Water Power Peer Review

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Hawaii National Marine Renewable Energy Center (HINMREC)

Richard Rocheleau, PI
University of Hawaii
rochelea@hawaii.edu
September 27, 2011

Wave Energy Conversion (WEC)

- To achieve TRL 8-9, developers need timely access to in-water test facilities to validate performance, durability, and environment impact of their technology

- Key objective of the Hawaii NMREC is to facilitate in-water testing via:
  - Development of permitted wave energy test sites for WEC systems up to ~ 500kW
  - Provide engineering/science/policy support to facilitate industry testing in Hawaii
    - Long and short term resource assessments
    - Numerical models for analysis of device performance
    - Baseline and post-test environmental studies
    - Materials testing and development
    - Support of permitting efforts
    - Policy Support

Ocean Thermal Energy Conversion (OTEC)

- **Development of pilot-scale and larger OTEC facilities hampered by high cost, lack of confidence in long-term performance, and environmental uncertainty:**
  - **Electricity generation and simultaneous desalinated water production has been demonstrated 24/7 at experimental scale (~ 250kW)**
  - **Economic models indicate scales > 50 MW needed to be cost competitive**

- **Key objective of Hawaii NMREC for OTEC is to reduce risks to move pilot scale testing forward via**
  - **Engineering support for MW-sized pilot plant design**
  - **Testing of critical components (e.g. heat exchangers) to reduce technical risk and uncertainty**
  - **Materials testing to improve cost and performance**
  - **Resource and environmental assessment**

Technical Approach

- **Leverage ongoing industrial activity and infrastructure in Hawaii**
  - OTEC Heat Exchangers Test Facility at NELHA, Big Island of Hawaii
  - Grid connected 40 kW WECS at Marine Corps Base Hawaii, Oahu
  - Utility (MECO)/WEC developer partnership at Pauwela Pt., Maui
- **Leverage broad UH faculty expertise to address industry**
  - Mechanical engineering, ocean engineering, oceanography, geology/geophysics
  - Direct industry support and research activities at UH
  - Oceanographic data base, numerical modeling, resource assessment and environmental impact studies
- **Leverage ongoing Department of Defense interest and investment in Hawaii ocean energy programs**
  - ONR - component & system testing, environmental studies, novel system design
  - NAVFAC - environmental surveys & permitting, infrastructure
- **Disseminate findings via Internet (http://hinmrec.hnei.hawaii.edu/)**

Budget Summary

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- **Budget Period 1: 9/15/2008 to 9/14/2012, $3,311,414**
  - **Phase 1: March 2009 thru Sept 2010, $ 978,048**
  - **Phase 2: Sept 2010 thru Sept 2012, $ 2,333,366**
  - **Expenditures thru September 2011**
    - **DOE: ~ $ 1.9 million**
    - **Cost share: ~ $ 1.9 million**
- **Budget Period 2: 09/15/2012 to 09/14/2014**
  - **$2,204,738. requested**

- **Expenditures on track to complete BP-1 activities.**
- **Cost share secured for BP1 and BP2**

Expenditures History					
FY2009		FY2010		FY2011	
DOE	Cost-share	DOE	Cost-share	DOE	Cost-share
[$135K]	[$174K]	[$441K]	[$1014K]	[$1305K]	[$717K]

Milestones

- Implemented MOUs and IP agreements with industrial partners: e.g., LM, OPT, OCEANLINX, OTEC International, Natural Powers
- Facilitated communication; (i) between academia & developers to ensure research usefulness & (ii) between developers & utilities
- Provided design advice to WEC & OTEC developers
- Attained NEPA compliance for field work in Kaneohe Bay and Pauwela Maui. Only CatEx activities at NELHA and no field work at Makai Pier
- Established ongoing working relationship with federal (NOAA, FERC, BOEM) and state permitting and licensing agencies
- Maintained web page as a source of information; and, disseminated findings through journals and conference proceedings
- Developed a concept to expand existing US Navy infrastructure at Kaneohe Bay from one into multiple-berth grid-connected wavehub

Leverage MECO-OCEANLINX partnership to develop utility intertied commercial scale wave energy test site

- Facilitated meetings to establish areas of responsibility:
  - ✓Oceanlinx: Provide & install WEC device
  - ✓MECO: Provide submarine power cable & land infrastructure
  - ✓HINMREC: Characterized wave resource, provided UH archival bathymetry, and conducted design reviews

- Challenges:
  - ✓Installed cost for 500 kW device > $9M including EIS
  - ✓PUC has not approved MECO's capital expenditures

HINMREC activities on hold pending new agreement to cover capital costs

Accomplishments & Results: WETS

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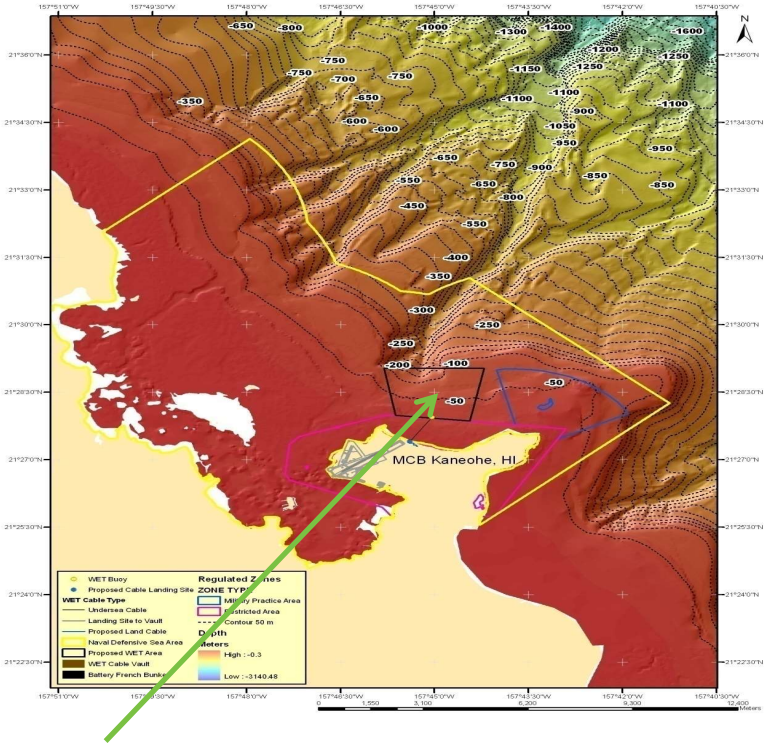
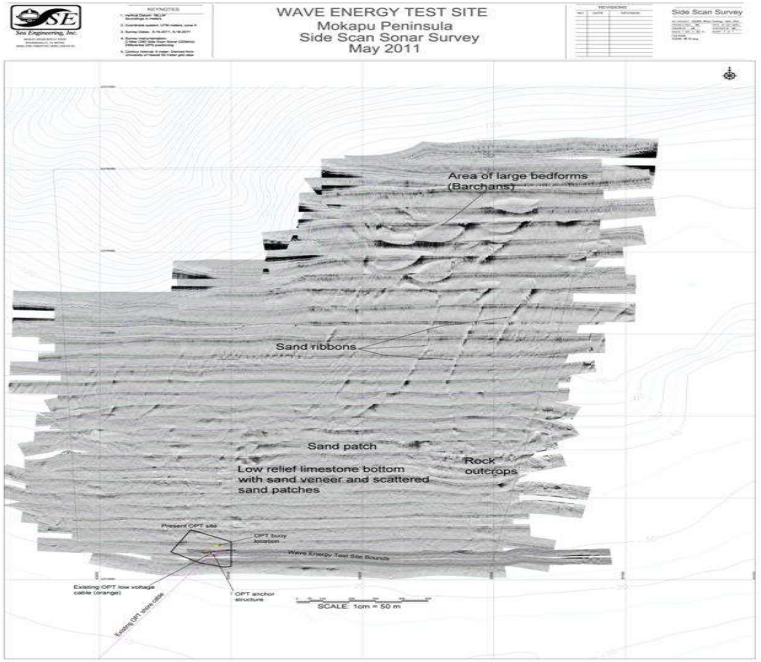
HINMREC collaborating with NAVFAC to complete EA for expanded multi-berth facility at Kaneohe Bay (MCBH)



5 km^2 area reserved by USMC for additional berths

HINMREC funded surveys required for EA and facility design (power cable routing & moorings):

- Side scan sonar survey completed
- Multiple-Beam survey completed
- Bottom/soil survey planned



Side Scan Sonar by Sea Engineering (May 2011)

Accomplishments and Results: University of Hawaii support activities

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Available (**http://hinmrec.hnei.hawaii.edu/**) and used by developers:

- Design oriented high resolution wave resource assessment and characterization of five sites throughout Hawaii in format required by designers & developers
- High resolution world-wide ocean thermal resource assessment and design oriented characterization of Kahe Point pilot plant site
- Seawater corrosion resistant ceramic-polymer coatings testing results
- 10 MW OTEC pilot plant conceptual design based on SOA components and standard offshore practices
- Documentation of comparisons between already regulated industrial activities and ocean energy systems to define differences in support of federal and state agencies permitting process:
  - OTEC deep seawater discharge
  - Visual and crowding impact of WEC arrays over coastal regions

Accomplishments: Wave Forecasting & Hindcasting

Computed wave energy potential for five sites:

- ✓Power Flux (kW/m);
- ✓Wave Spectra, S (ω);
- ✓Extreme conditions (H_s,T_p)
- ✓Time windows for deployment & operation

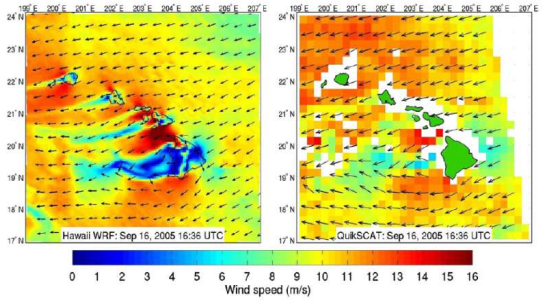


Fig. 8. Comparison of wind fields from Hawaii WRF and QuikSCAT for Case Study 2.

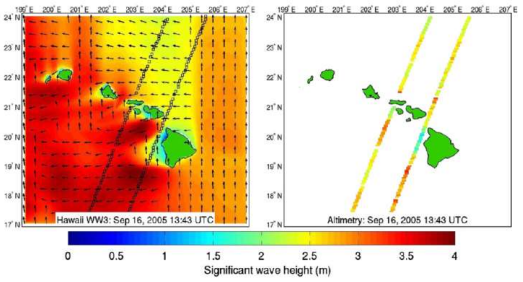
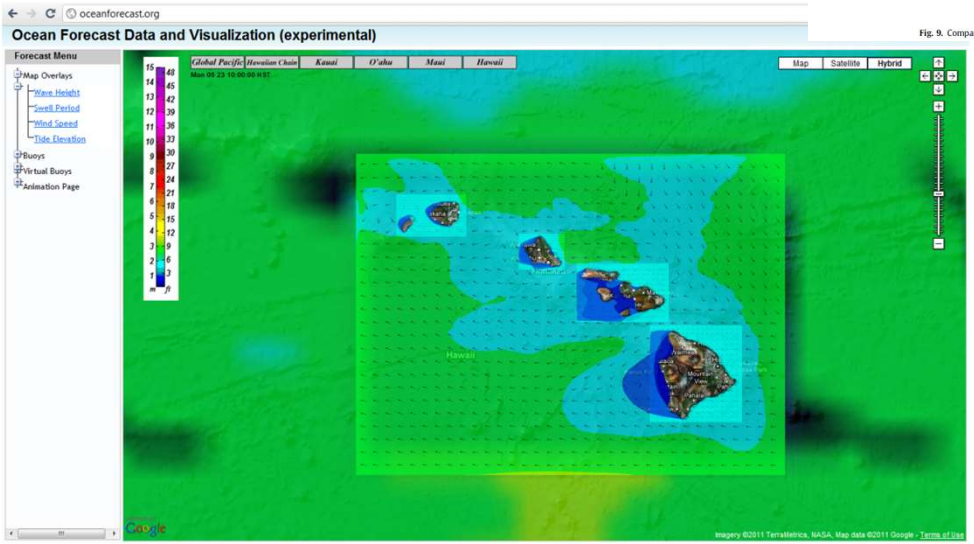


Fig. 9. Comparison of wave fields from WW3 Hawaii and altimetry for Case Study 2.

Validated wind data

Wave model validation: WW3 vs. Altimeter & field observations



Outcome

High resolution wave model provides: daily wave forecasts and wave energy hindcasts

Accomplishments: Thermal Resource

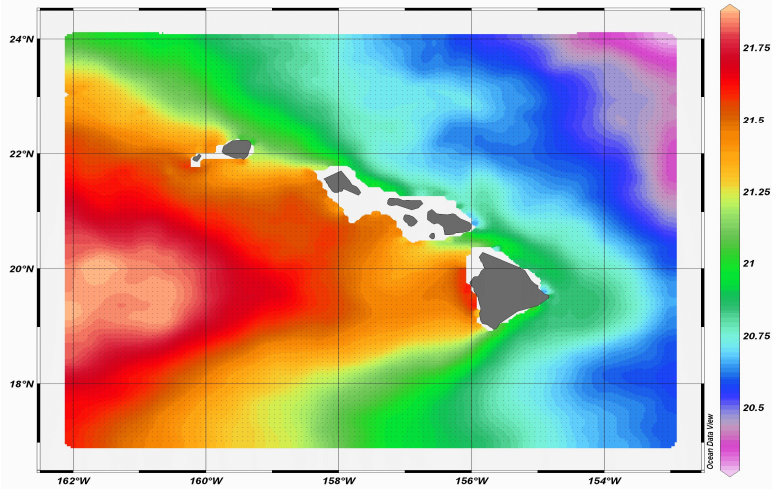
- Documented annual, monthly and daily averages of worldwide and Hawaii resource,

$$\Delta T = T_{20m} - T_{1000m}$$

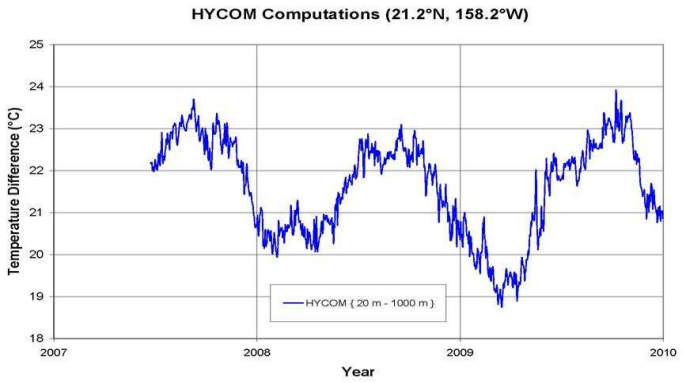
- Initiated modeling to address resource degradation and global sustainability to improve accuracy of extractable resource estimate

- Characterized long-term daily ΔT average at Kahe Pt. pilot plant site

Hawaii ΔT: Two Year Average



Kahe Station ΔT: Four Year Daily Avrg.

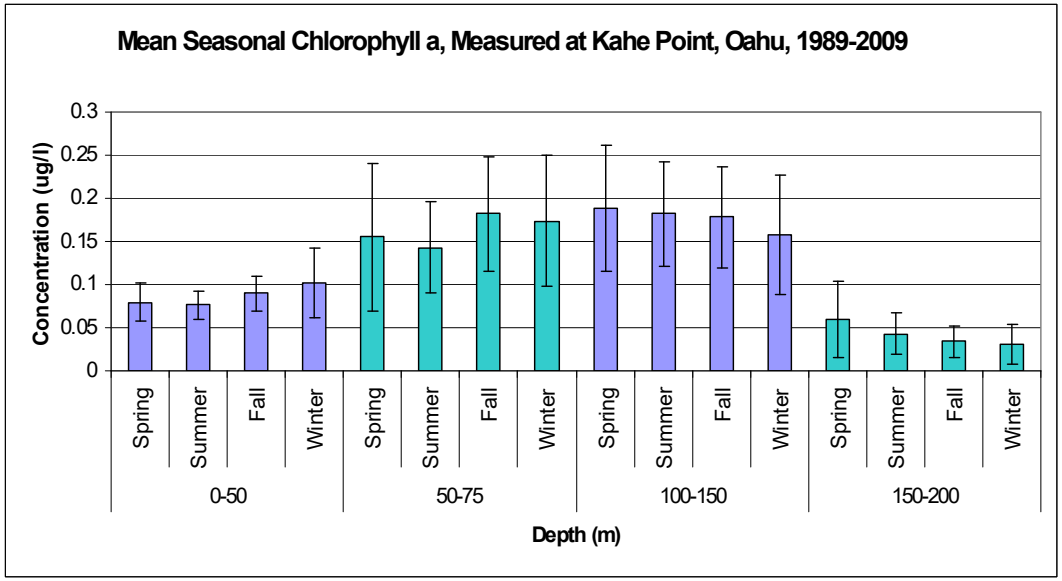


Accomplishments: OTEC Environmental

Kahe Pt.: Pilot Plant Site

• Gathered & documented oceanographic database & numerical models from UH & MOE to determine plume equilibrium depth

• Provided background information and assisted NOAA in holding and documenting Environmental Impact Workshop with engineers & oceanographers



Findings:

• Plume equilibrium depth below photic layer ~120 m in Hawaii

• Proposed parameters to monitor as impact indicators during plant operations:

- ✓**Chlorophyll a** (*nutrients*)
- ✓**Temperature/salinity/oxygen** (*physical & chemical*)
- ✓ **pH** (*carbonate system*)

Accomplishments: Corrosion/Biocorrosion

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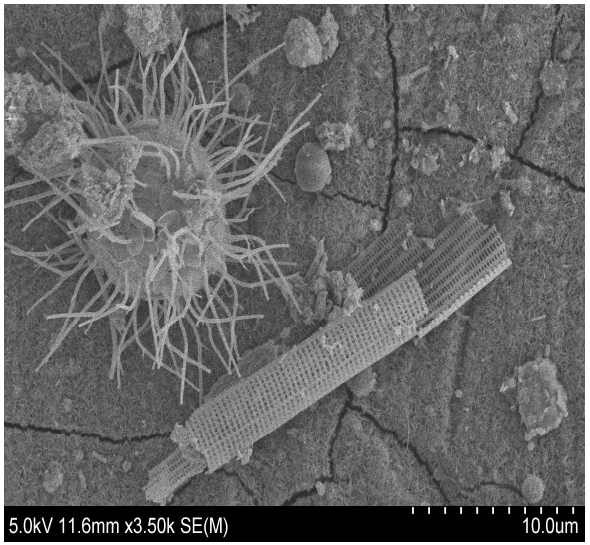
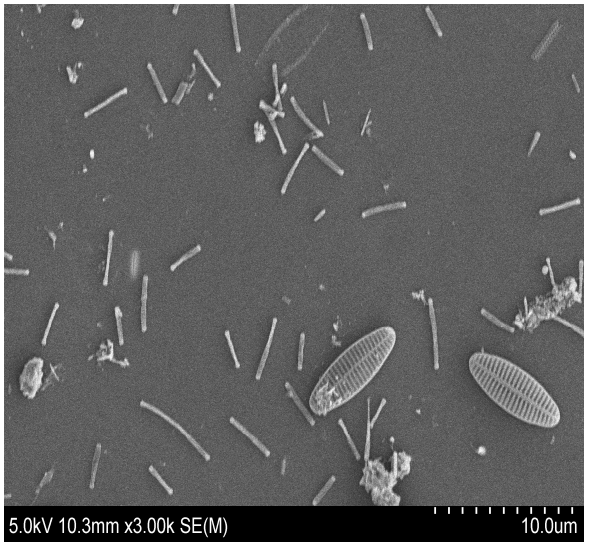
- Built upon seminal DOE/ANL research (‘83-‘87) to evaluate coating systems for aluminum alloys (UH Hawaii Corrosion Laboratory, HCL)
- HCL coats form an impervious thin layer and show antifouling characteristics

  - ✓ Six hundred coupons coated for 12-month seawater immersion test at UH facility
  - ✓ Information shared with MOE for testing phase at the OTEC HXs Facility
  - ✓ 4-week submersion shows reduction in fouling community development (photo width: 40 μm)



Uncoated (4-weeks)



Coated (4-weeks)

Next Steps – through Sept 2012

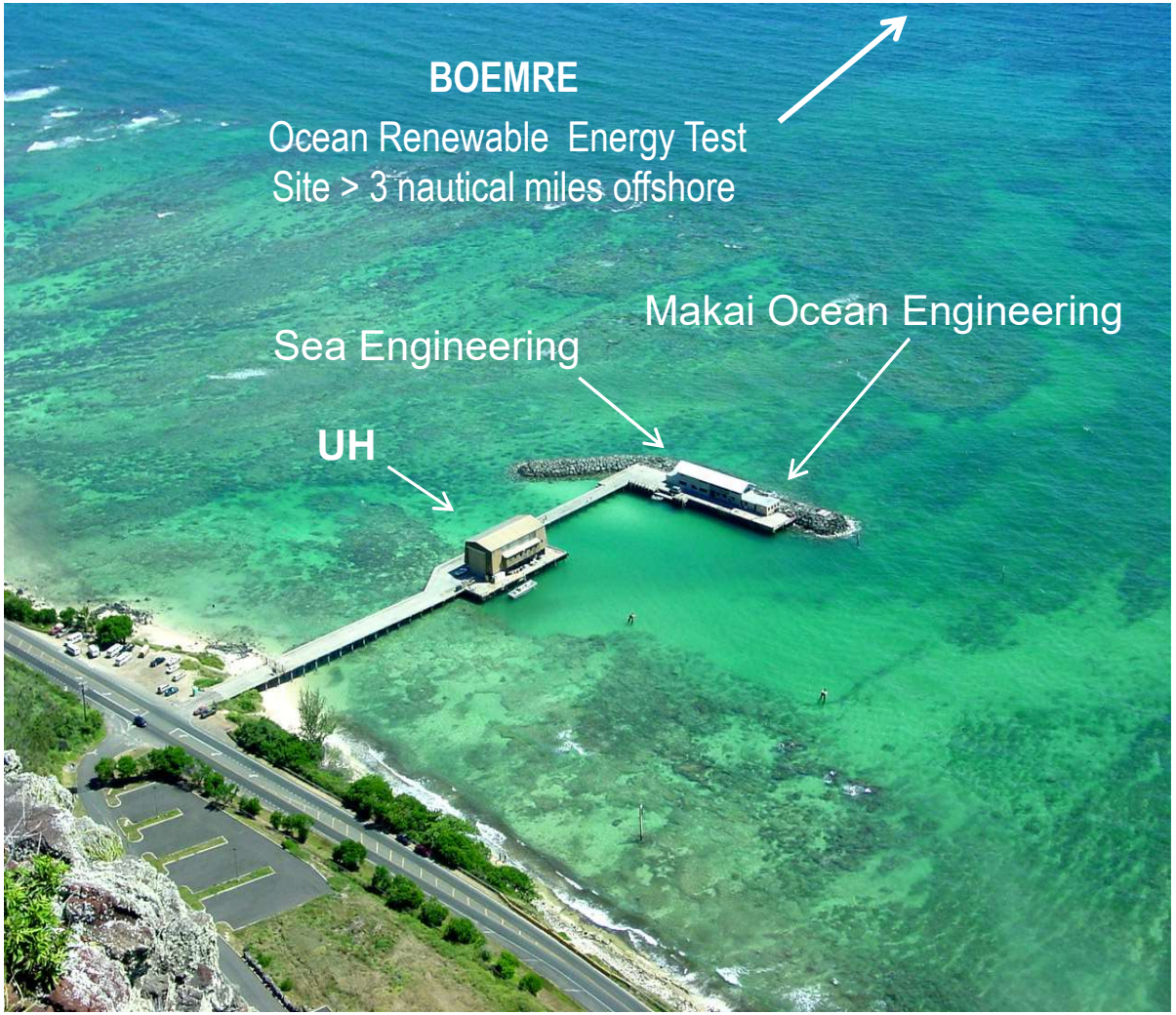
Pauwela, Maui - on hold until OCEANLINX identifies additional funding

Makai Research Pier – continue testing of emerging small scale (<10kW) WEC devices (TRL 7) using ONR funding and participate on Research-Lease deliberations under DOI Task Force

Kaneohe Bay - Complete EA, bathymetric surveys, continue mini-hub infrastructure design and seek funds for acquisition ($6M to $9M) in coordination with NAVFAC

OTEC - Continue supporting developers in design and permits phase; support HXs testing at NELHA (NEPA compliance under CatEx

Next Steps – through Sept 2012: Makai Pier



- Sea Eng. and Makai Ocean Eng. are HINMREC partners
- UH fully instrumented for WEC testing in protected waters (TRL 7)
  - –6 m x 15 m moon pool
  - – 3.5 m water depth
- BOEMRE (DOI) working on research lease for the Outer Continental Shelf (3 nm to 200 nm offshore)

Next Steps – through Sept 2012: OTEC Field Work

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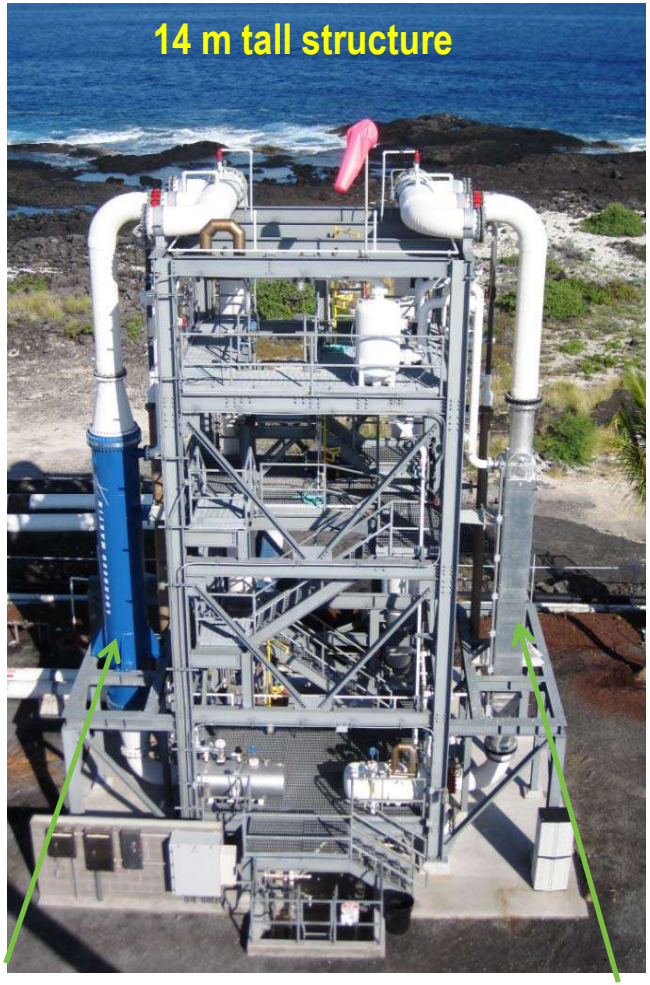
Photo courtesy of MOE, August 2011



S&T Condenser (by LM)

Brazed Fin Evaporator (by CHART)

OTEC Heat Exchangers (HXs) Test Facility at NELHA

- Designed & operated by Makai Ocean Engineering
  - Integrated NH_3 system
  - Deep (600 m or 900m) & surface seawater system
- NAVFAC funded infrastructure
- ONR (via HNEI) funded development & testing of advanced designs of aluminum HXs
- UH (HINMREC) corrosion & biocorrosion testing results to be incorporated into testing program at NELHA
- HINMREC to support future testing (CatEx activity)

Next Steps – through Sept 2012: OTEC Desk Studies

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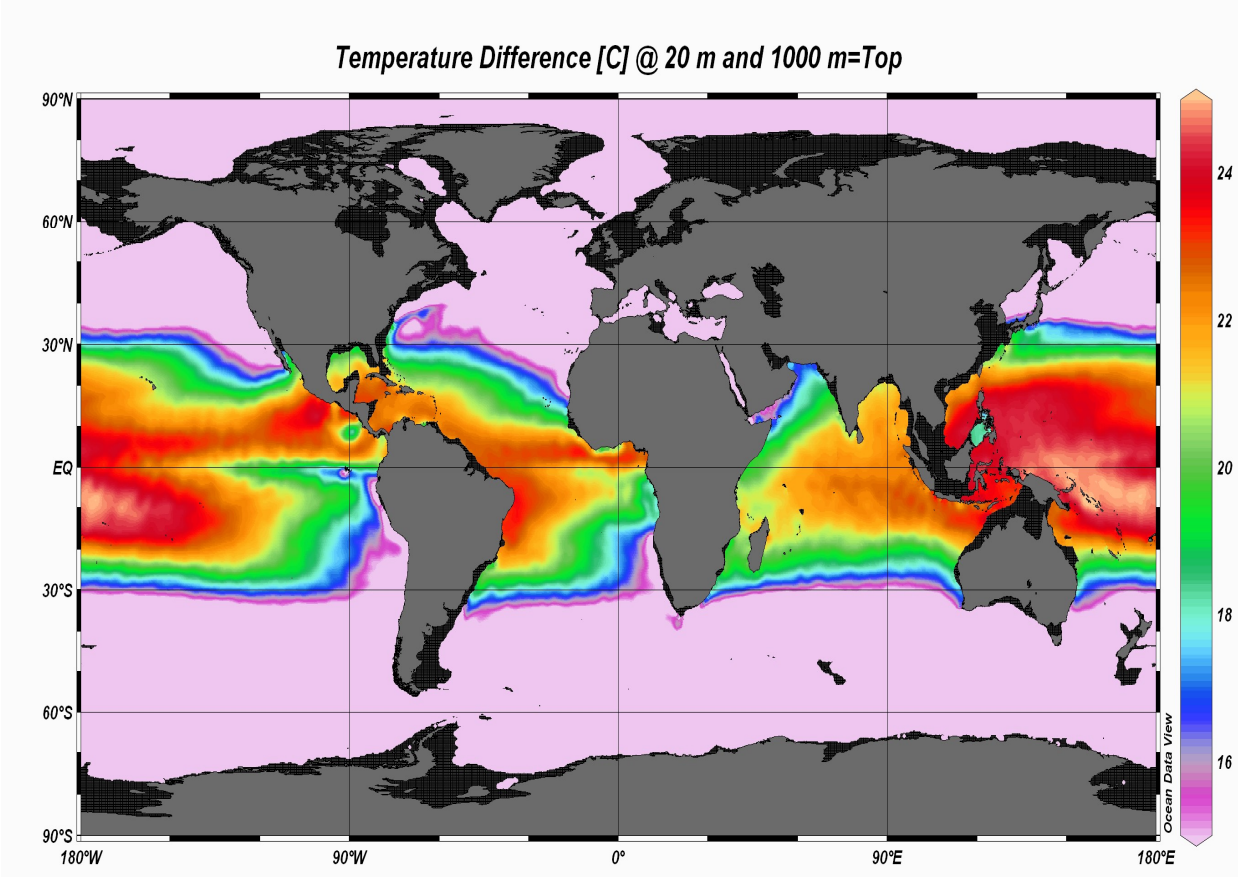
98 Nations with appropriate resource within their EEZ implies market potential for future USA based OTEC industry



Annual Average ΔT with higher resolution and finer details than 80's Maps

- Implement web-based interactive atlas to determine plant power output for user inputted location (Long/Lat)
- Upgrade model of worldwide extractable thermal resource

Next Steps – through Sept 2012: University of Hawaii

- Complete WEC array numerical modeling to estimate ocean area requirements
- Publish PC based seakeeping and structural model of OTEC plantship with cold-water-pipe
- Conceive and document protocol for monitoring environmental impact of OTEC operations using parameters already identified
- Upgrade wave hindcast model to examine inter-annual cycles and extreme events
- Continue work with federal agencies and state energy office to streamline permitting process for ocean energy projects

Future plans/challenges – beyond 2012

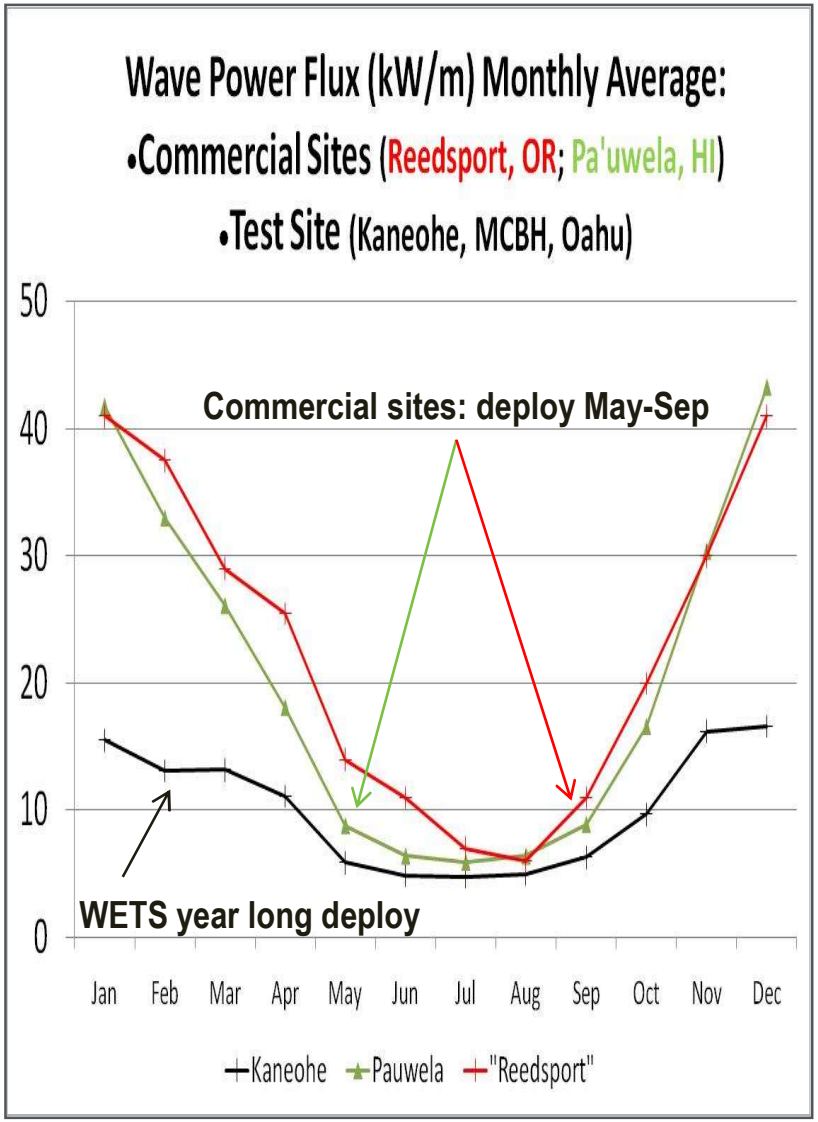
- Continue testing phase at OTEC HXs Facility *(TRL 5)*

- Continue providing developers with engineering and environmental tools & services required to evaluate WEC and OTEC designs

- Leverage DOD & DOE funding to achieve fully operational multiple-berth WETS facility in Kaneohe Bay *(TRLs 8-9)*

  - ✓Navy/MCBH – Provide/host test site, use/purchase power
  - ✓HINMREC – Operate & manage
  - ✓Developers – Responsible for: device, mooring, connection to socket, user fee *(plug & test)*

Why WETS at MCBH



- Leverages DOD/DOE funding

- Year long deployment/retrieve authorized by US Army Corps

- Wave resource suitable for testing under varied conditions and scales

- Select winter days with energy four times monthly average allows for survival testing

- Record of no-significant-adverse env. impact

- Area secluded from general public

- Close to metal shops & shipyards (~ 30 km)

- HINMREC partners 10-years site experience:
  * OPT design & operations
  * Sea Eng cable laying; WEC deploy & retrieve

- Expansion of existing site expected to be cost competitive compared to new site