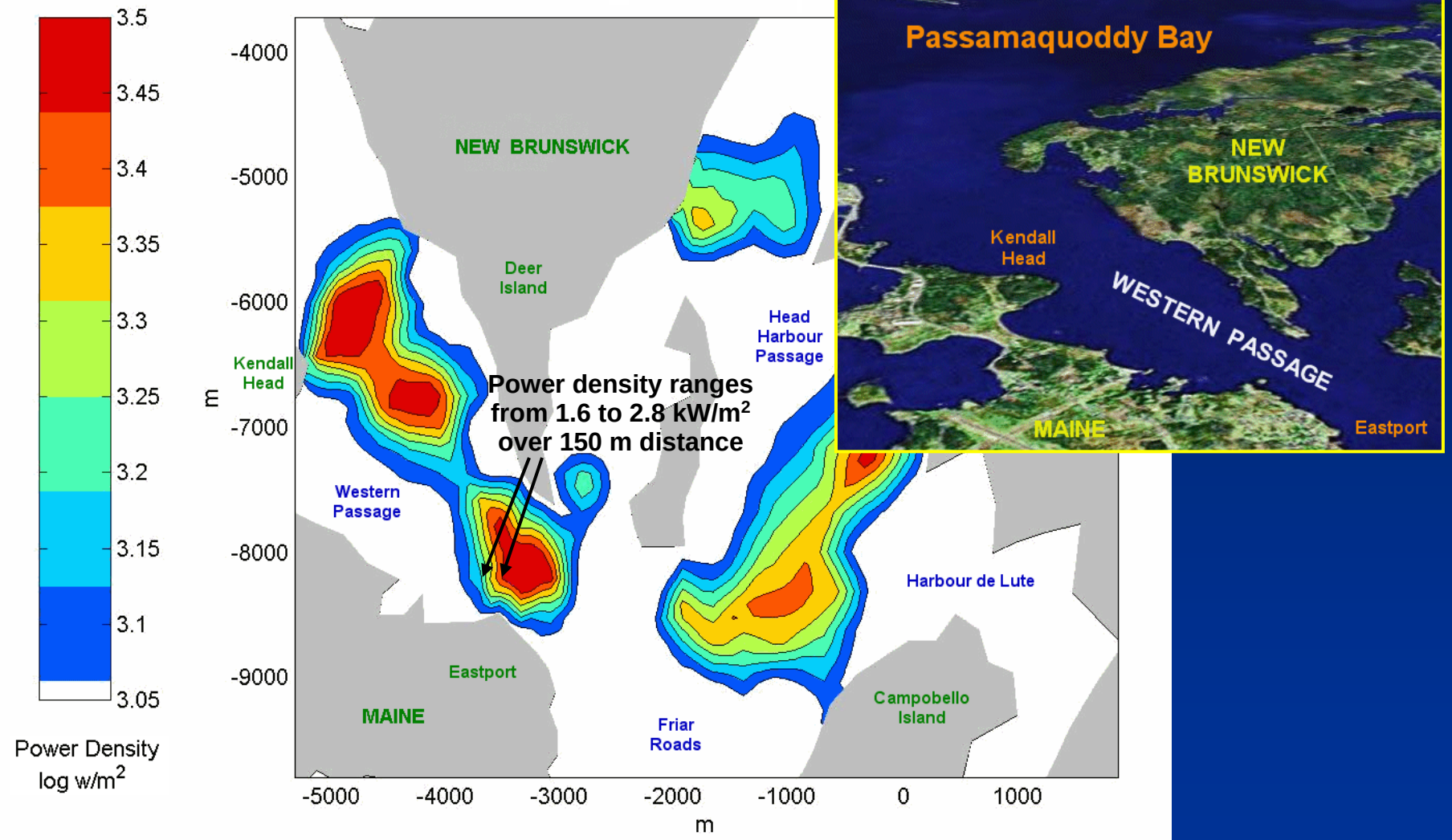
Tides Governed by Earth-Moon-Sun

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

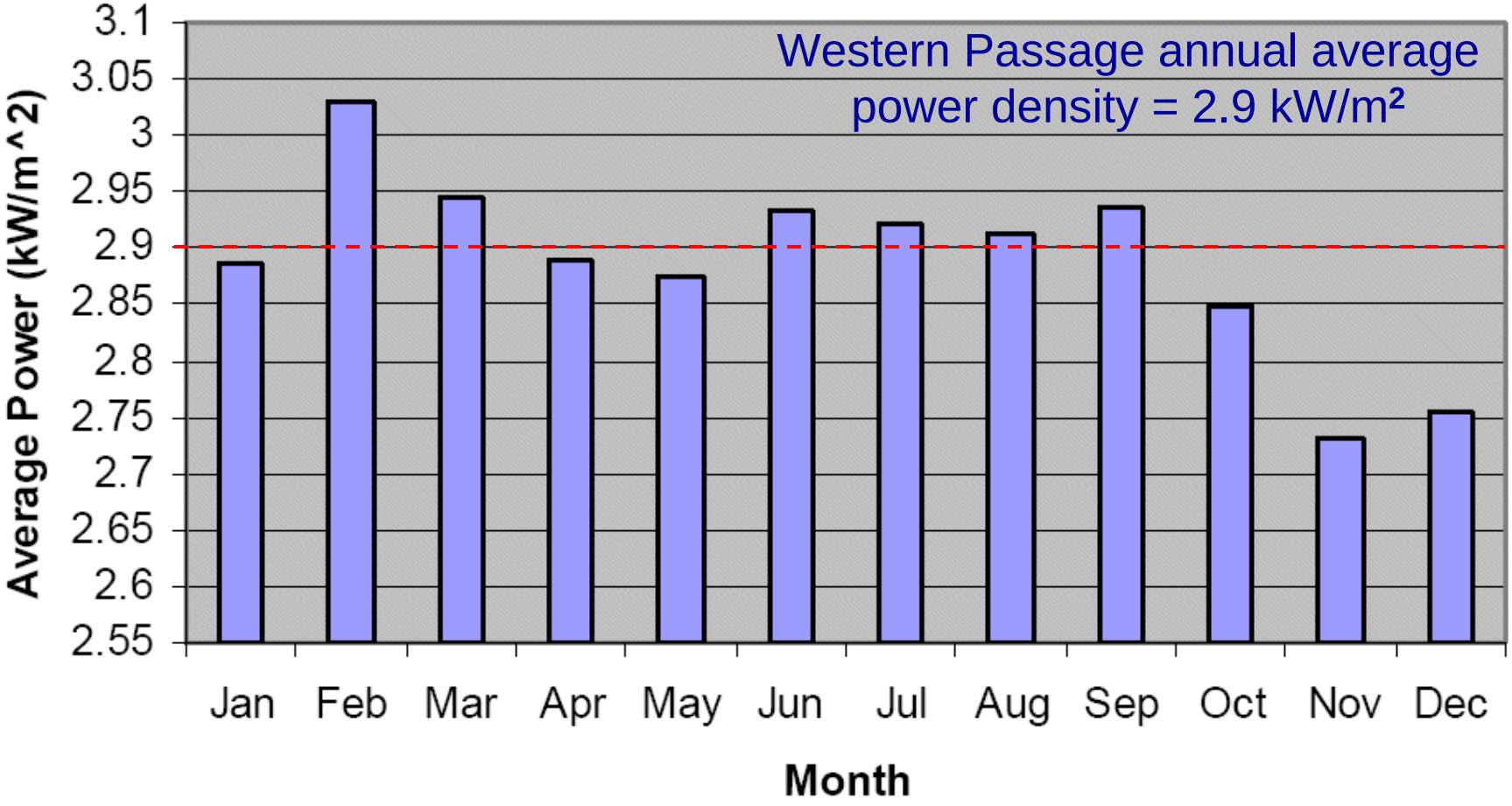




Power Densities Highly Localized

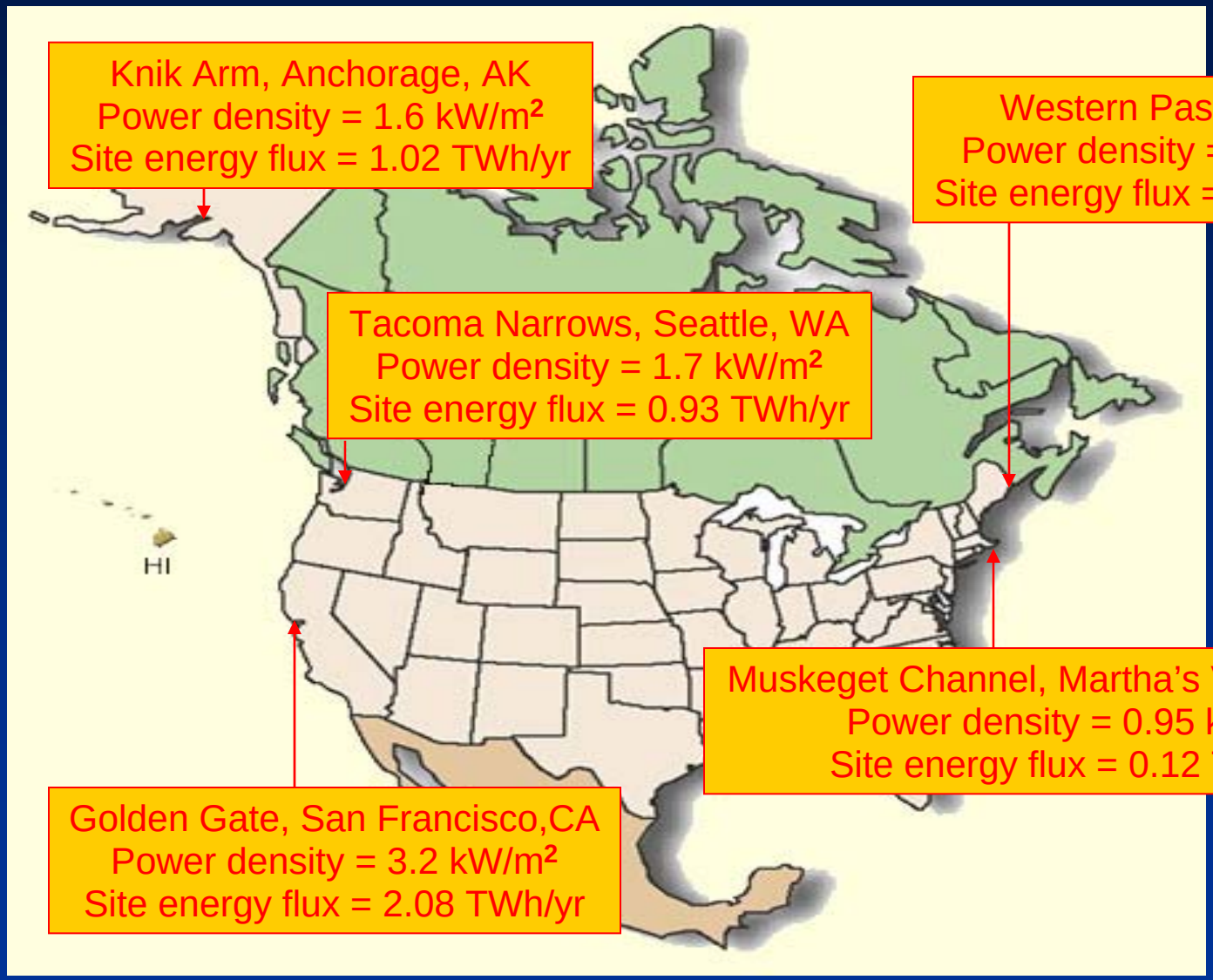


No Significant Seasonal Trend



Apparent seasonal pattern actually shifts forward by 48 days each year

Tidal Stream Resources at EPRI Study Sites



Tidal Current Turbines

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

- GCK (vertical-axis, Gorlov helical rotor)
- Lunar Energy (h-axis, shrouded rotor)
- Marine Current Turbines (h-axis, open rotor)

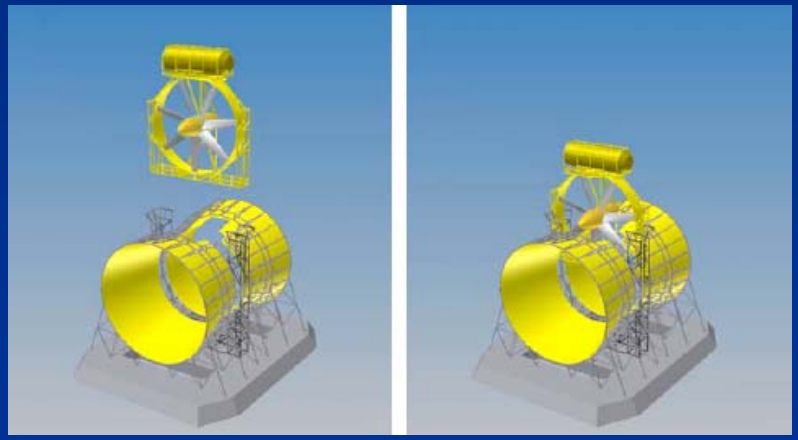
- Open Hydro (h-axis, open rotor, rim-drive)
- SeaPower (vertical axis, Savonius rotor)
- SMD Hydrovision (h-axis, open rotor)

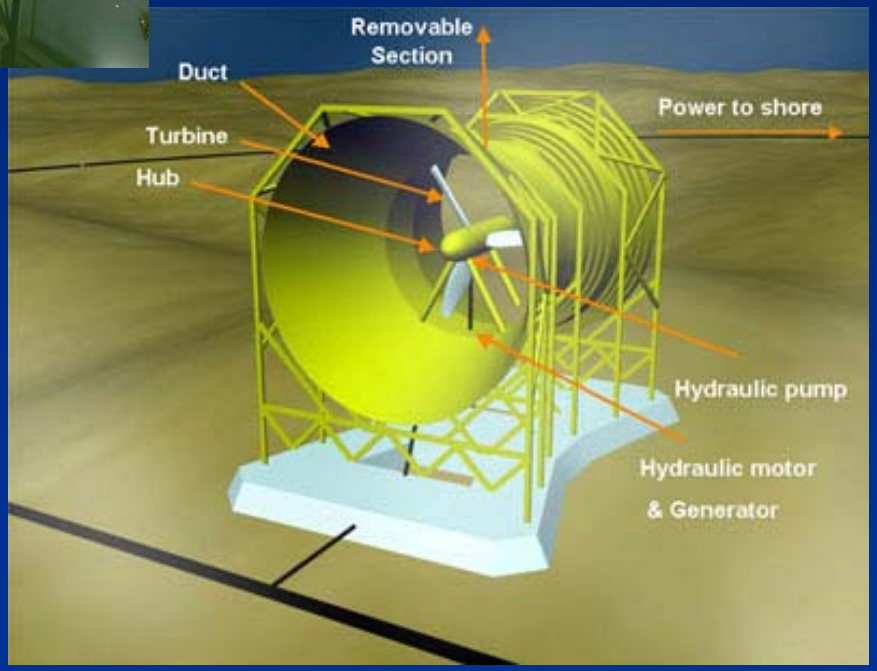
- UEK (h-axis, shrouded rotor)
- Verdant Power (h-axis, open rotor)

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

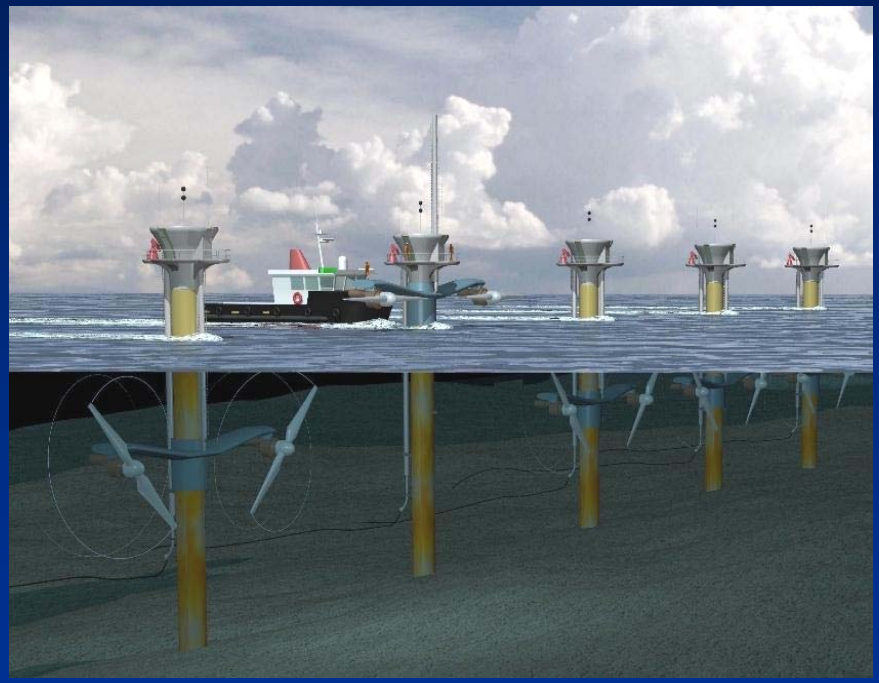




UK-Based Marine Current Turbines

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

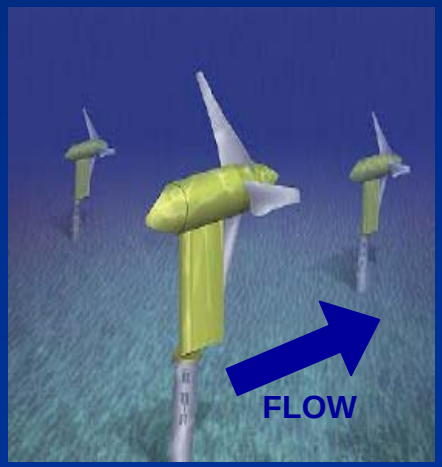
Upstream, two-blade rotor; blades pitch 180° to accommodate reversing flow



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 being installed Nov-Dec 2006 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

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 update, building on successful tidal stream study in 2006)*

General types of conversion technology

- *Underwater turbines in various configurations*

Conversion technology status

- *Challenges: no predictable slack water, higher suspended sediment loads, greater probability of drift wood and ice*

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)*

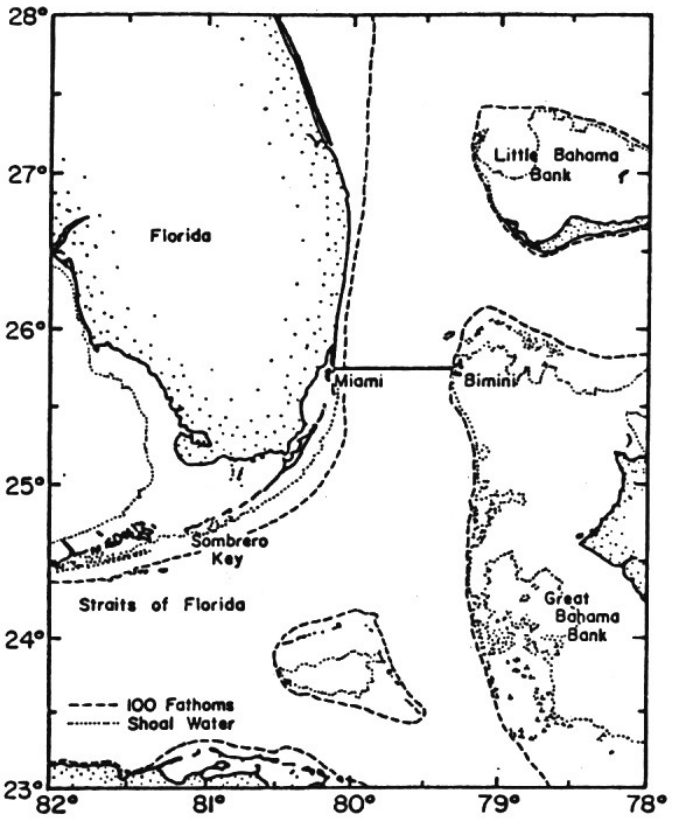
General types of conversion technology

- *Underwater turbines in various configurations*

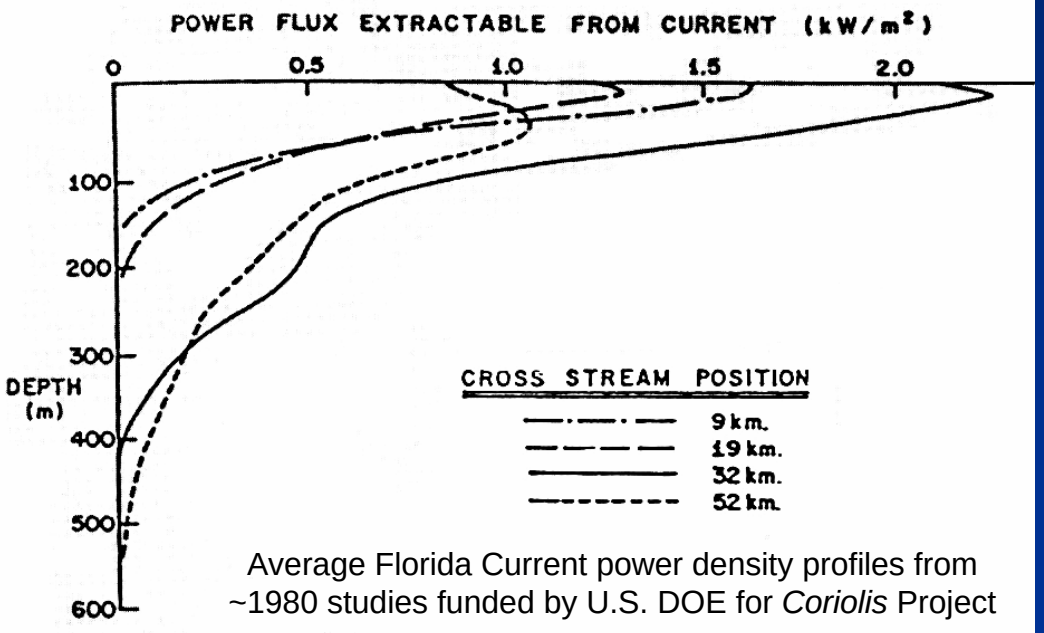
Conversion technology status

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

Florida Current Resource



Maximum percentage of base resource that can be utilized will 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)*

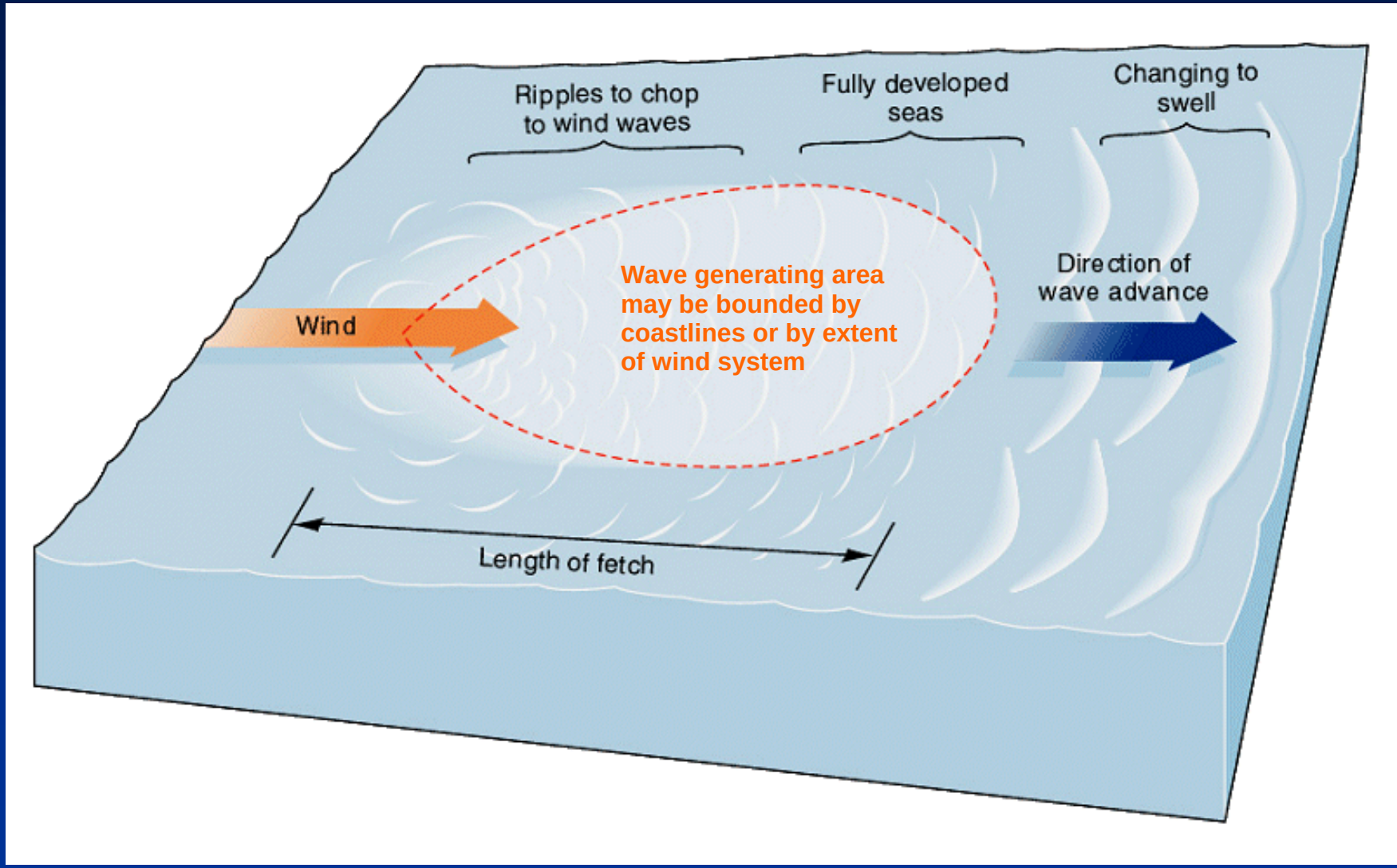
General types of conversion technology

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

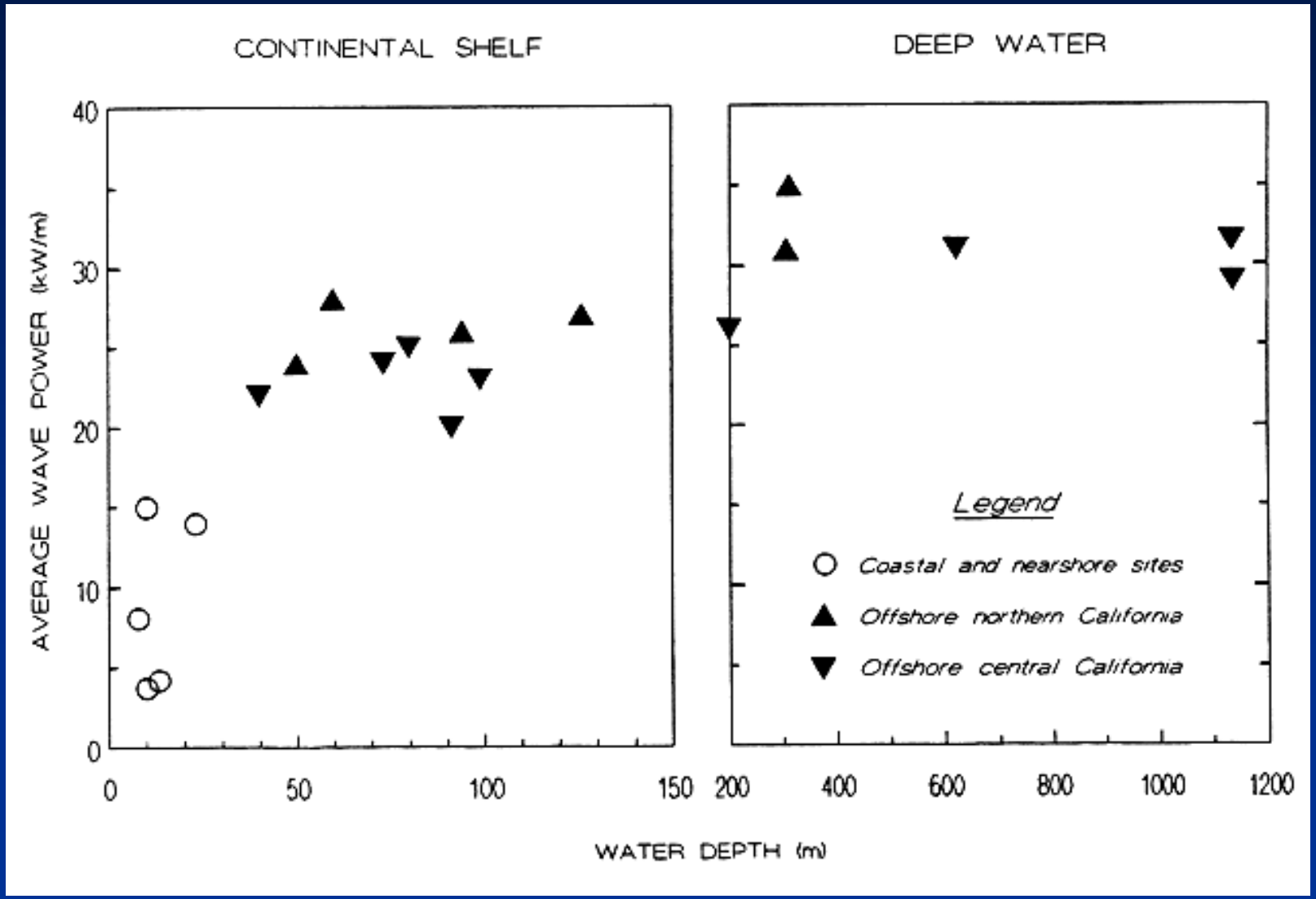
Conversion technology status

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

Waves Governed by Wind Over Water

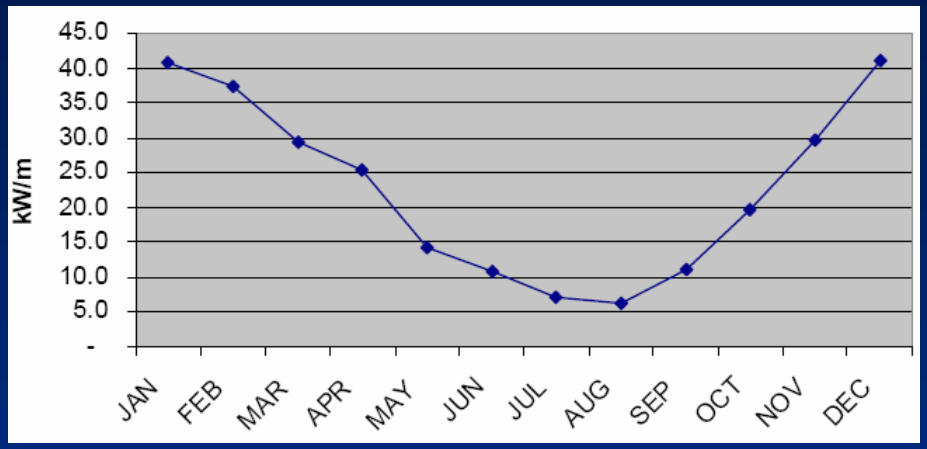


Offshore Power Densities Broadly Distributed in Depths > 50 m

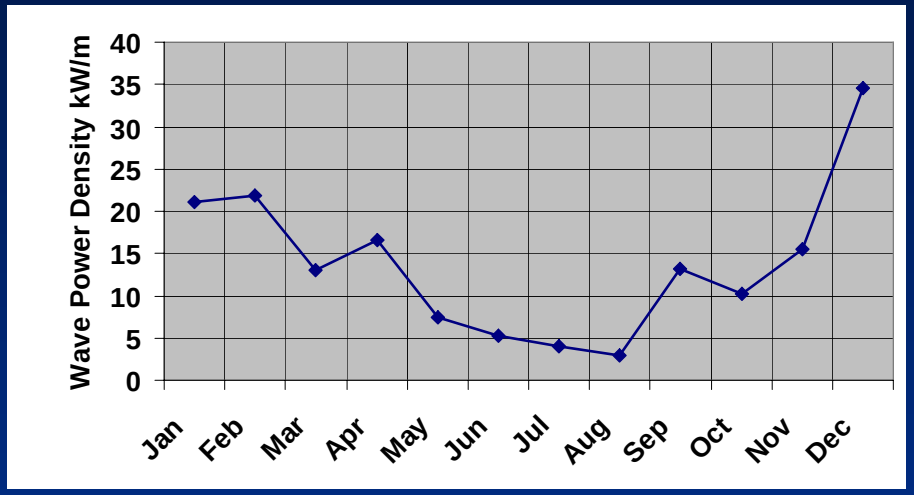


Substantial Seasonal Differences

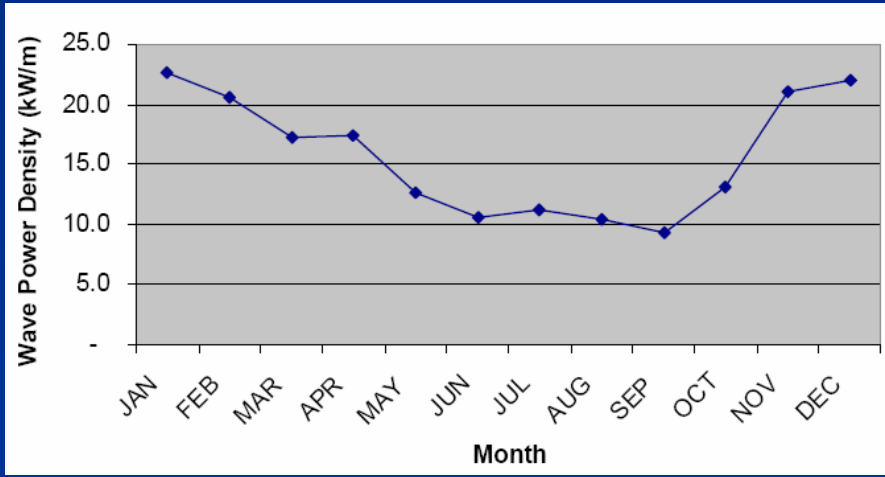
West Coast (Oregon)



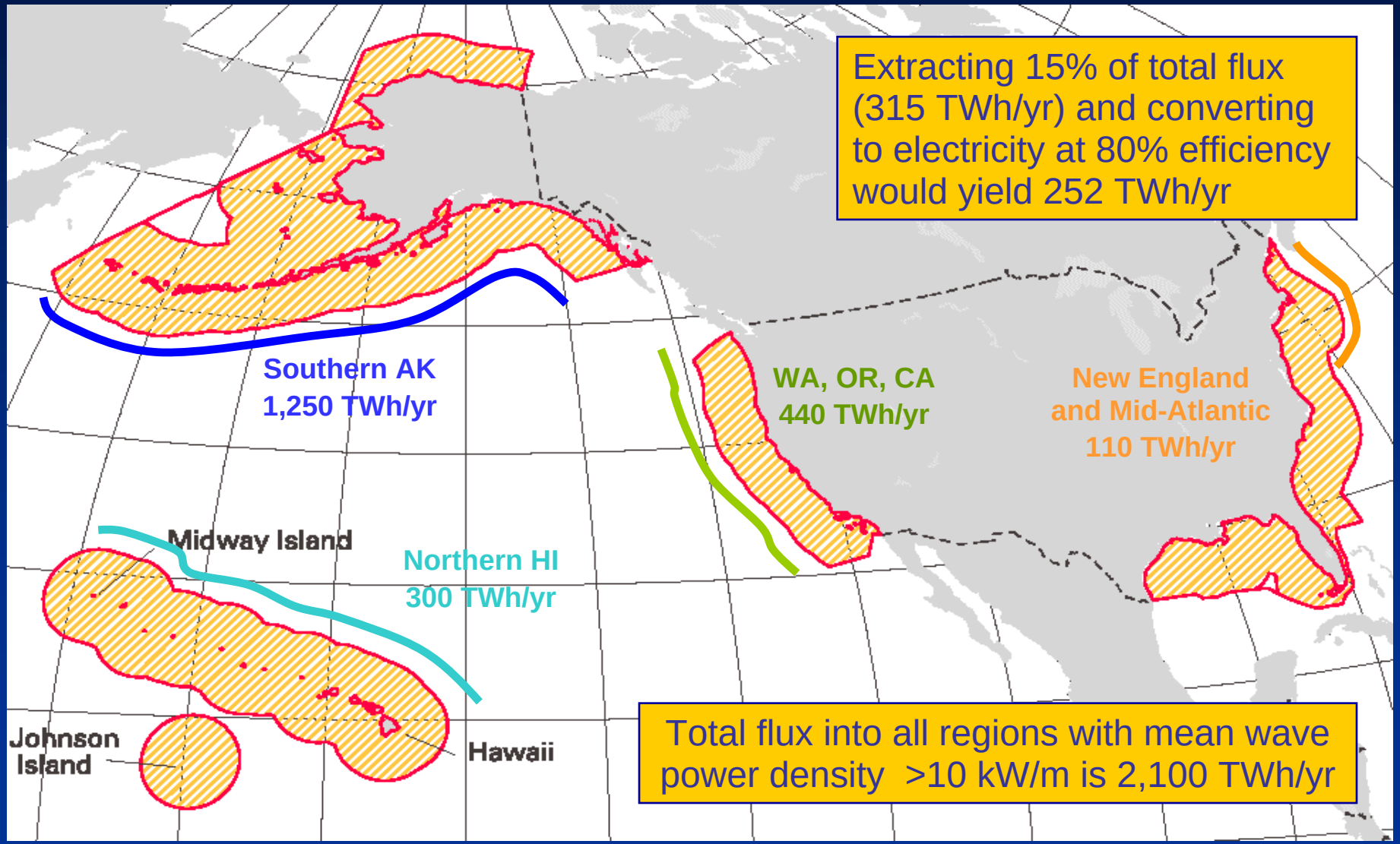
East Coast (Massachusetts)



Hawaii

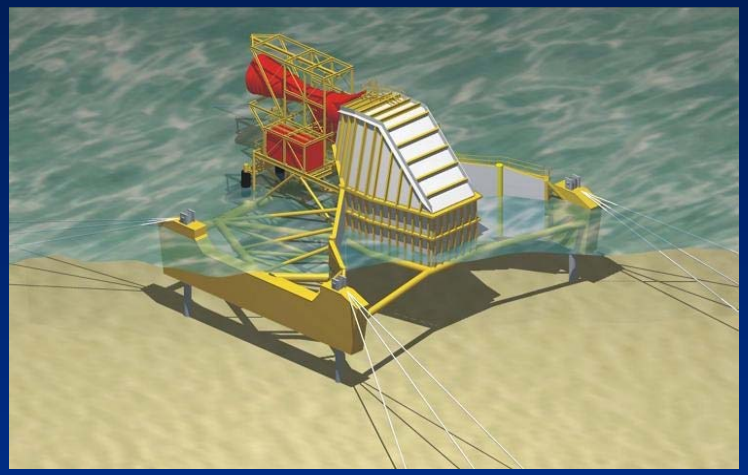


U.S. Offshore Wave Energy Resources



Wave Energy Devices Highly Diverse

Fixed Oscillating Water Column Terminator (Energetech)

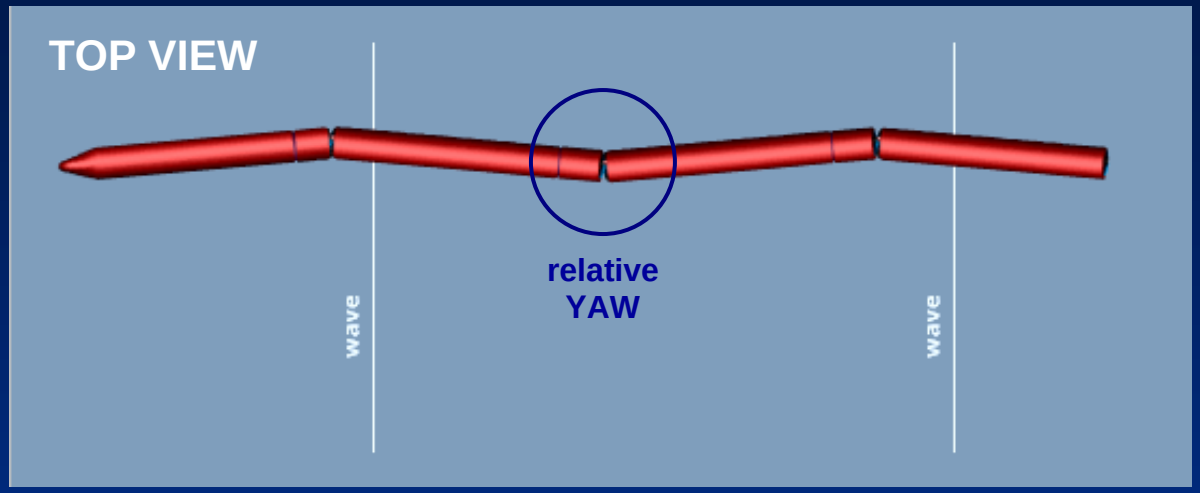


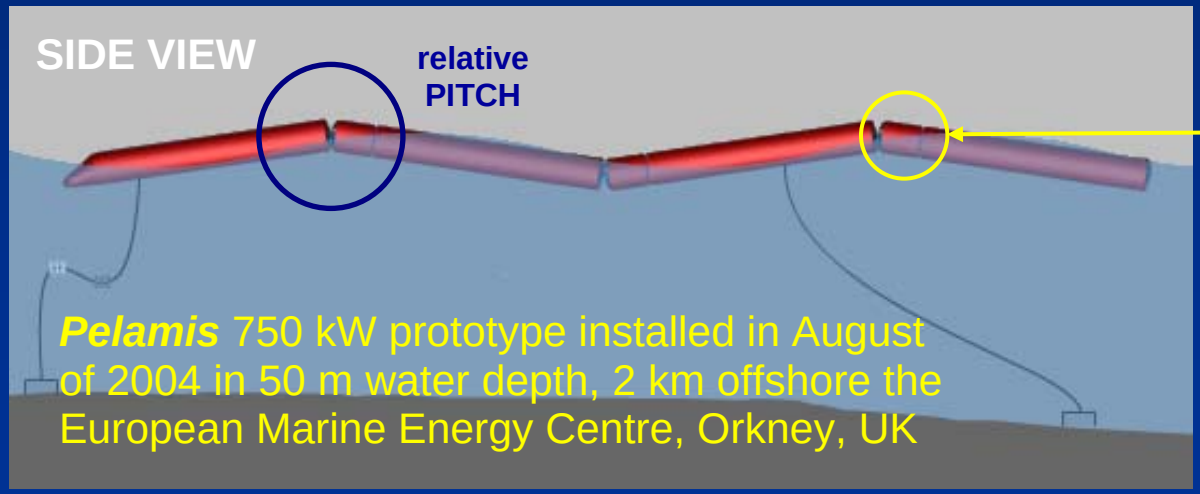
Floating Attenuator (*Pelamis*)

Floating Overtopping Terminator (Wave Dragon)

Floating Point Absorber (AquaBuOY)

Pelamis Selected for EPRI Feasibility-Level Design, Cost, and Performance Studies





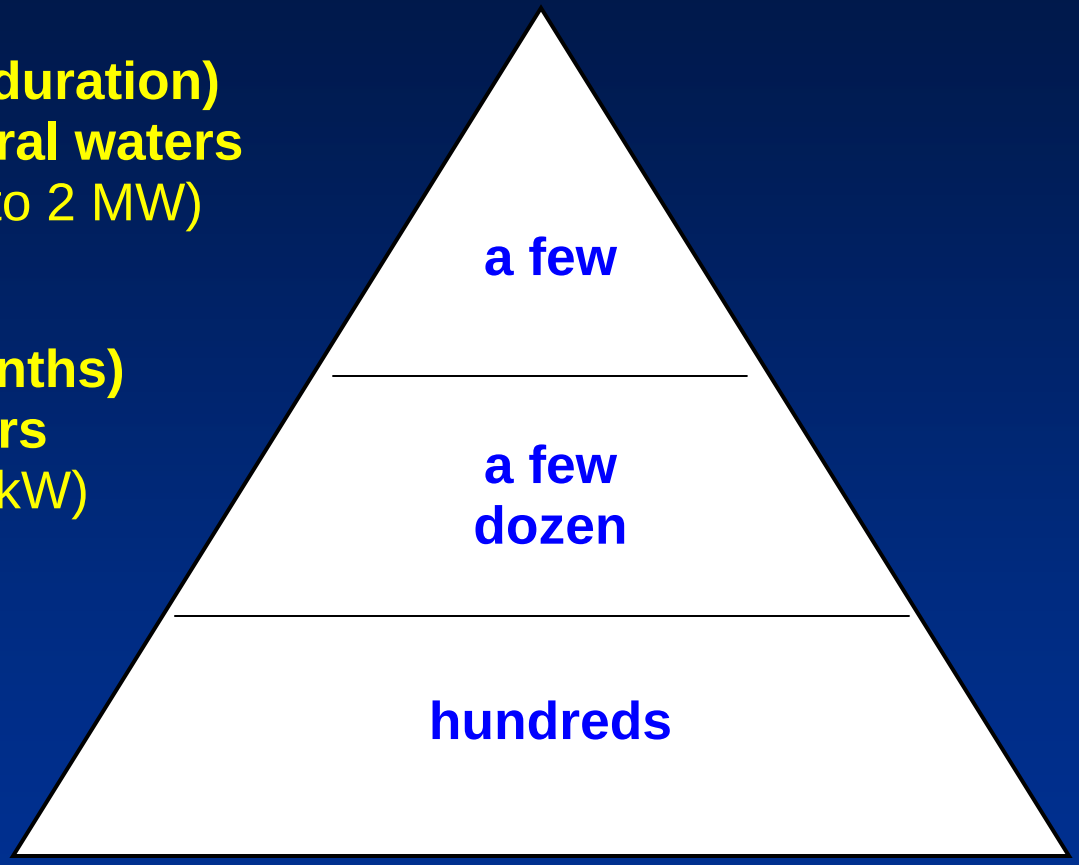
Power module at front of each tube section contains two hydraulic cylinders that are stroked by relative pitch and yaw between adjacent sections

Technology Development Status

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

Short-term (days to months) tests in natural waters
(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

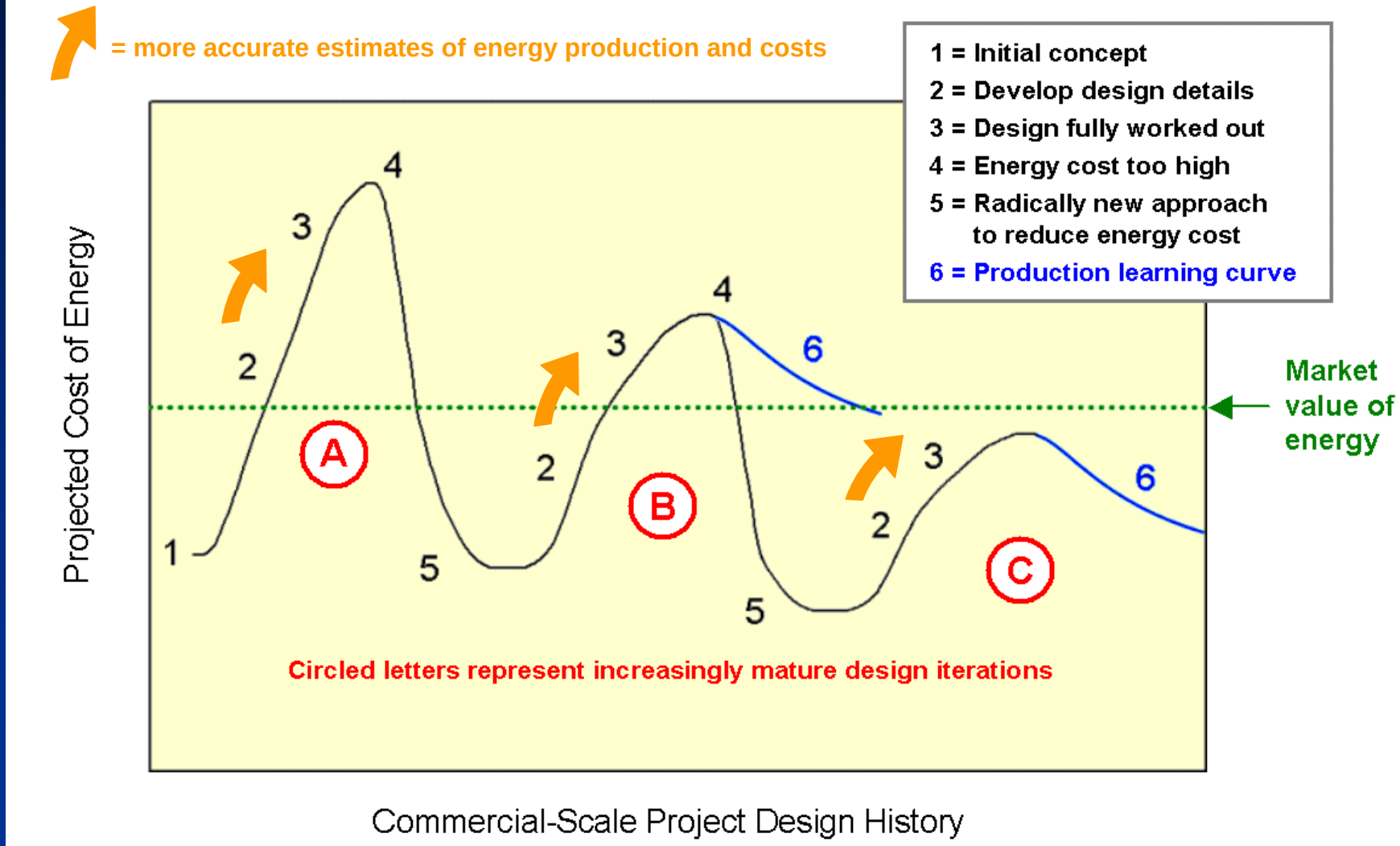
Key Points and Concerns

- Basic oceanography and hydrology are well understood, but "extractable" resource (percent utilization) is not
- Technology still evolving, as evident from major subsystem changes emerging from short-term tests in natural waters
- Exclusive site access for project developers using immature technologies could result in sites being tied up for years of experimental iteration before commercial-scale power is produced – can be avoided by merit-based competition in study phase, as condition for exclusive license
- Environmental effects of commercial projects uncertain due to lack of technology experience in natural waters – can be improved by monitoring of commercial-scale units deployed in "pilot" arrays before full build-out

Thank You!

Email: hagerman@vt.edu

Where is the Project Business Case?



Where are the EPRI Case Studies?

EPRI results cannot be generalized to other sites and technologies

MCT – Dog Island Transect, Western Passage, ME

Commercial-Scale Project Design History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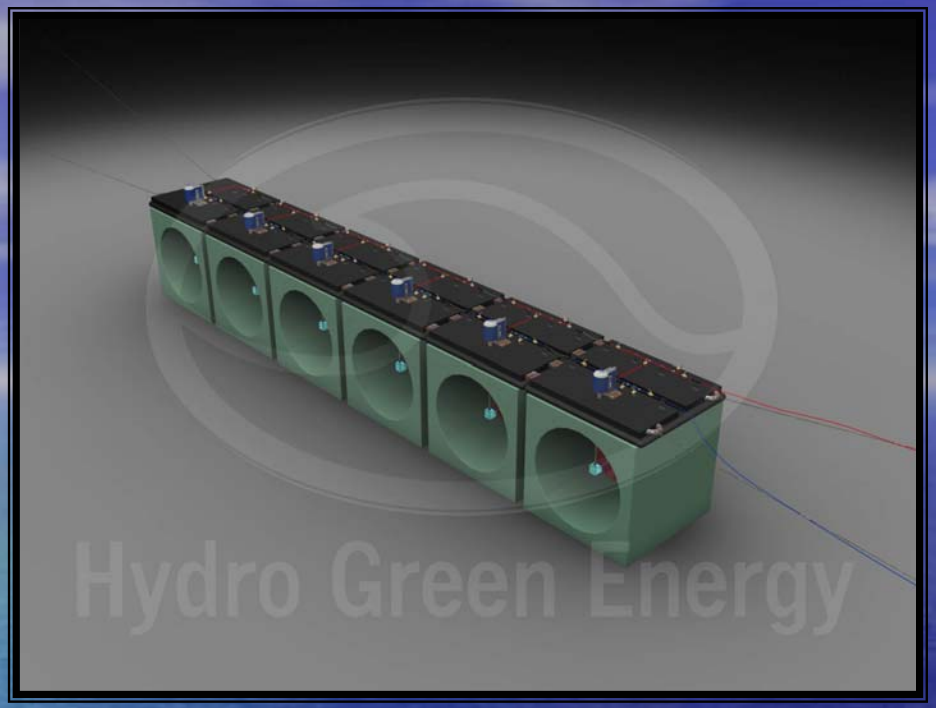
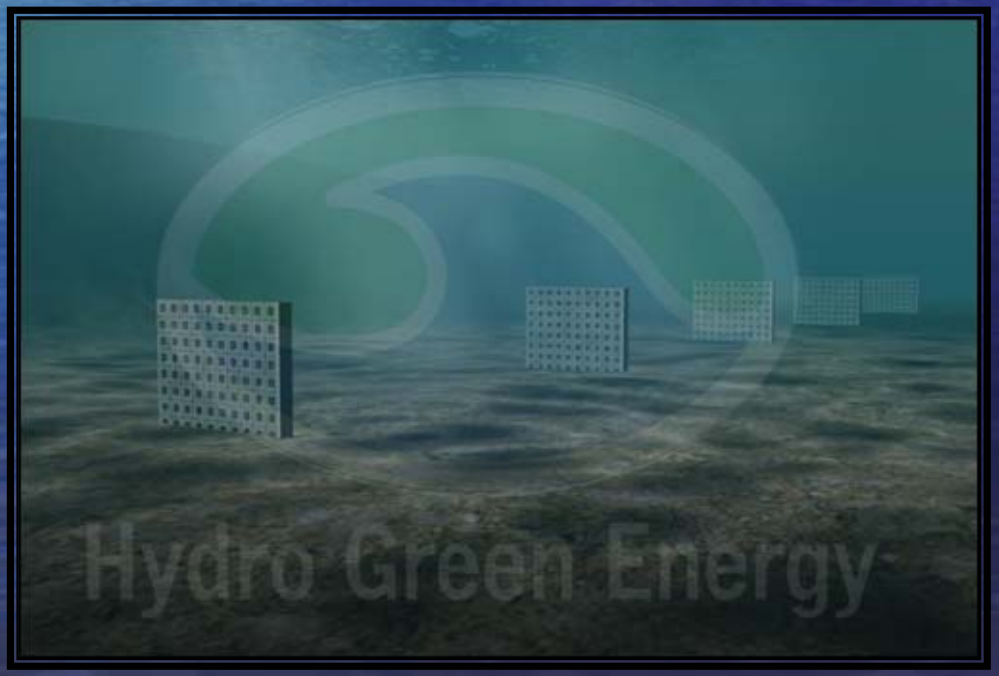

Hydro Green Energy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First Industrial Use of Hydropower in CA
Standard Mine Company, Bodie (Nov. 1892)


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