



SFPUC Tidal & Wave Power Studies

BCDC Commission Briefing

October 2, 2008

Ian Austin, PhD, PE
Vice President, Marine Services

Outline:

- A bit of history...
- SFPUC In-Stream Tidal Power Feasibility Study at Golden Gate
- SFPUC Wave Power Feasibility Study



Wave power has arrived?

“The possibilities of utilizing the forces of the sea’s waves will soon be manifest”

Adolph Sutro, 1887

Wave power has arrived?

Wave-power schemes near Cliff House:

- 1887 Sutro's catch-basin, a wave overtopping scheme; planned that extra head would drive water wheels
- 1887 Sterns' wave motor on rocks near Cliff House – possibly a pump storage scheme – ended dramatically with the explosion of a grounded schooner
- 1891 Henry Holland's wave motor; pump driven by a large iron buoy - another pump storage scheme

Wave power has arrived?

Sutro Aquarium



Wave Motor



2007-2008: San Francisco PUC Studies

- San Francisco has goal of generating at least 10% of annual average power demand from renewables - about 60 MW
- In-stream Tidal power through the Golden Gate appeared to be a major resource
- Wave power outside the Golden Gate is likely to be a much larger resource

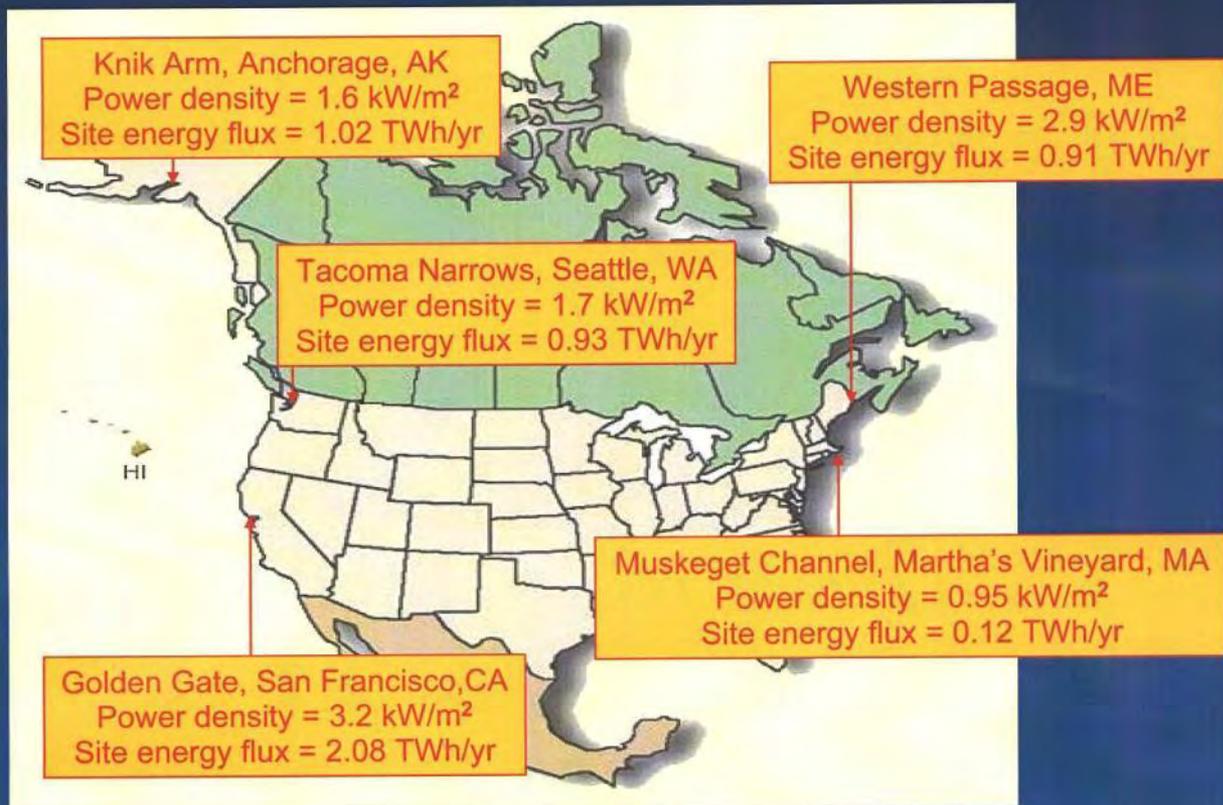
What's the difference: "In-Stream Tidal" Power and "Wave" Power?

- **In-stream Tidal power** – tides create strong currents at narrows such as the Golden Gate, Tacoma Narrows:
 - Submerged devices in the tidal flow
 - Many look like variations on a wind turbine
- **Wave power** – storms create waves a few to 30+ feet high
 - At least 5 groups of technologies proposed to capture wave energy

What is In-Stream Tidal Power?

- A new technology intended to reduce costs and impacts associated with old barrage projects
- **Emerging** technology, only 1 unit installed world-wide rated at more than 1 MW (MCT Strangford Narrows, Ireland)
- UK has been technology leader; government subsidies and tidal/wave power test sites in Scotland, Cornwall and Ireland
- In-stream tidal energy proportional to velocity cubed:
$$E = 1/2 \rho V^3$$

Tidal Stream Resources at EPRI Study Sites



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



Clean Current Power Ducted Turbine

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



SFPUC In-Stream Tidal Power Study: URS Scope of Work

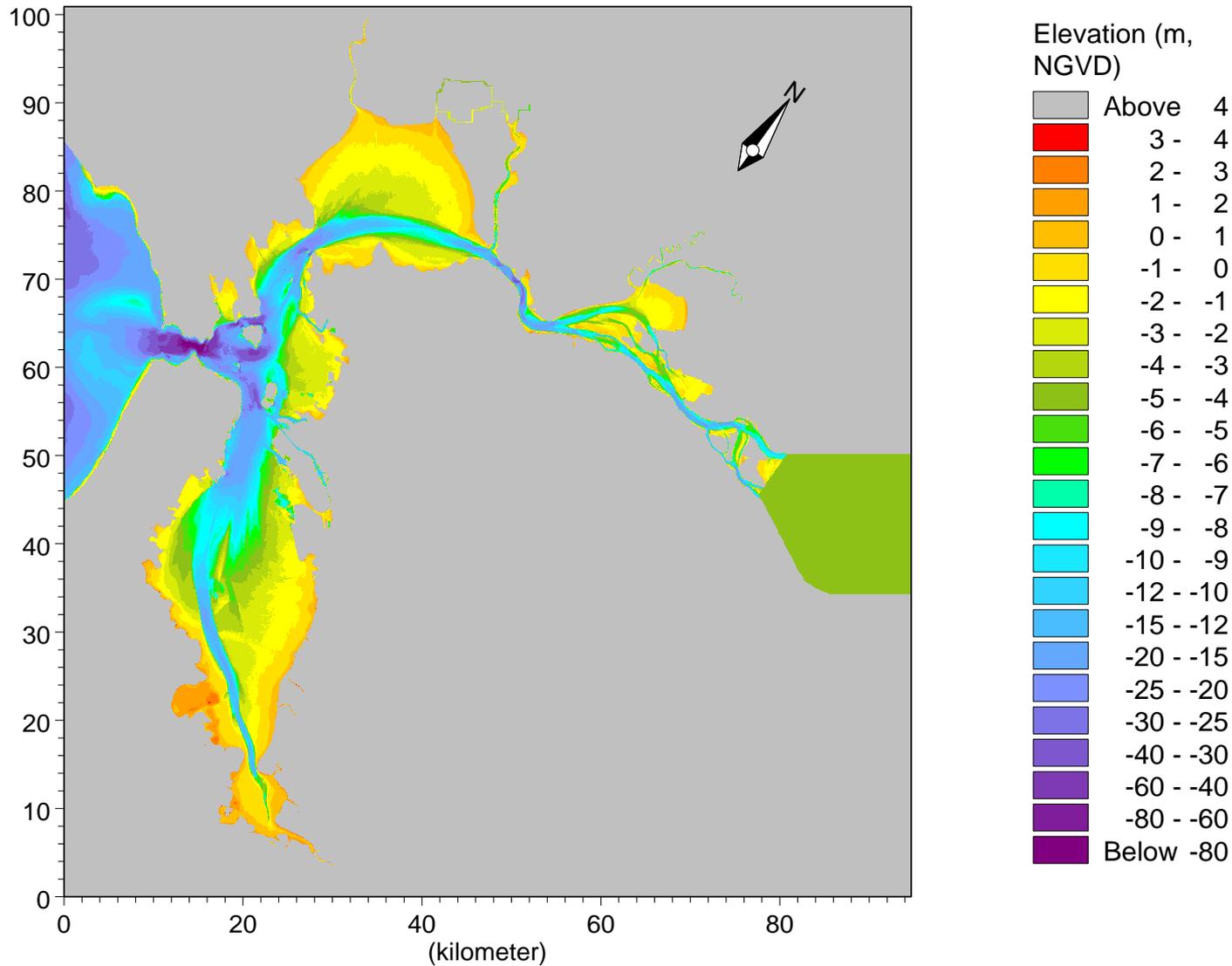
- Technology assessment
 - stage of development, impacts, costs
- Computer modeling of tidal power resource
 - how much power in the Golden Gate?
 - how much can be extracted without impacts?
- Stakeholder assessment
 - agencies, owners, interest groups, permits
- Develop recommendations for a Pilot Study



Total Tidal Energy Resource: Modeling

- 2-dimensional and 3-dimensional computer modeling using measured velocities to *calibrate* and *verify* models
- Models validated by independent expert panel (NOAA, USGS, academics)
- Model bathymetry updated to include latest USGS measurements

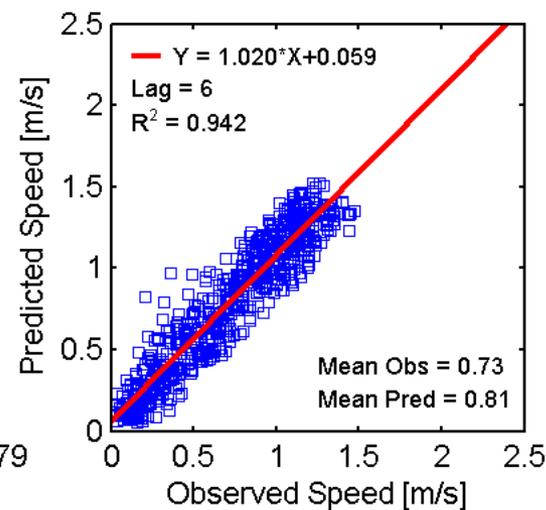
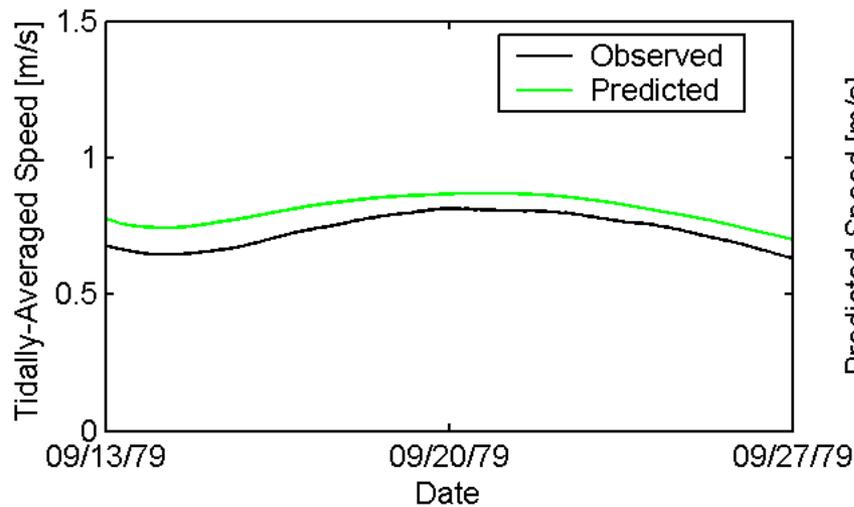
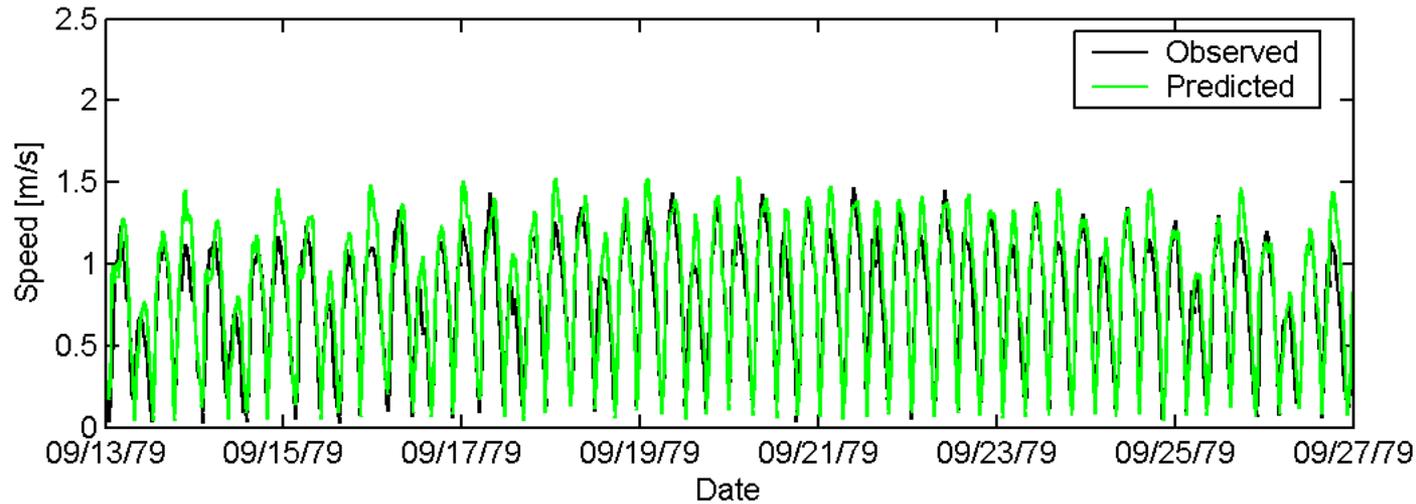
Computer Model Domain



Station Locations



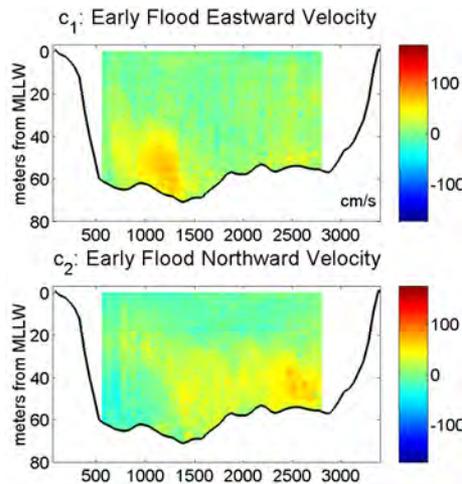
Speed at C1, 21m below MLLW



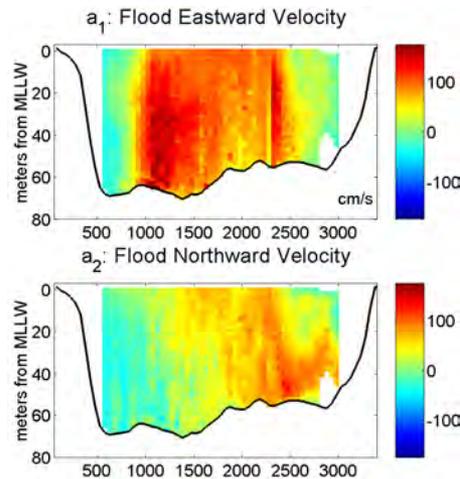
Velocity Structure, Golden Gate

(4-24-2007: Mark Stacey data set)

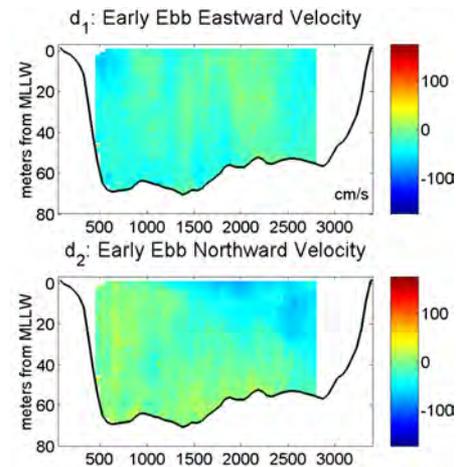
Early Flood



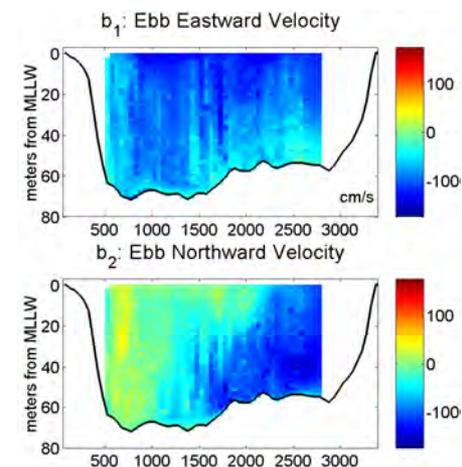
Peak Flood



Early Ebb

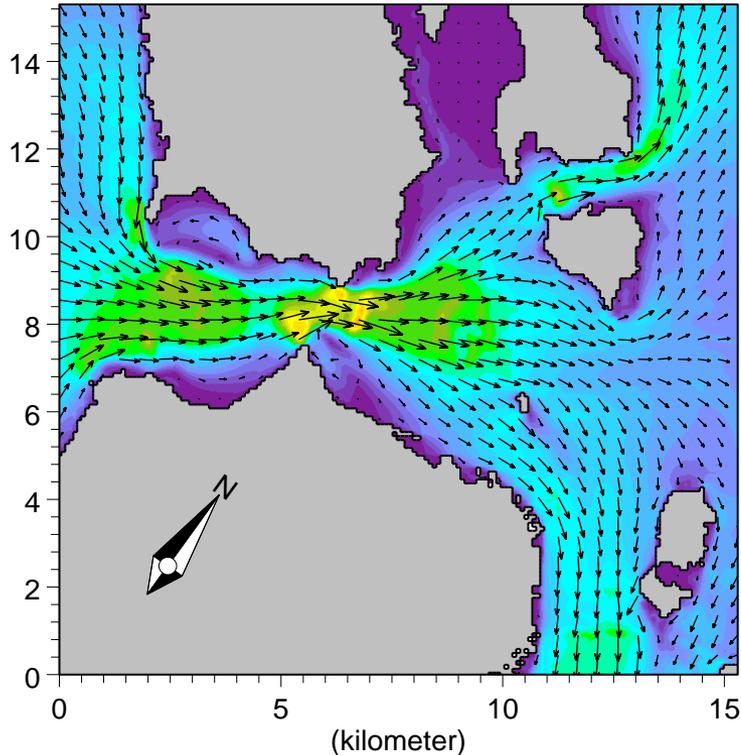


Peak Ebb



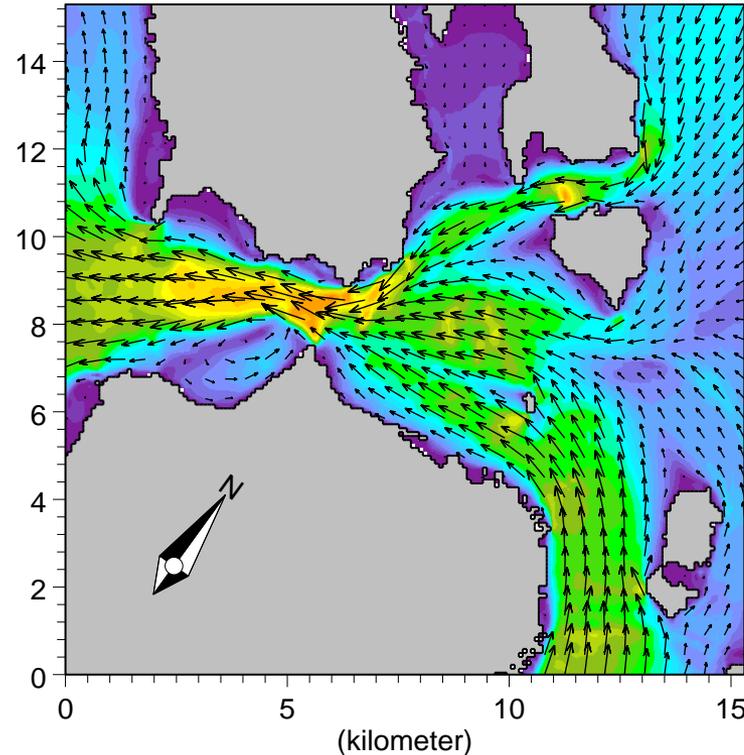
Current Speed and Direction During a Spring Tide

Max Flood



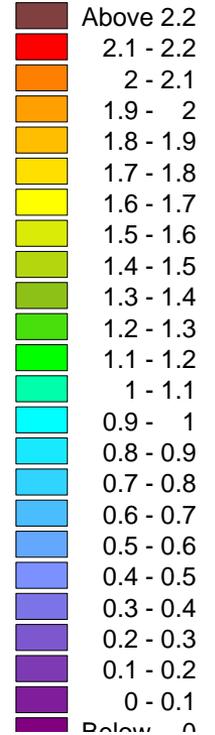
06/10/1980 19:30:00

Max Ebb



06/11/1980 01:30:00

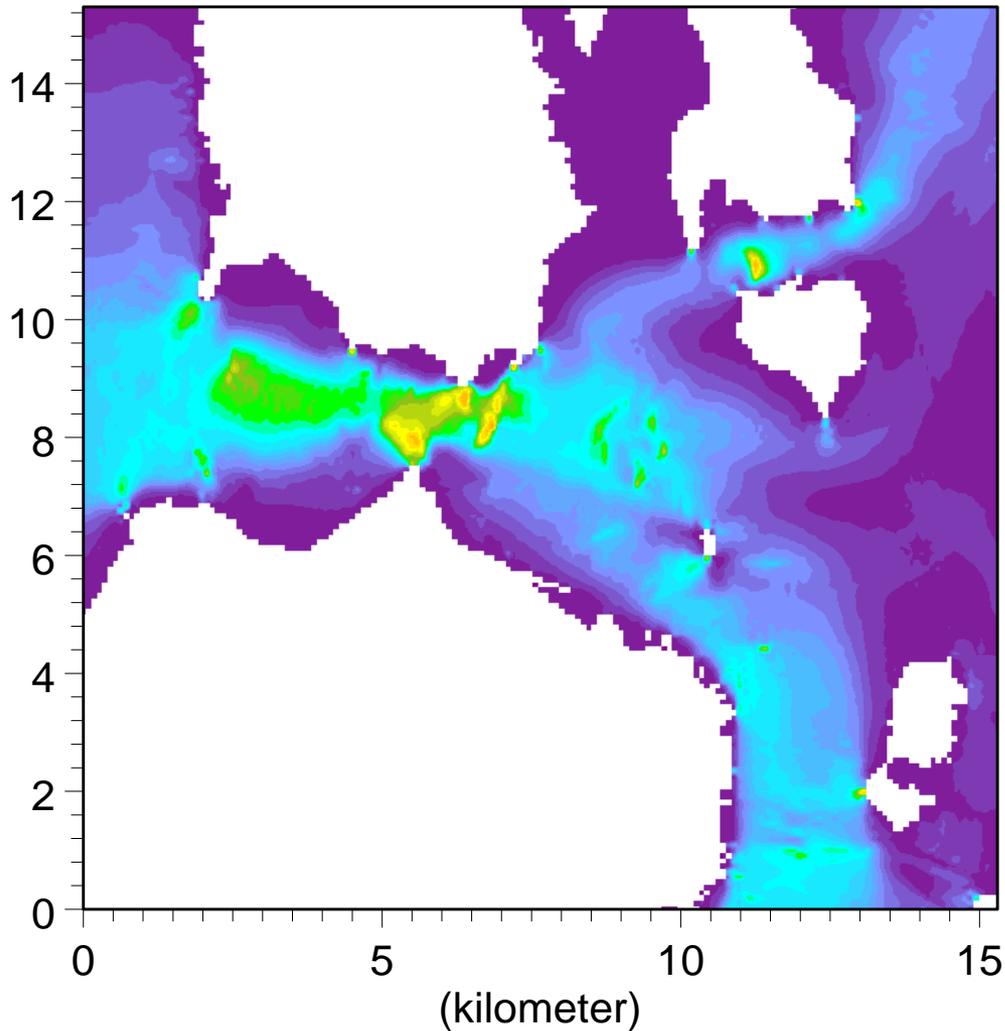
Current speed (m/s)



Mean Power Density

Four locations with greater than 1 kW/m²

$$P = \frac{1}{2} \rho \cdot A \cdot u^3$$



3D Model/Flythrough Animation Creation (separate file)

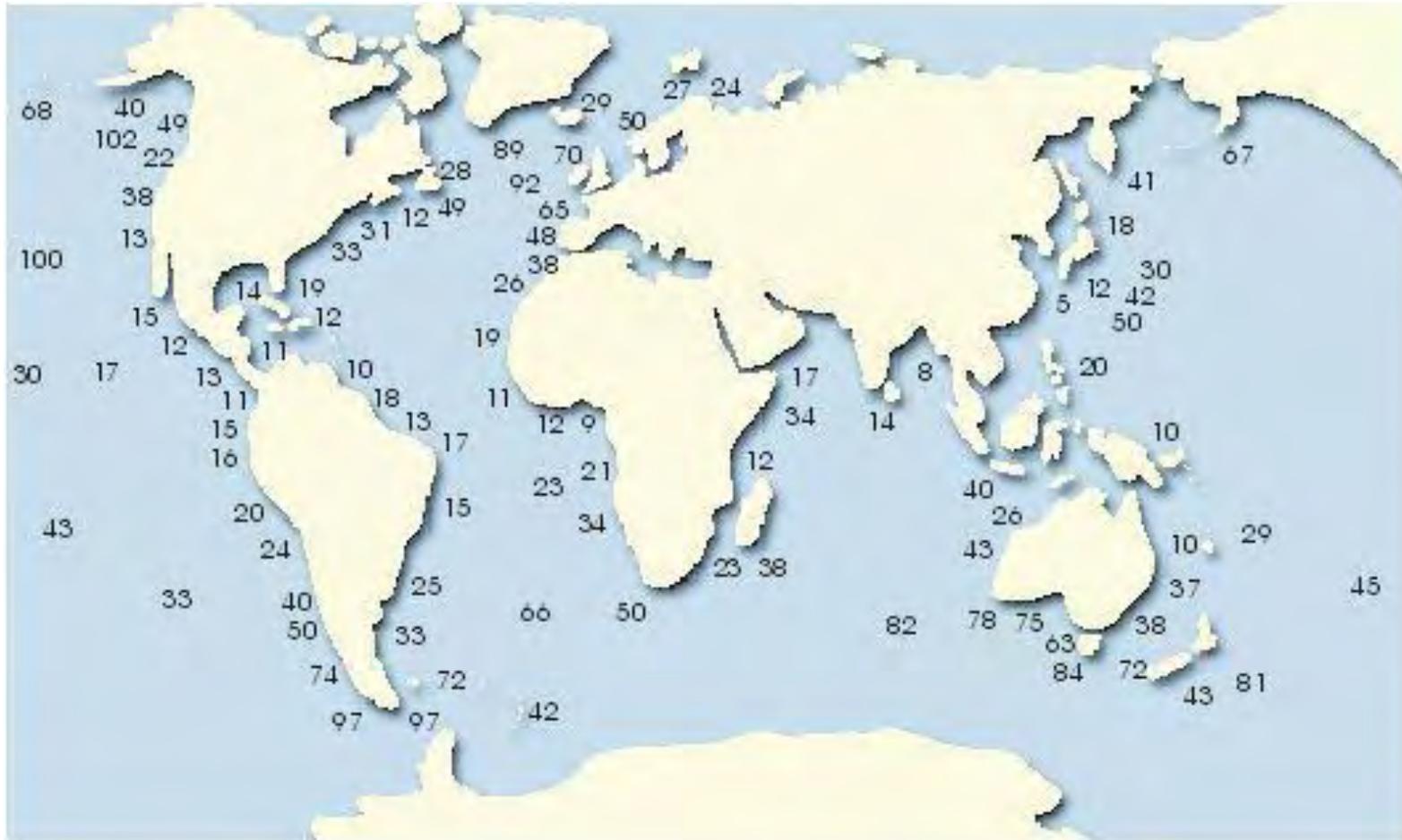
- Collected base data from various sources (including USGS, California Spatial Information Library, NOAA, Furgo, USACE, SFEI)
- Draped aerial imagery over elevation data for a realistic representation
- Obtained 3D model of the Golden Gate bridge and wind turbines, then scaled and converted to useable format for import to model
- Exported animation to an .avi media file

Total In-Stream Tidal Energy Resource – URS Estimate

- Average energy density in range 0.4 to 0.6 kW/m²
- Very localized sites with greater than 1.0 kW/m²
- Total average resource in range of 12 to 15 MW
- Extractable power in range of 1.0 to 1.5 MW
- Cost of Power: \$0.80 to \$1.40 / kwh

Wave power has arrived?

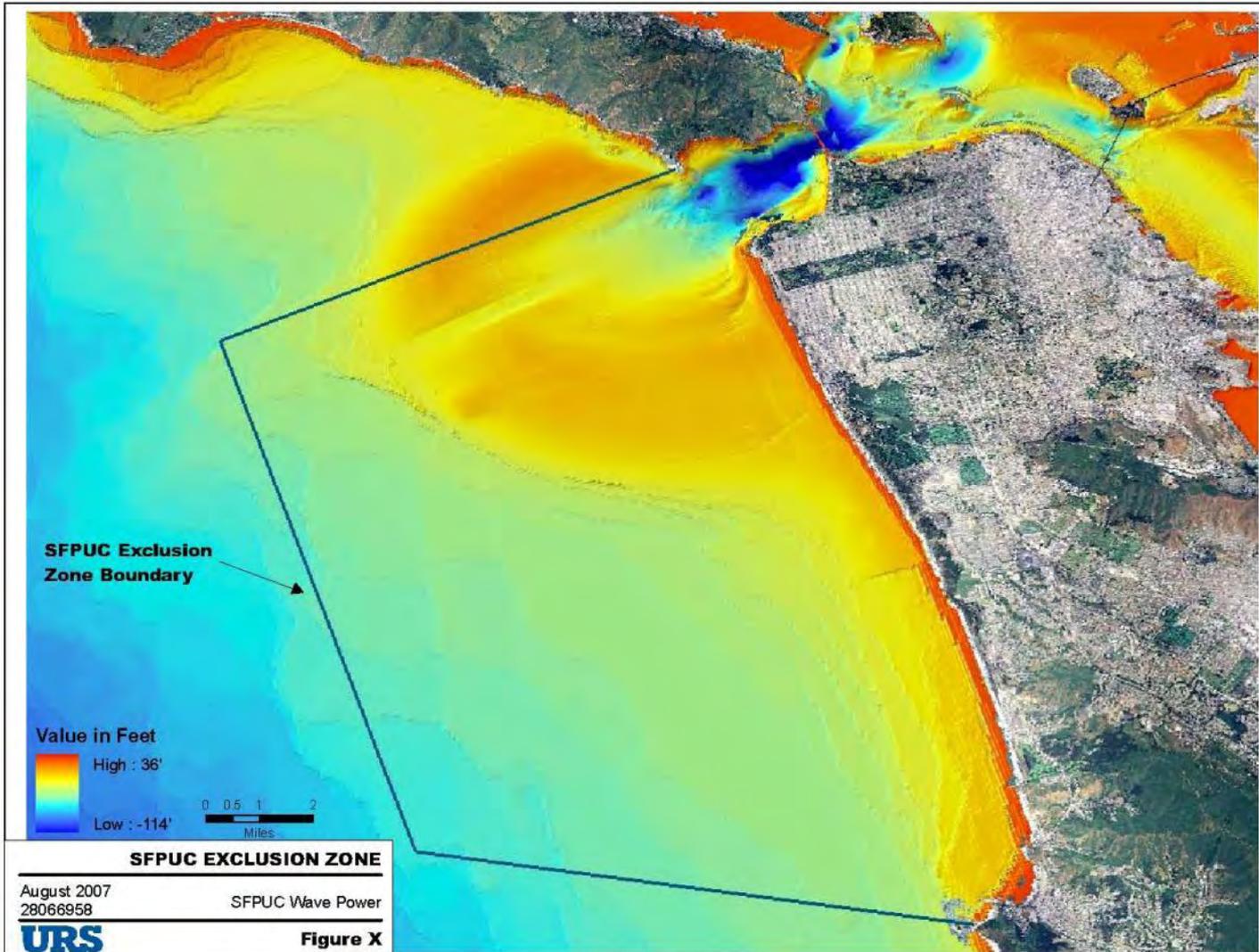
Wave energy in kW per meter of wave front



SFPUC Wave Study

- SFPUC feasibility study addressing wave energy resource, extraction technologies, permitting
- Deployed an ADCP wave gauge in September '08 to measure wave resource
- Goal is to identify 1 or more technologies for pilot studies

Exclusion Zone in Marine Sanctuary

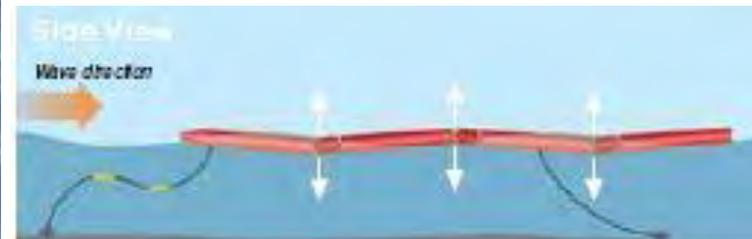
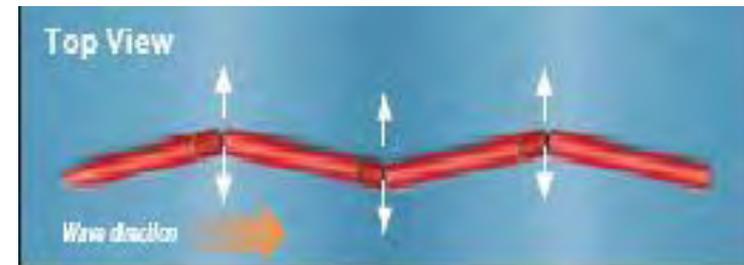
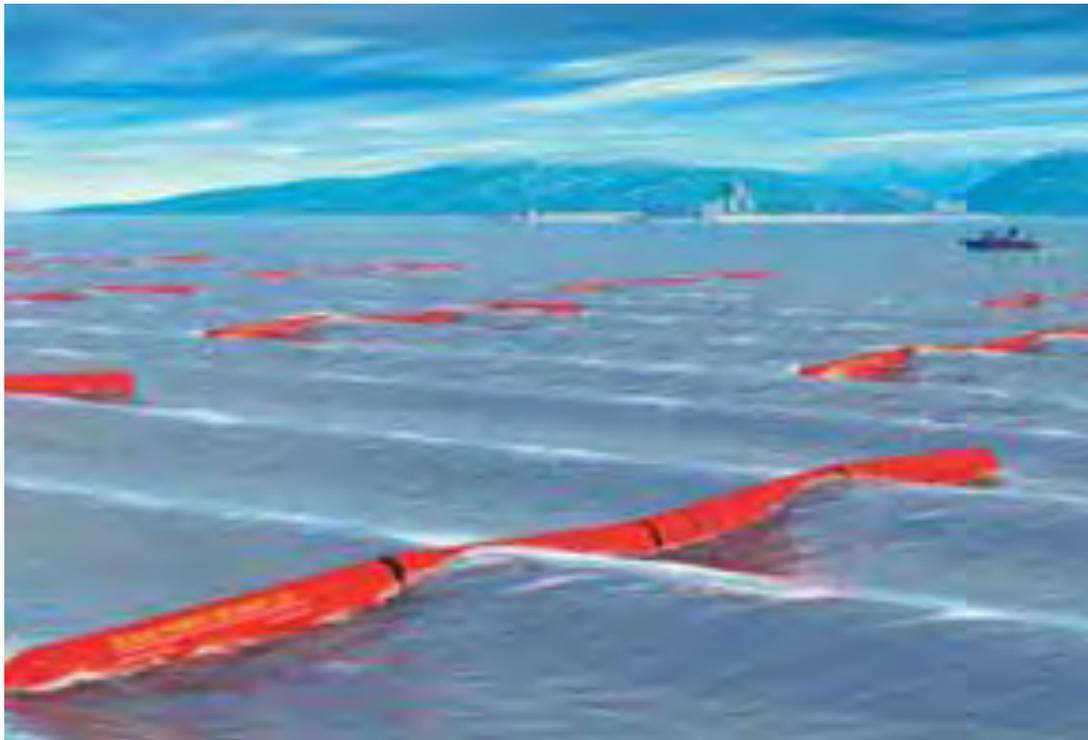




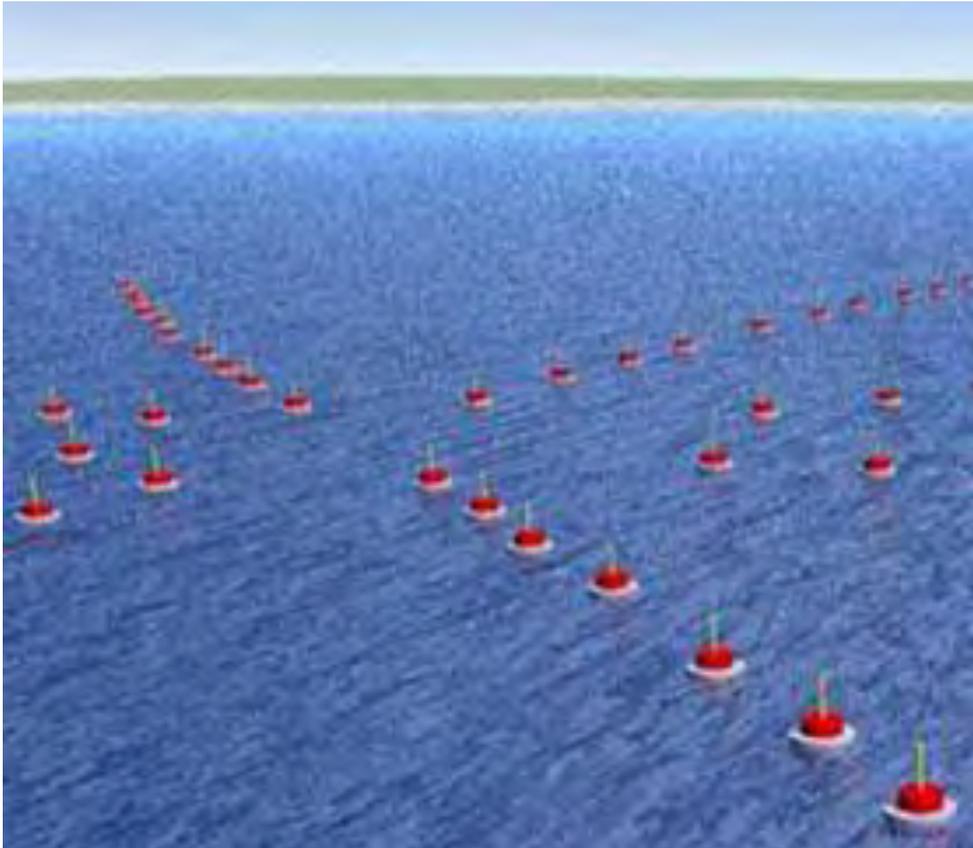
Types of wave devices:

- Pitching (Pelamis)
- Heaving (OPT, Finavera)
- Surging (bioWave, CETO)
- Overtopping (Wave Dragon)
- Oscillating water column (OceanLinx)

Types of wave devices: Pelamis



Types of wave devices: Finavera



Finavera AquaBuOY Array



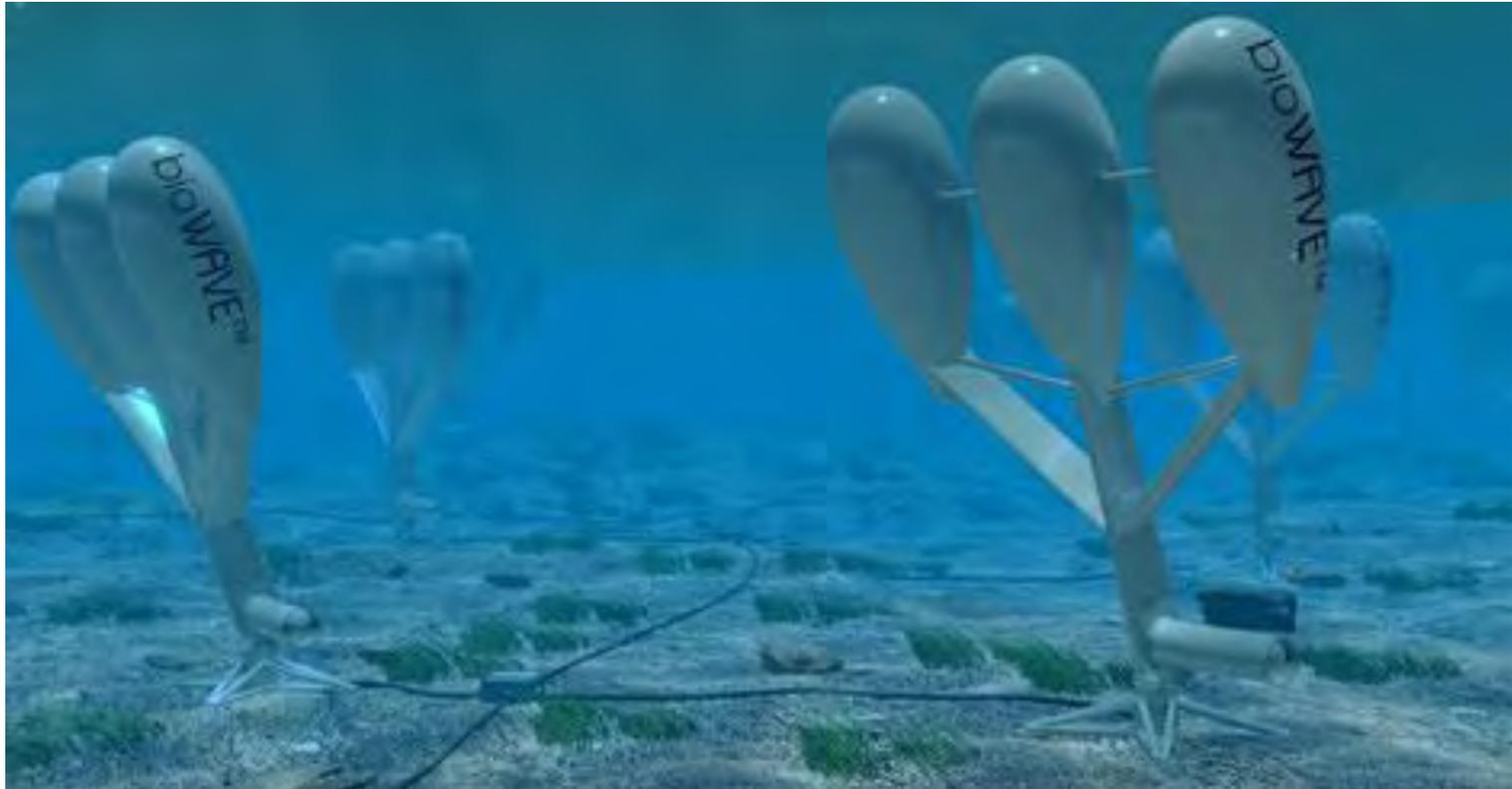
Types of wave devices: Ocean Power Technologies



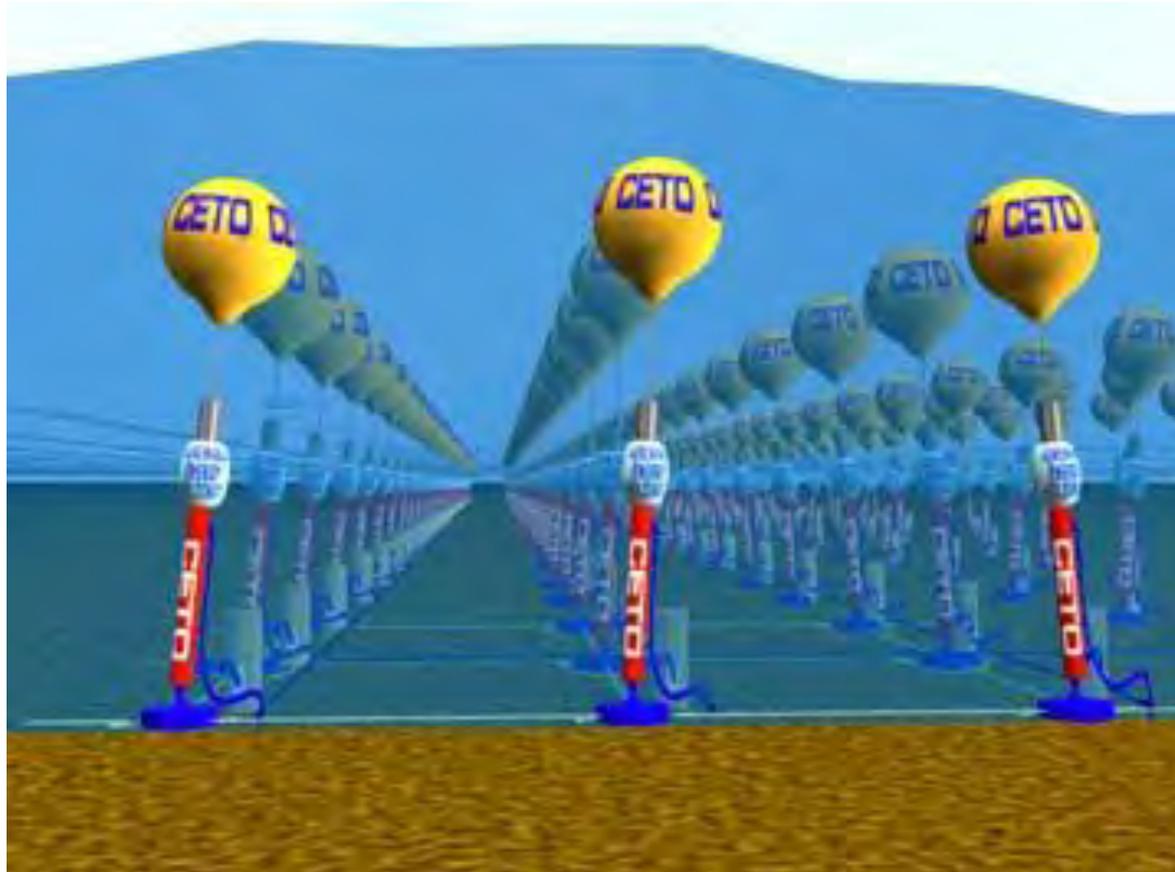
OPT Multiple Buoys



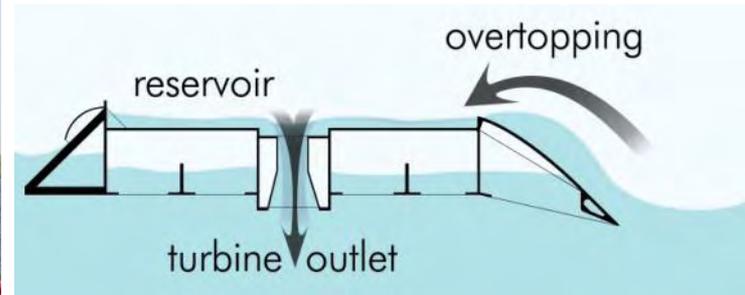
Types of wave devices: [bioWave](#)



Types of wave devices: CETO



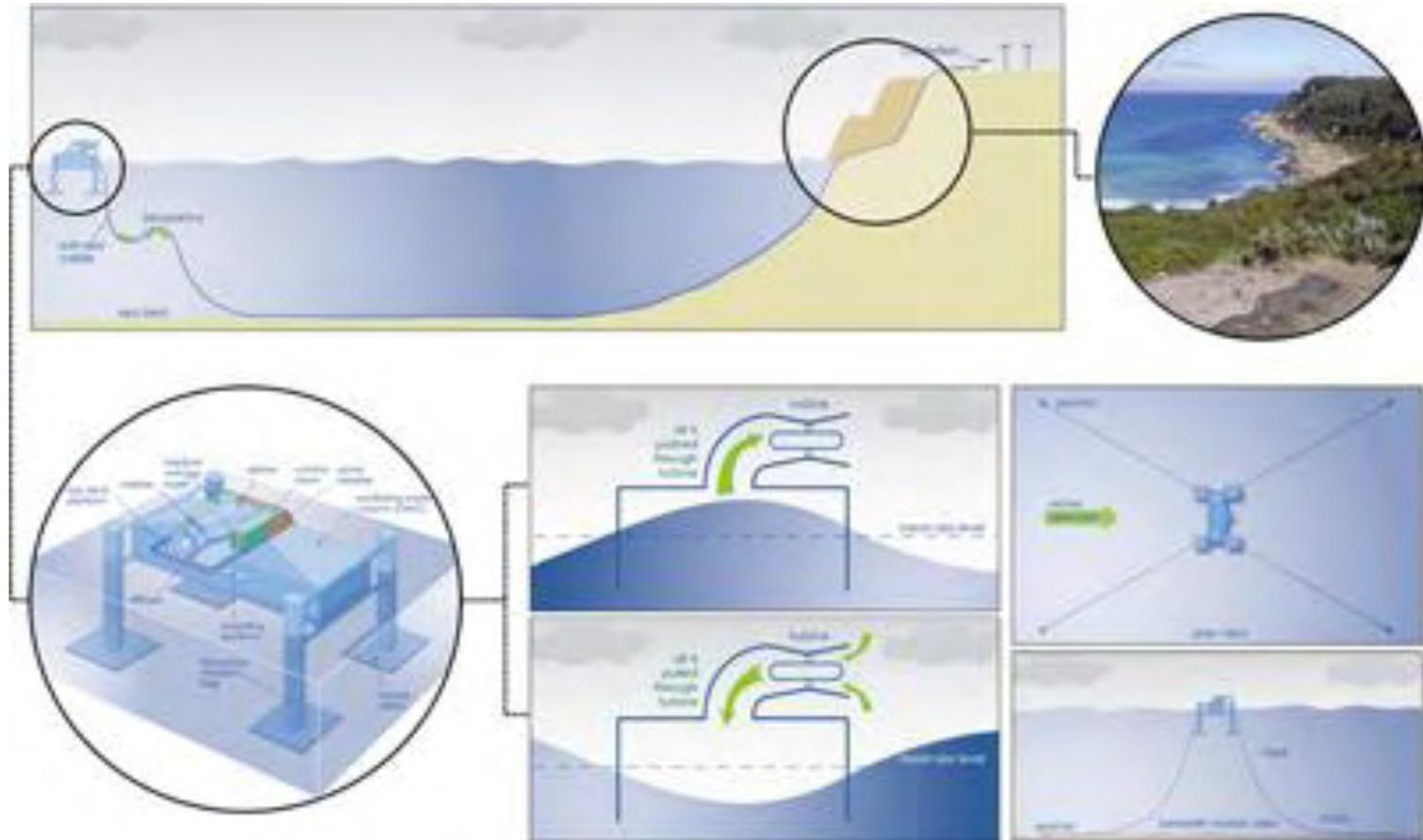
Types of wave devices: Wave Dragon



Types of wave devices: OceanLinx



Types of wave devices: OceanLinx



Wave power has arrived?

To be feasible:

- Costs need to be similar to those for voltaic solar power - order of 25 to 30 cents/kwh
- Potential environmental impacts
 - mooring lines can snag whales
 - submerged to minimize aesthetic concerns
 - recreational boating / fishing / ship traffic
 - reduced shoreline waves – less shoreline erosion and reduced surf
- Permitting – FERC / MMS, State & Local



Wave power has arrived?

“The possibilities of utilizing the forces of the sea’s waves will soon be manifest”

Adolph Sutro, 1887