Pacific Northwest
NATIONAL LABORATORY
Proudly Operated by Battelle Since 1965

Opportunities and Challenges
Sustainable Ocean Energy Development in Washington

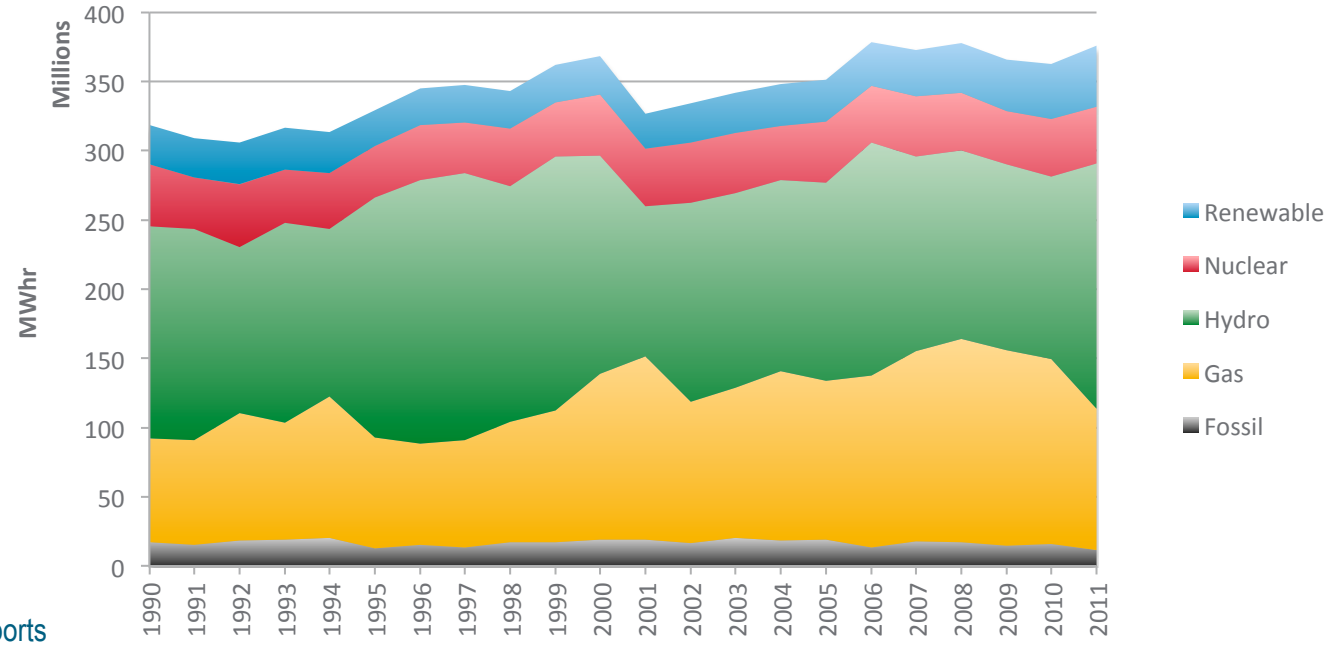
Charlie Brandt, Ph.D.

Director
Marine Sciences Laboratory
Pacific Northwest National Laboratory

Washington State Academy of Sciences
6th Annual Meeting & Symposium
September 12, 2013

Pacific Coast Generation Status and Trends

- Electricity generation in Pacific coast states dominated by natural gas, conventional hydropower
  - Growth primarily in natural gas; secondarily in renewables lead by wind
  - Hydro declined to 72% of peak in 1996-1999; returned to 90% of peak in 2011 due to extremely high flows – displacing wind and gas
- Consumption increased annually through 2006, then faltered
  - Down in all sectors except renewables

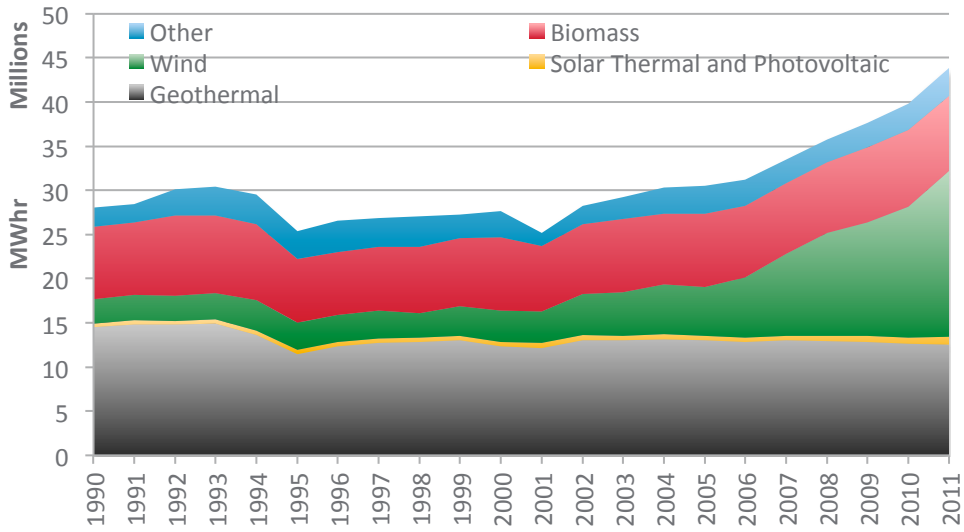


Data from EIA annual reports

Wind Dominates Growth in Renewable Generation in Pacific Coast

Pacific Northwest NATIONAL LABORATORY
Proudly Operated by Battelle Since 1965

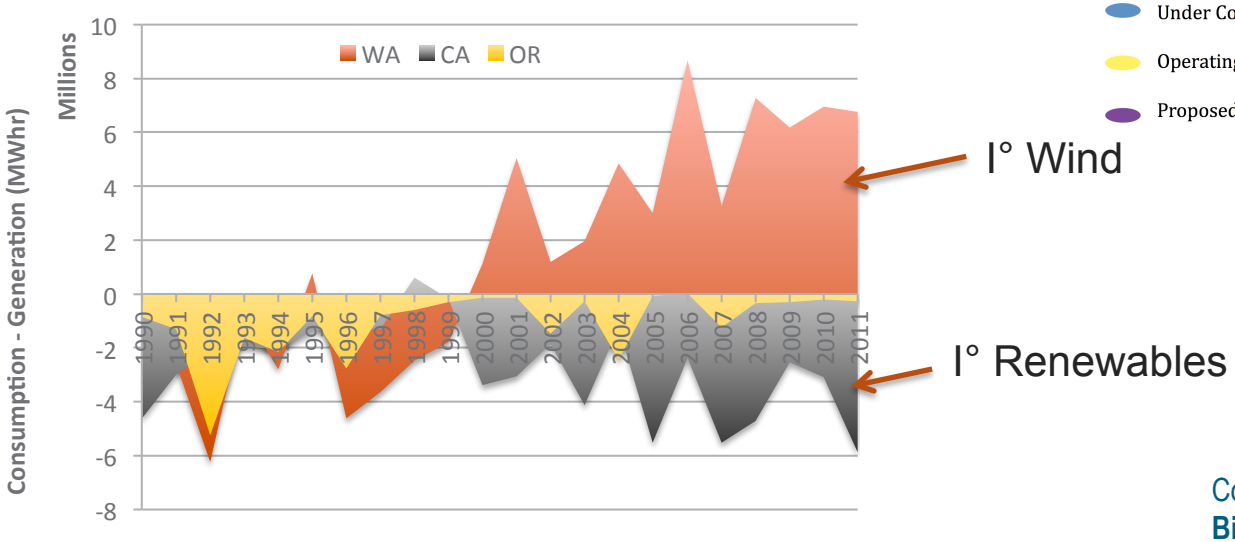
- Wind generation grew ~7x over past decade
  - Solar up 2.4x but remains small
  - Biomass and miscellaneous sources flat
  - Geothermal declining
- Constraints seen on rapid growth
  - Load balancing to accommodate intermittent generation
  - Constrained ability to move wind power to California during peak hydropower flow
  - East-side generation vs. West-side demand

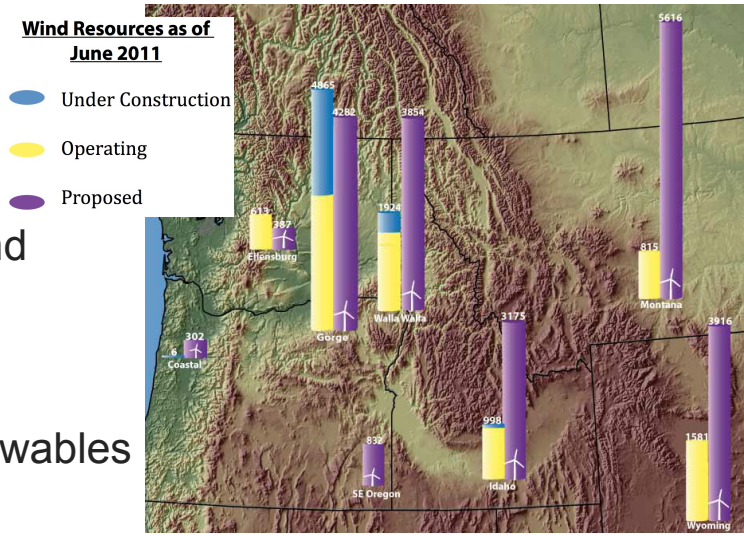


Data from EIA annual reports

WA Exports Renewable Electricity

- Before 2000, west coast energy depended upon exports from Canada
- Since 1990, California has increased its importation of electrical energy
  - Oregon's deficit has been low for the past 7 years
- Since 2000, Washington has been a net exporter of electricity
  - Exceeding net imports by Oregon and California combined for 7 out of the 11 years





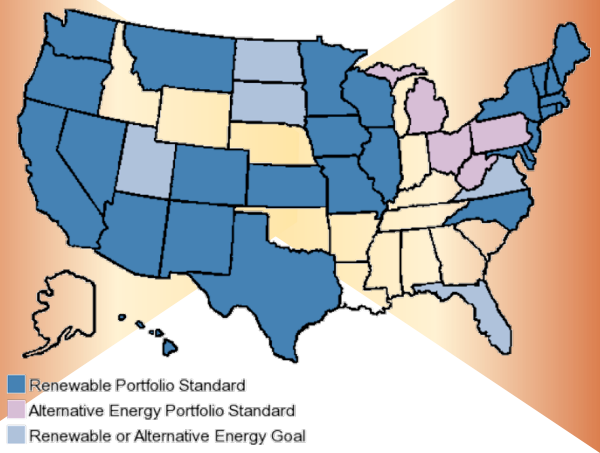
ColumbiaGrid (2012) **2012 Update to the 2011 Biennial Transmission Expansion Plan**

Data from EIA annual reports

Renewable Energy Goals Drive Investment

- DOE – 30% by 2030
- DoD– 3 GW by 2025 (1 GW from each force)

State	Goal	Date
AZ	15%	2025
CA	33%	2020
CO	20%	2020
KS	20%	2020
MT	15%	2015
OR	25%	2025
NM	20%	2020
NV	25%	2025
UT	20%	2025
WA	15%	2020

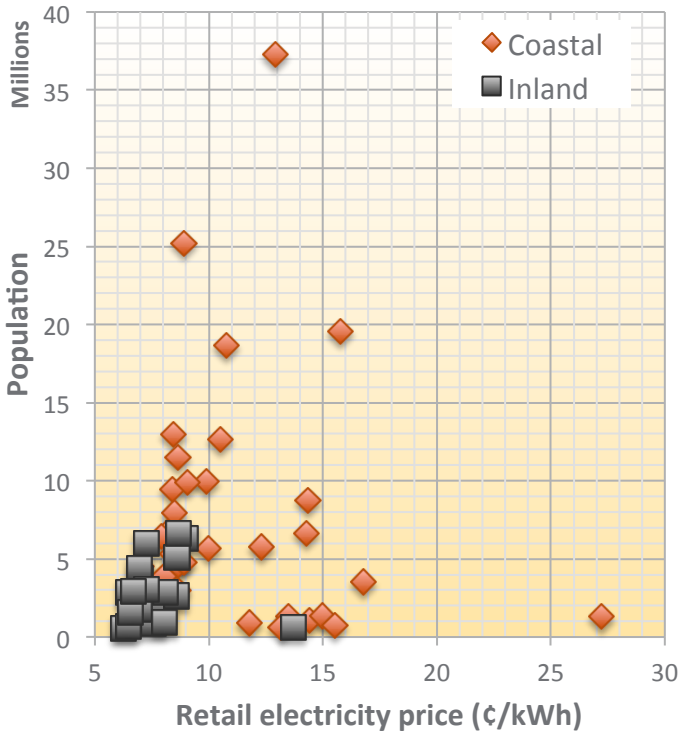


State	Goal	Date
CT	27%	2020
IL	25%	2025
MA	15%	2020
MD	20%	2022
ME	40%	2017
NH	25%	2025
NY	25%	2013
RI	16%	2019
VA	15%	2025
VT	25%	2025

Data from http://www.pewclimate.org/what_s_being_done/in_the_states/rps.cfm

Why Use Ocean Renewable Energy?

- **Large renewable energy source, with positive attributes relative to demand**
  - Potential exceeds demand
  - Higher/steadier wind speeds
  - Highly predictable waves and tides
- **Resource is near load centers**
  - 52% of US population lives in coastal counties
  - 28 coastal states consume 78% of nation's electricity
  - Simplifies transmission requirements
- **Reduced environmental effects**
  - Reduced conflict with human uses
  - Few bats and birds
- **Significant economies of scale**
  - Larger devices
  - Larger arrays
- **Best or only opportunity for utility-scale renewables in parts of the country**

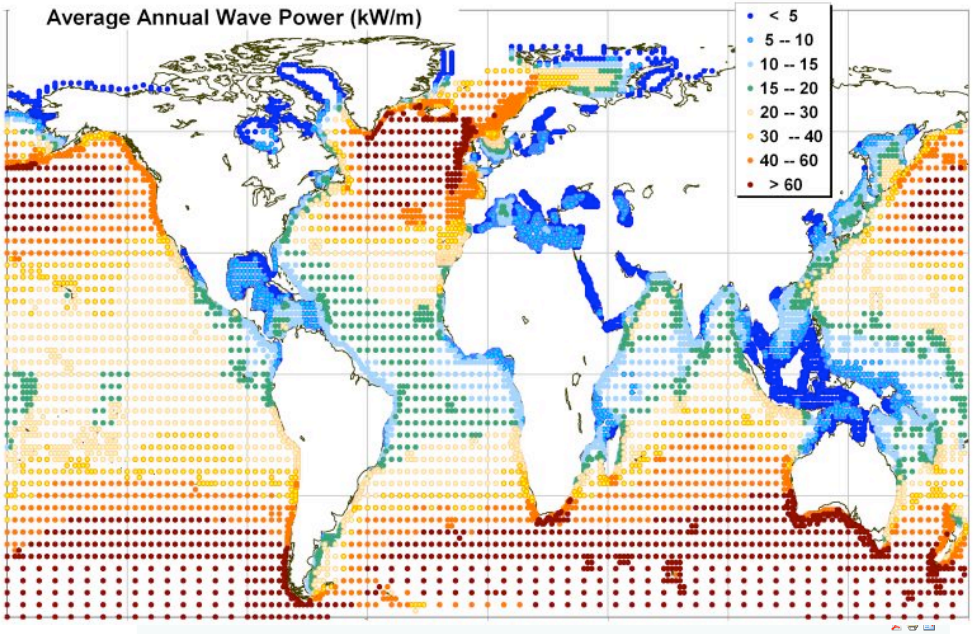


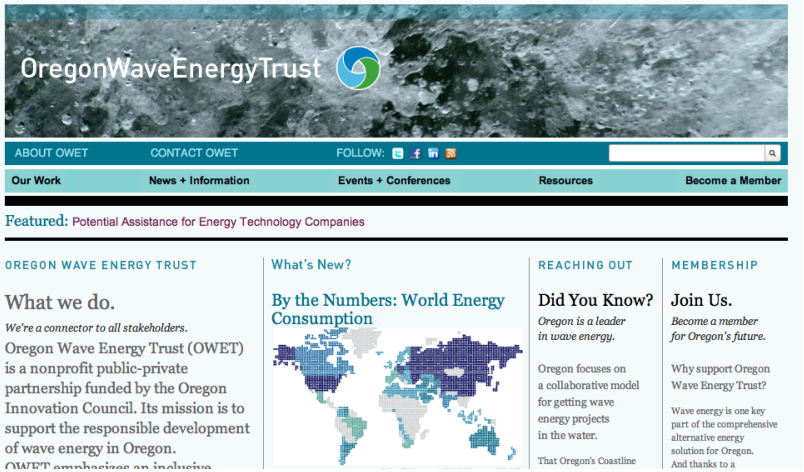
Data from EIA annual reports

Resource Base – Wave Energy

Pacific Northwest NATIONAL LABORATORY
Proudly Operated by Battelle Since 1965

- Greatest potential at higher latitudes
- Well conditioned
  - Predictable
  - Consistent
- Effective for remote coastal communities
- WA / OR / CA
  - Total recoverable energy estimated at 250 TWh/yr
  - Compared to total electricity generation in 2011 of 376 TWh

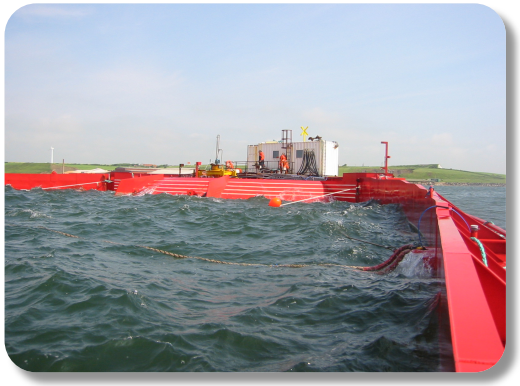




http://www.oceanor.no/Services/Worldwaves/WW_database, EPRI 2011; EIA annual report

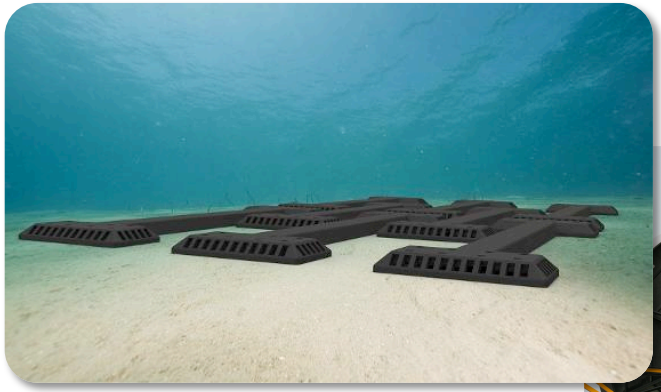
Wave Energy Technologies

Wavegen



Wave Dragon

Pelamis



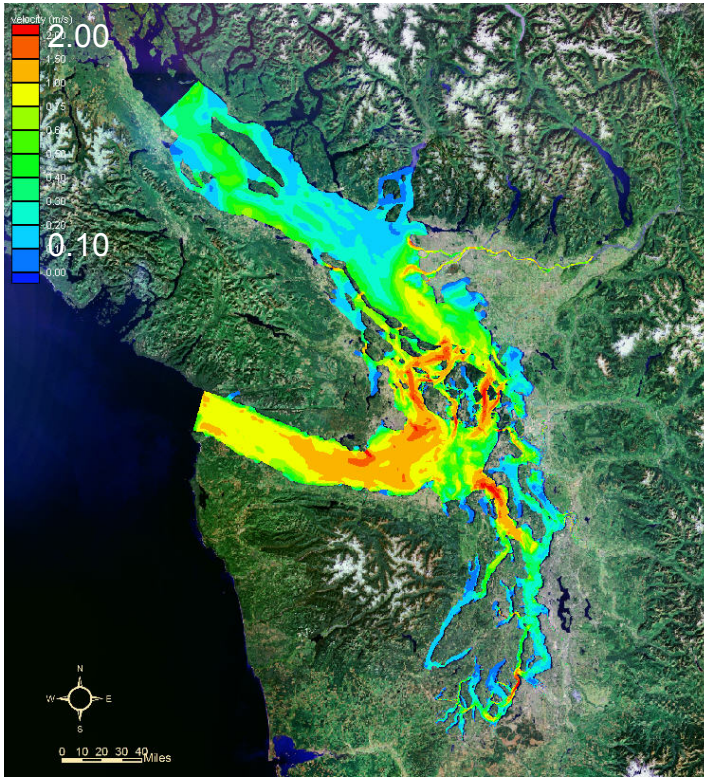
M3

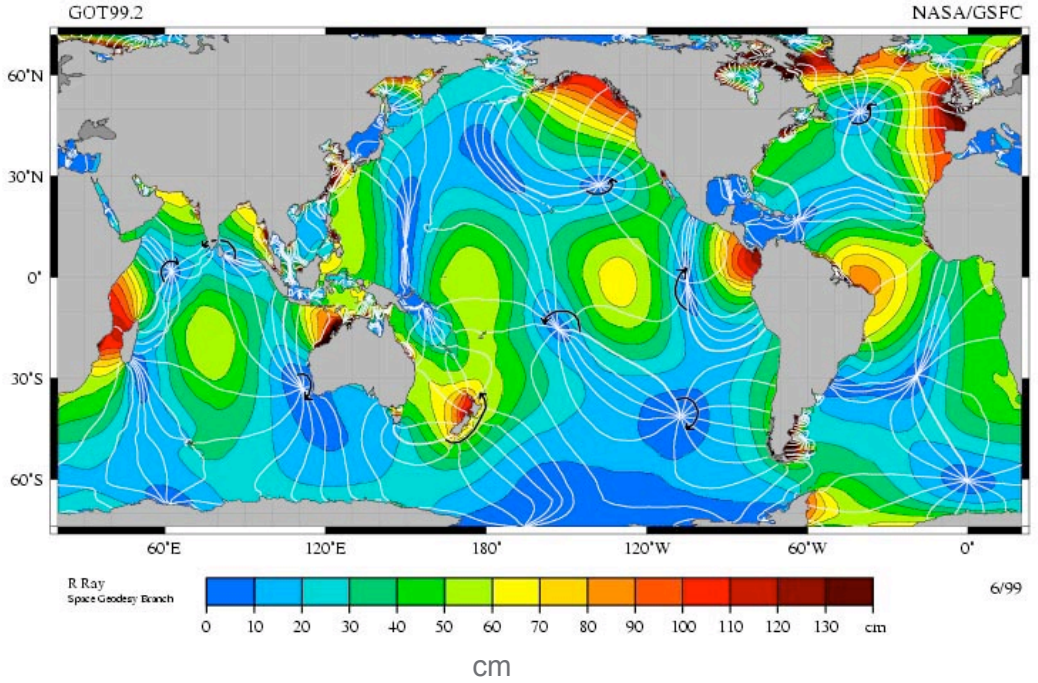
Ocean Power Technology

Aquamarine

Resource Base – Tidal Power

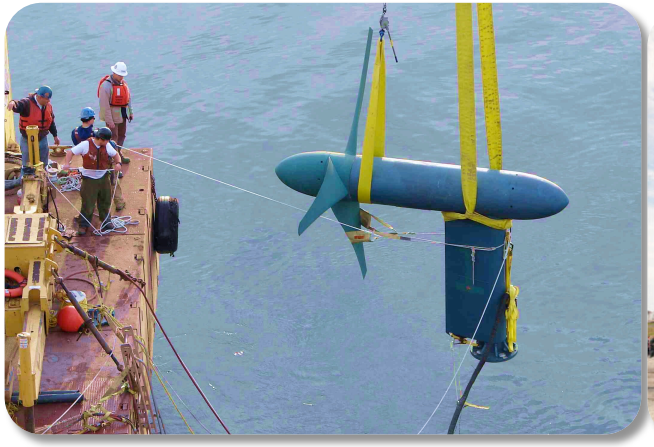
- Greatest potential above 45° North, Sea of Cortez, and Bay of Fundy to Gulf of Maine
  - Salish Sea estimate exceeds 2 GW, or 6% of current WA generating capacity





Georgia Tech (2011) **Assessment of Energy Production Potential from Tidal Streams in the United States**;
PNNL (2007) **Development of Hydrodynamic Model of Puget Sound and Northwest Straits**

Tidal Power Technologies



Verdant

OpenHydro

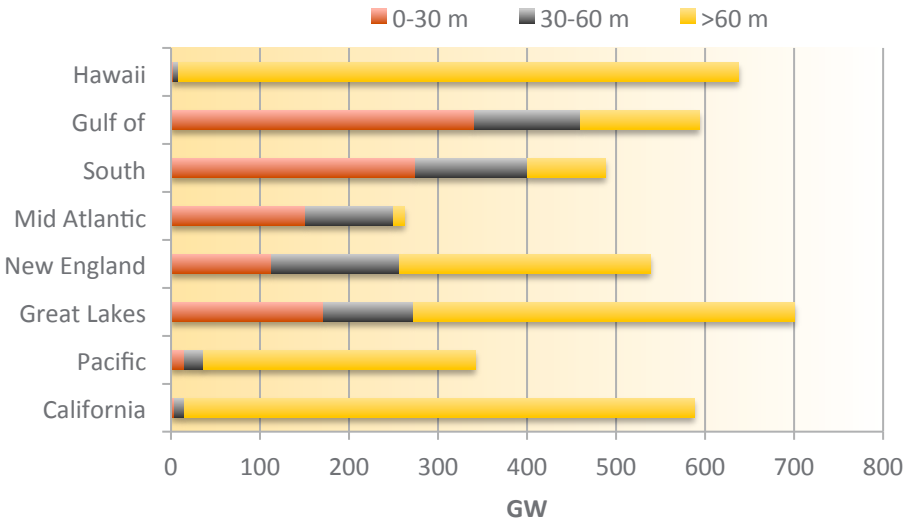
Clean Current

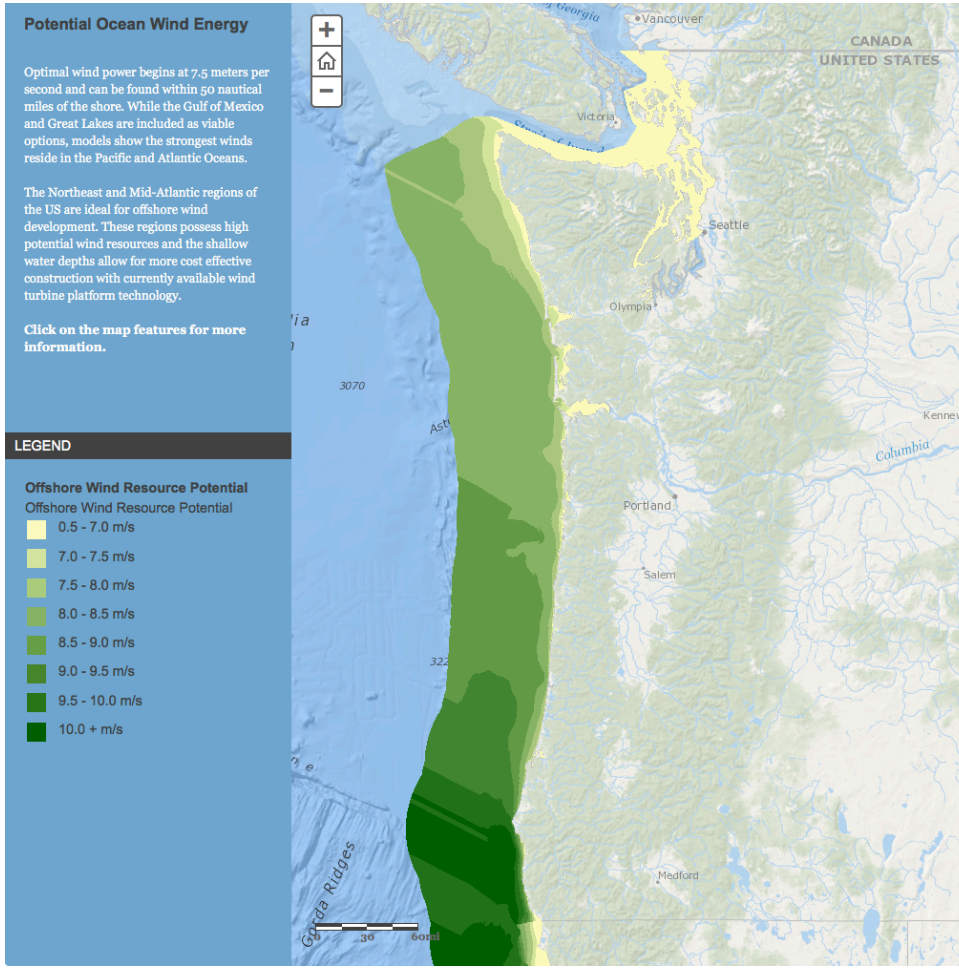
Ocean Renewable Power Company

Marine Current Turbine

Resource Base – Offshore Wind

- Over 4 TW of extractable power – 4 times US generating capacity
  - Highest wind speeds, fewer competing uses, fewer bats/ birds further from shore
  - 74% of power is over water > 30 m – **Floating Platforms**





NREL (2010) **Assessment of Offshore Wind Energy Resources for the United States**
http://www.arcgis.com/apps/StorytellingTextLegend/index.html?appid=46b2bf2c83bc4ce594ec4a5bbb4ff794

Established Offshore Wind Technologies

Siemens 20m monopole

BARD 50m tripole

OWEC Quattropod 20m jacket

Challenges to Development

Pacific Northwest NATIONAL LABORATORY
Proudly Operated by Battelle Since 1965

Resources >4X Total Land-based Generation, but…

Barrier	Status	Path Forward
Resource characterization insufficient for investment	AWS Truepower wind model from USCG stations, lighthouses, satellite 10 m wind speeds; wave energy from Wavewatch III from NOAA; tidal from ROMS	Reference Facility for Offshore Renewable Energy, LIDAR buoys; WaveGlider vehicles, etc.; high-skill flexible grid modeling
Deep water challenges technology	Floating platforms for wind exist as prototypes – through O&G sector experience	Deep water pilot projects: Coos Bay by Principle Power, Gulf of Maine by DeepCwind
Ports and maritime not ready	Massive wind machines assembled at sea; no US-flag vessels (Jones Act)	Regional collaboration; assembly in port
No US/State experience permitting and siting	Marine spatial planning underway; technology compatibility data are scarce	MSP completion includes outreach/ education; lab-field research; TETHYS database; permitting underway for pilot projects
High cost and non-ocean markets	No grid-scale deployments in US; no pricing for ancillary benefits; 2-4X average regional cost	Quantify and monetize benefits; Develop/test advanced materials, components, and systems

Resource Characterization

- Wind resource based on extrapolating near-shore wind model
  - Note disclaimer in maps
  - Note unlikely features in zones
  - Note unusual homogeneity over large space
    - Need calibrated measurements of wind fields at 90-200m height
    - Reference Facility for Offshore Energy in Chesapeake Bay

Floating Platforms

Principle Power

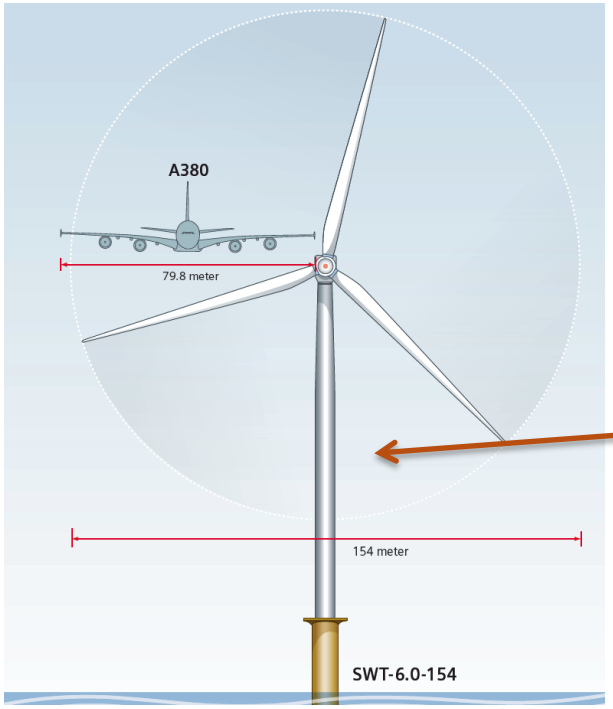
Sway

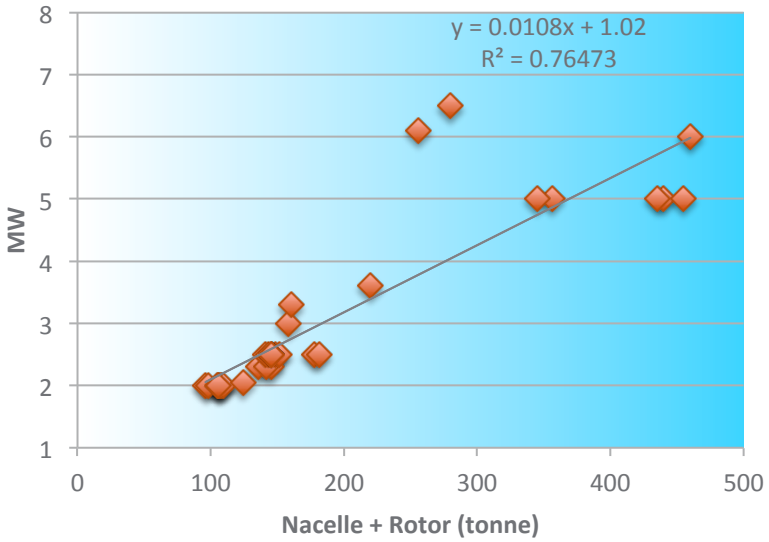
Hywind

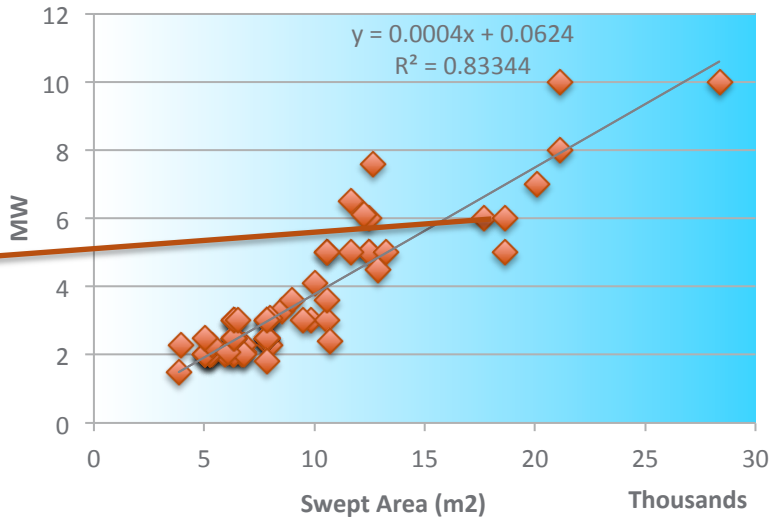
Blue H

Physical Challenges for Ports and Vessels

- Offshore turbines are large, heavy, and getting bigger
  - 15 MW: 220 m diameter, 1,300 tonnes
  - ~2.5x Airbus A380)





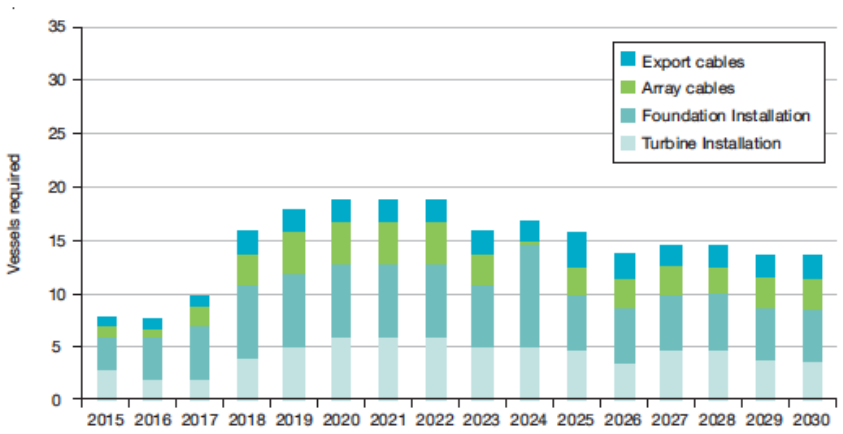


Data from Wind Energy Market 2009, 4coffshore.com/windfarms database

Specialized Vessels & Ports

- Construction – Ports
  - 8 ha laydown/preassembly
  - 300m length pier with high load capacity
  - Access for 140 x 45 x 6m draft vessels
  - Overhead clearance of >100m
- Manufacture – Ports
  - 500 ha for factory, storage
  - Direct access to 500m length pier, high load bearing
  - Access to skilled workforce
- Vessels – Jones Act, no US vessels
  - Cable laying
  - Foundation installation
  - Turbine installation
  - O&M

Figure 27: Low Added Value – Installation Vessels 2015-2030 by Installation Date



Seajacks Leviathan

Department of Energy and Climate Change (2009) **UK Ports for the Offshore Wind Industry: Time to Act**

Research to Resolve Uncertainties

Pacific Northwest NATIONAL LABORATORY

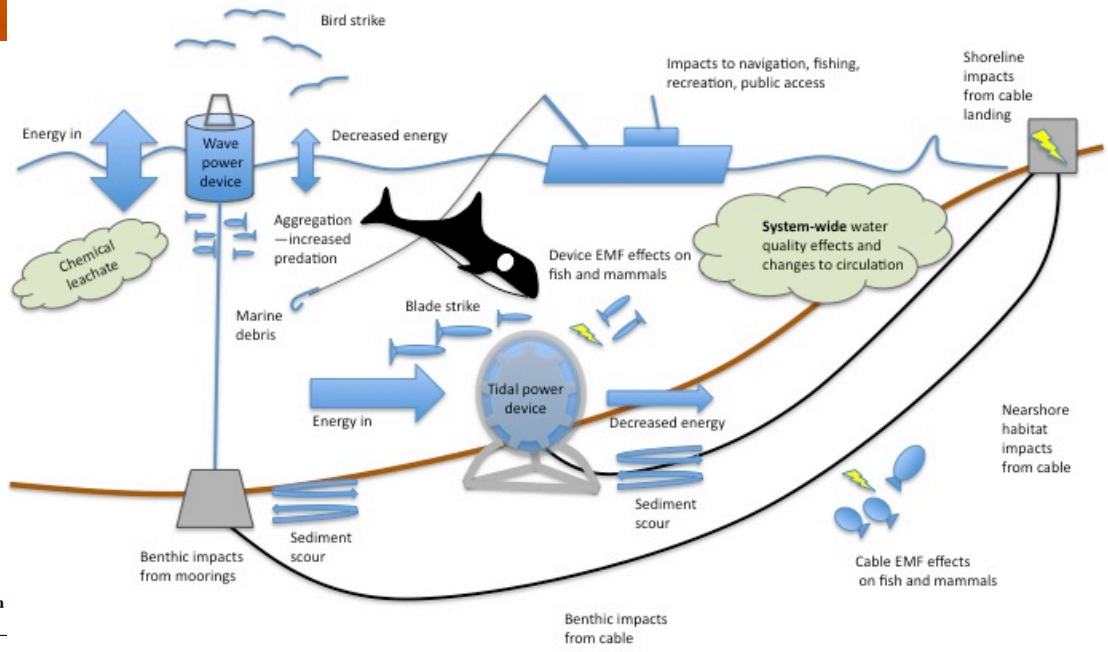
Ecological Effects of Wave Energy Development in the Pacific Northwest

A Scientific Workshop, October 11–12, 2007

George W. Boehlert, Gregory R. McMurray, and Cathryn E. Tortorici, editors

U.S. Department of Commerce
National Oceanic and Atmospheric Administration
National Marine Fisheries Service

NOAA Technical Memorandum NMFS-F/SPO-92



Receptor-specific effects table for fish and fisheries. KEY: L=low impact, M=medium associated with the estimate, + positive effect

Activity (agent or stressor)	Market Squid[a]	Dungeness Crab	Pink Shrimp[b]	Sharks	Salmon and Steelhead[c]	Albacore Tuna[b,d]	Smelts, herring, sardines, anchovies	Rockfish, Lingcod[e]	Other Demersal Roundfishes	Flatfish	Skates and Rays	Green Sturgeon	Pacific Sandlance[f]
Emplacement													
Mooring System	L	L	L	L	L	L	L	L	L	L	L	L	L
Electrical Transmission Infrastructure	L	L	L	L	L	L	L	L	L	L	L	L	L
Operation													
Mooring System & benthic habitat (shell mounts)	H+	H	M+	M+	M[g]	M+	L	H+	H+	M[h]	L	H	L
Buoy or Other Generation Device	L	L	L	M+	M[g]	M+	L	H+	H+	L	L	L	L
Electrical Transmission Infrastructure(EMF)	L	M?	L	H	H?	L	L	M?	M?	L	H	H	L
Chemical Coatings	L	H	L	L	H	L	L	M	M	M	L	L	L
Wave and Current Attenuation	U	U	U	U	U	U	U	U	U	U	U	U	U
Acoustics	L	L	L	L	H?	L	M	M?	M?	L	L	L	L
Decommissioning													
Buoy or Device Removal	L	L	L	L	L	L	L	L	L	L	L	L	L
Transmission Infrastructure Removal	M	M	M	L	M	L	L	M	M	M	M	M	M
Anchor Removal or Decommissioning	M	M	M	L	M	L	L	M	M	M	M	M	M
Routine Maintenance													
Vessel Traffic, Maintenance Activities	L?	L?	L?	L?	L?	L?	L?	L?	L?	L?	L?	L?	L?

[a] *Doryteuthis opalescens* (formerly *Loligo opalescens*)
[b] Low vulnerability given our understanding of the current wave energy structures and technology
[c] Sea-run rainbow trout, *Oncorhynchus mykiss*
[d] *Thunnus alalunga*
[e] *Ophiodon elongates*
[f] *Ammodytes hexapterus*
[g] positive effect for adults, negative for juveniles
[h] positive or negative effect, varies with species

Environmental Effects of Tidal Energy Development

Proceedings of a Scientific Workshop

March 22-25, 2010

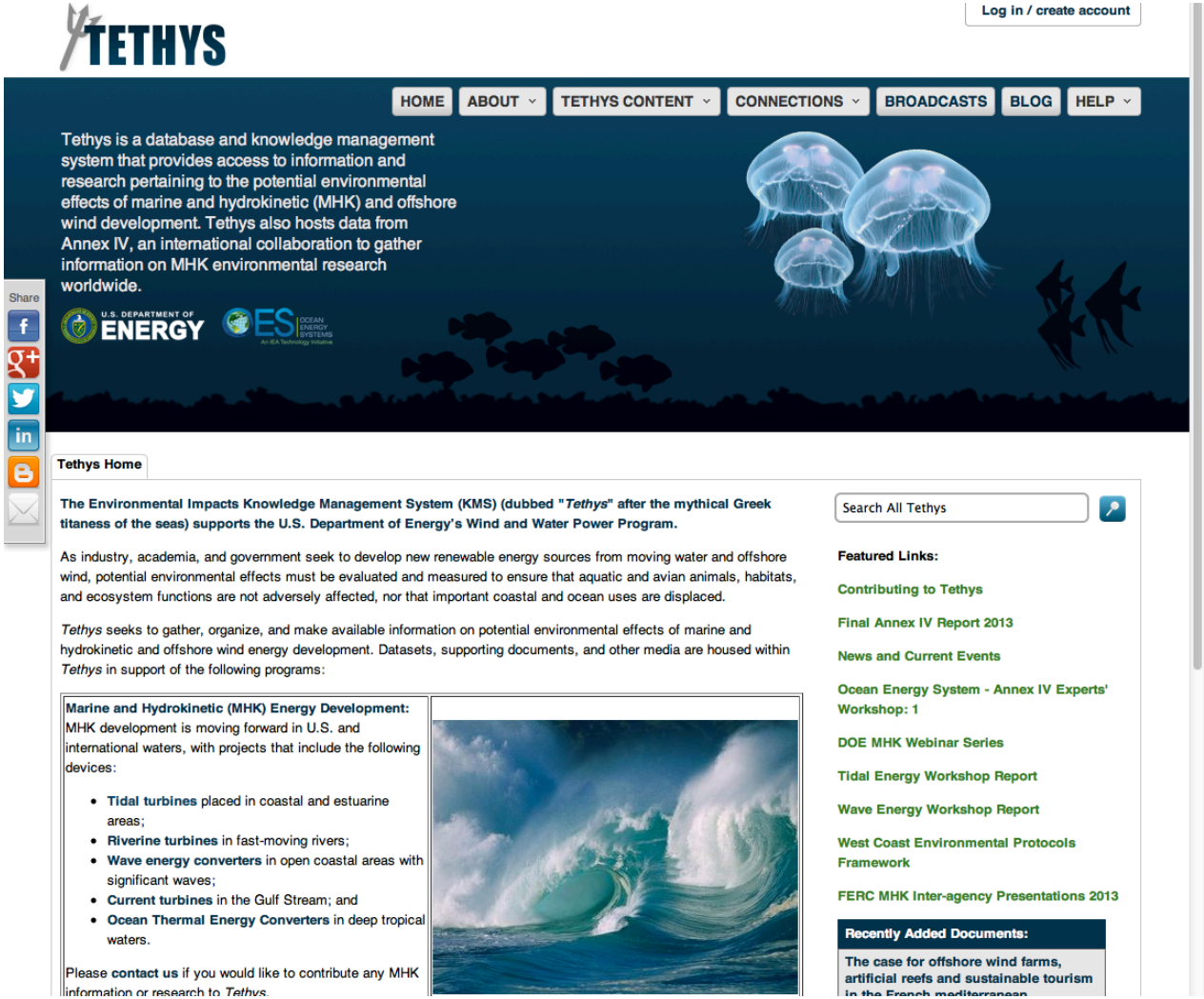
Brian Polagye, Brie Van Cleve, Andrea Copping, and Keith Kirkendall, editors

U.S. Department of Commerce
National Oceanic and Atmospheric Administration
National Marine Fisheries Service

NOAA Technical Memorandum NMFS F/SPO-116

Links to Information

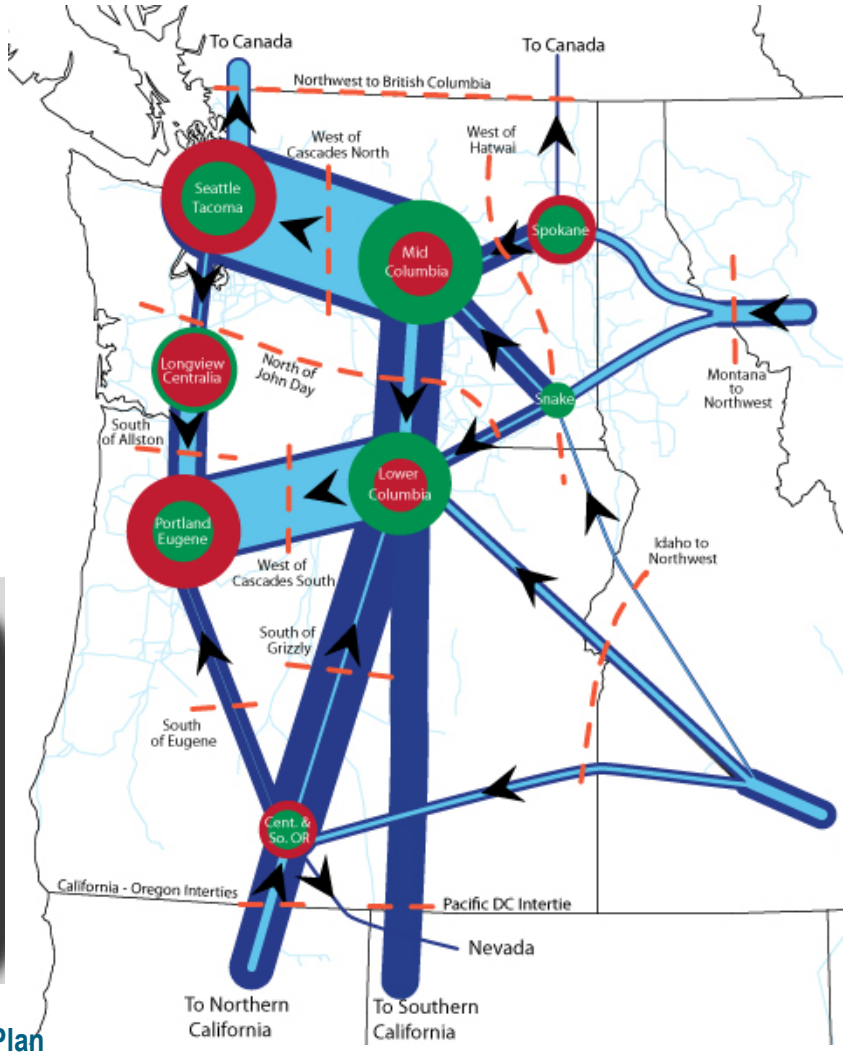
- Established by US DOE - Tethys database contains
  - Global ocean energy project data
  - Environmental effects reports and information
  - Links to other knowledge- and databases globally



http://mhk.pnnl.gov/wiki/index.php/Tethys_Home

Ancillary Benefits – In-State Transmission

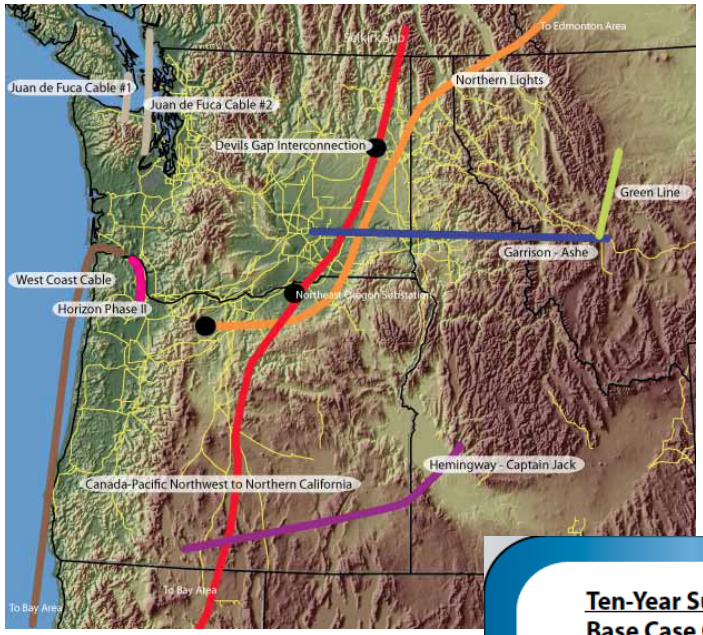
- Transmission across Cascades is highly constrained
  - Loading rate increasing ~2%/yr
  - High wind generation east of Cascades
- Increased west-side generation can potentially reduce need for new transmission

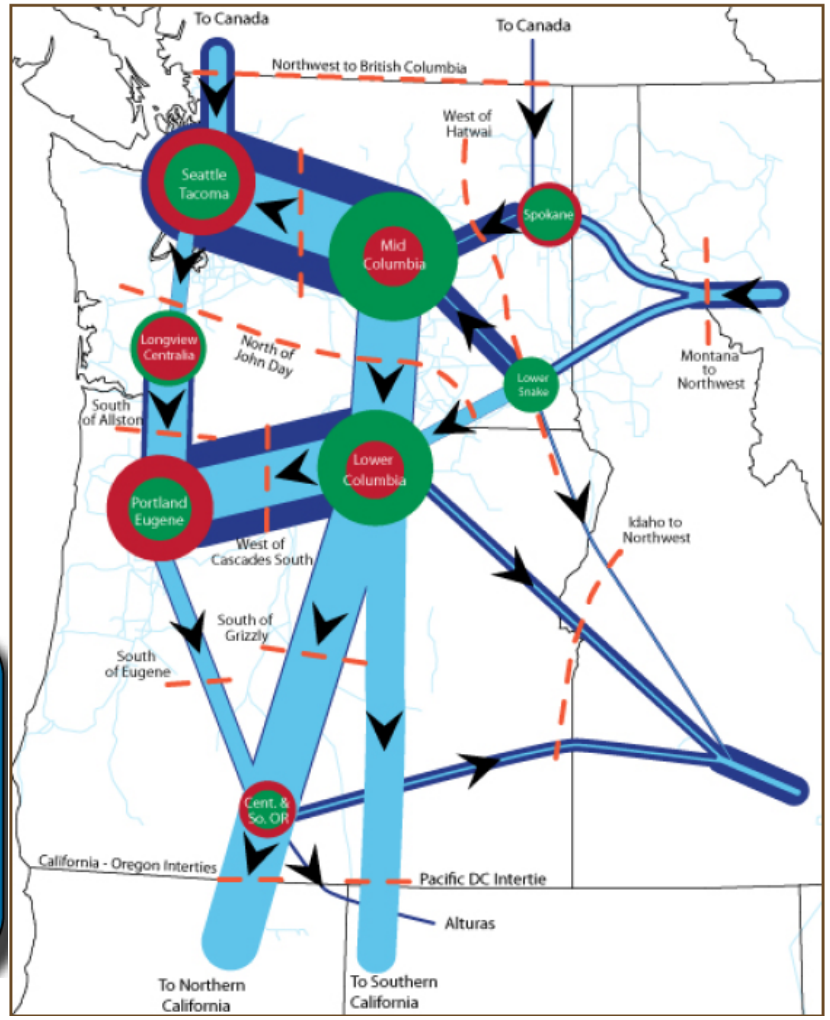


ColumbiaGrid (2012) **2012 Update to the 2011 Biennial Transmission Expansion Plan**

Ancillary Benefits – Alternative Transmission to California

- Proposed transmission for ocean renewables could alleviate summer congestion to California market

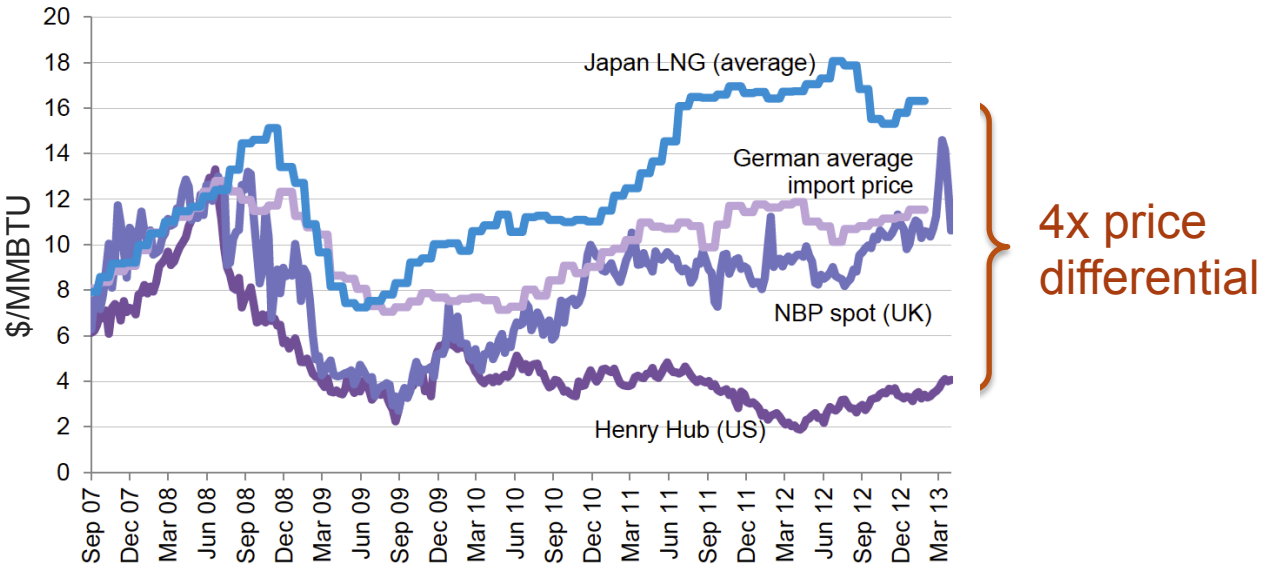


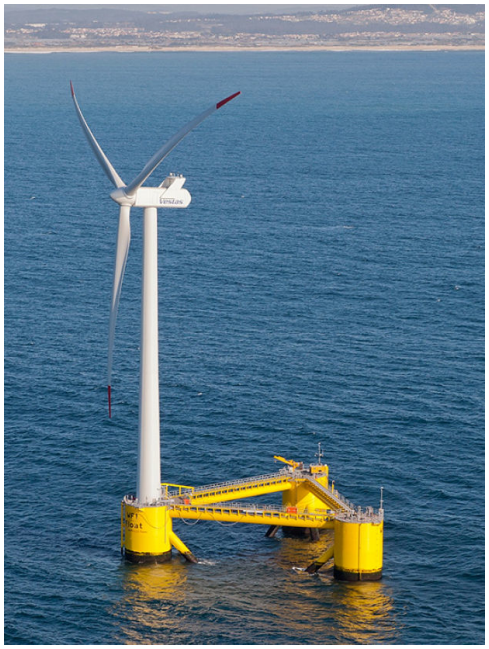


ColumbiaGrid (2012) **2012 Update to the 2011 Biennial Transmission Expansion Plan**

Alternative Markets

- Principle Power's 30MW Coos Bay development's preferred option is based not on grid, but on gas
  - Producing LNG (Jordan Cove export facility) to take advantage of tremendous price differential between US and Asian markets, and high cost of oil-based generation in HI

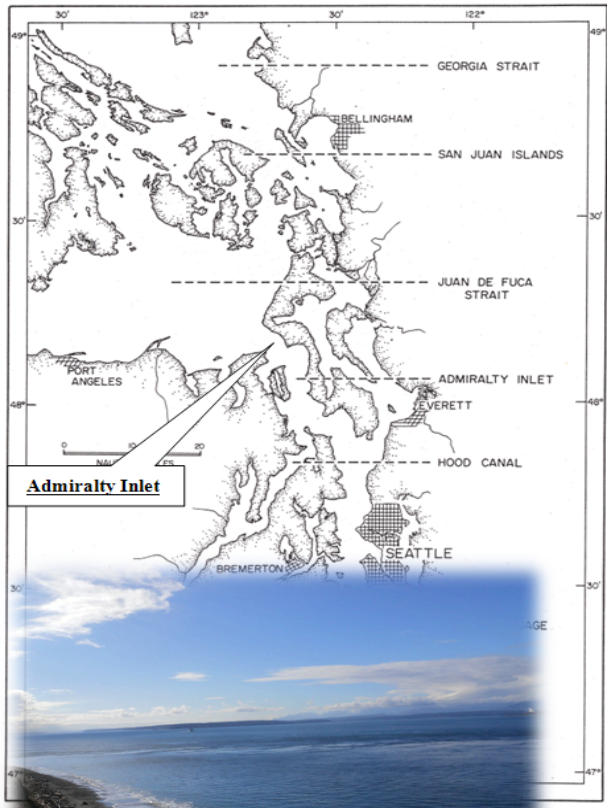




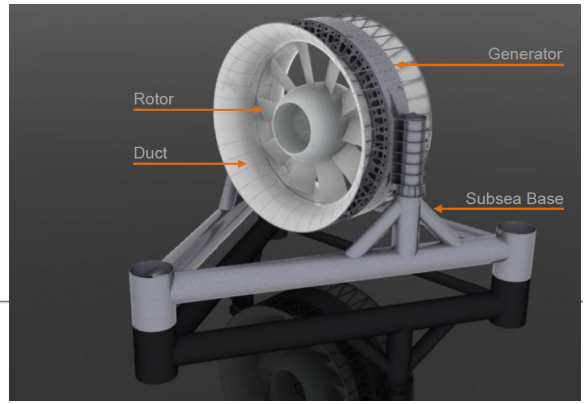
Bloomberg New Energy Finance (**bnef**.com/Presentations/download/132), http://www.oregonwave.org/tag/principle-power/, http://boostsouthwestoregon.org/qa/

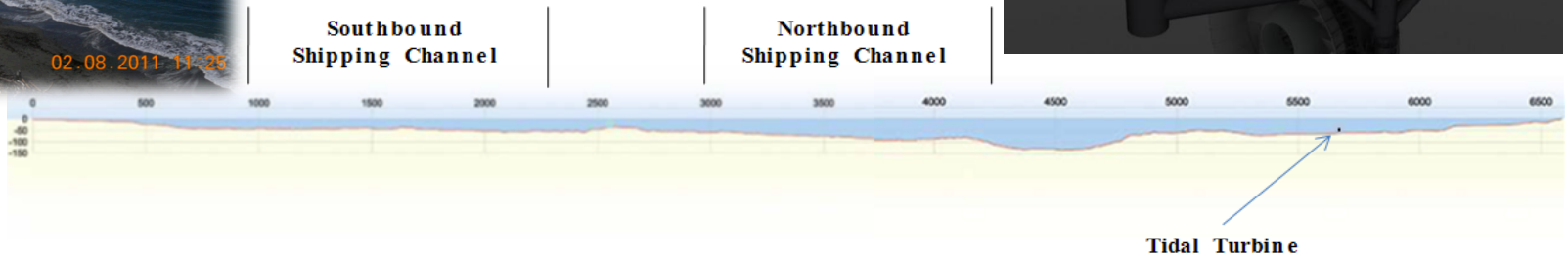
Snohomish PUD tidal turbines, Puget Sound

Pacific Northwest NATIONAL LABORATORY
Proudly Operated by Battelle Since 1965



- Snohomish Public Utility District proposes to deploy two 6m OpenHydro grid-connected turbines
- To be deployed in 55m water at mouth of Puget Sound (Admiralty Inlet)
- Only one moving part, permanent magnet, direct drive generator. No lubricating oils or greases
- Typical rotor speeds of 6-16 rpm, rotating ~70% of the time.
- Planning for 3-5 years of turbine operation





Bottom Lines

- Opportunities
  - WA-produced power
    - For WA energy customers **and** western US energy customers
  - WA-produced technology and WA-produced capability
    - For WA energy production **and** global energy production

- Challenges
  - Higher costs of development within context of hydro-dominated market
    - Early days for technology
    - Early days for understanding environmental consequences and mitigation
    - Early days for regulators and stakeholders
  - Converting ancillary benefits into market price

Thank you for your attention!

Pacific Northwest
NATIONAL LABORATORY
Proudly Operated by Battelle *Since 1965*

Charlie Brandt
Pacific Northwest National Laboratory
charles.brandt@pnnl.gov
360.681.4594

We would like to acknowledge generous support by the US Department of Energy's Wind and Water Power Technologies Office