



Sandia
National
Laboratories



Marine Energy for Guam

Dr. Andrea Copping
Hayley Farr

Pacific Northwest National Laboratory

Megan Anderson
Sandia National Laboratories

In partnership with:

University of Guam
Guam Power Authority
Makai Engineering

September 2026



PNNL is operated by Battelle for the U.S. Department of Energy



Today...

- Meeting energy needs of a remote island
- Generating energy and cooling: OTEC and SWAC
- Using wave energy for Guam
- Next steps





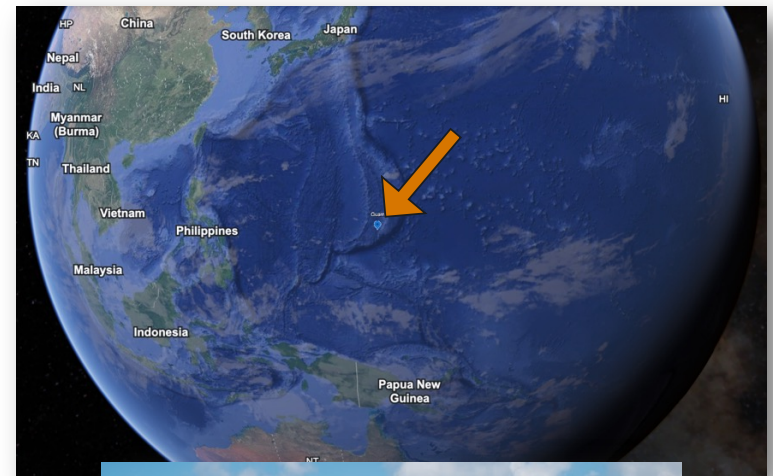
Meeting energy needs of a remote island

- Understanding generation and distribution of power
- Assessing loads and specific uses of power
- Examining specifics for the location:
 - Appropriate renewable sources
 - Hazards
 - Economic costs and benefits
 - Additional uses of renewable power
 - Potential effects on the environment
 - Community values that must be considered
 - Techno-economic analysis of renewable sources
- Different scenarios for different islands
- Ensure the energy solution is fit for purpose

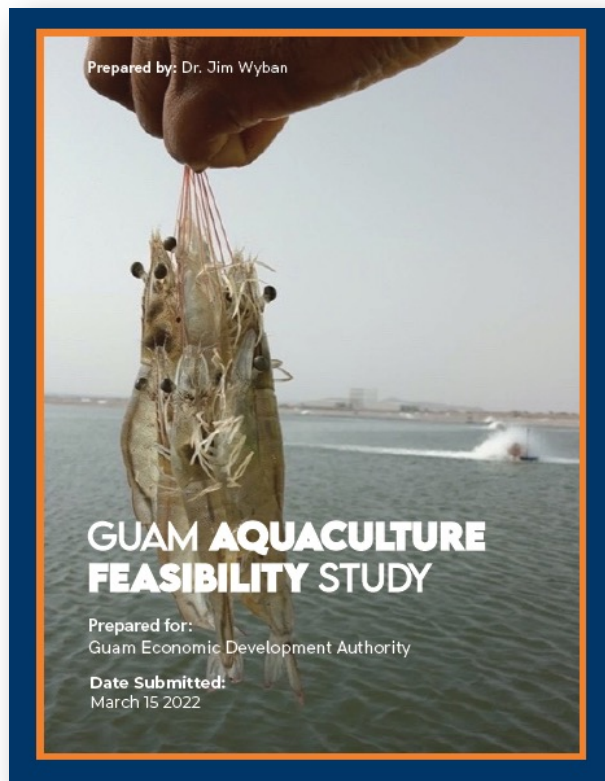


Power generation for Guam

- Electricity generated from imported diesel and some solar PV
- Single electrical utility - Guam Power Authority
- Air conditioning is large load
- Important strategic US security location
- Land is limited for more PV expansion
- Wind energy not really feasible
- Adequate freshwater available on most of the island
- Almost all seafood & supplies imported; aquaculture could be expanded
- Power from the ocean is very compelling



Background of this project



- Began as a community scale project to assess marine energy as power source for a planned aquaculture facility
- Wave energy might be a good power fit for aquaculture
- After typhoon Mawar, project expanded to assess marine energy systems as power source for Guam to stabilize grid and reduce A/C load on grid
- Recent typhoons underscore the needs
- Project assesses infrastructure needs, technical feasibility, costs, and impact to Guam's environment and economy

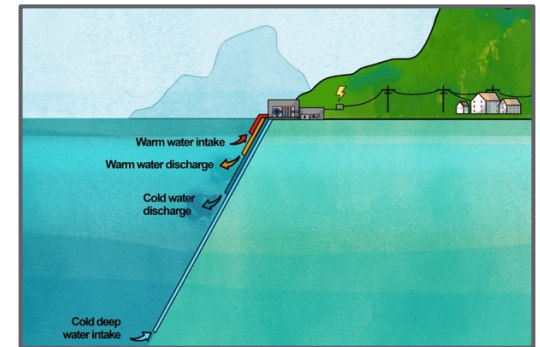
Marine energy meeting Guam's needs

- Grid stabilization, baseload energy = **OTEC**
- Cooling to relieve A/C electricity = **SWAC**
- Specialized uses like aquaculture = **wave energy**

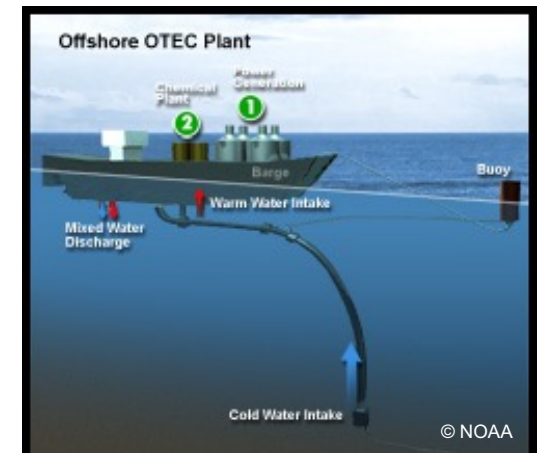


OTEC and SWAC

- **OTEC** generates power from temperature differentials from cold deep seawater to warm surface water
 - Requires minimum 20°C temperature differential
 - Only viable in tropics or subtropics
- **Onshore OTEC**
 - Where deep cold ocean water relatively close to the coast
 - Intake and discharge pipes laid from shore to deep ocean
 - Generally small, 1-10 MW
- **Offshore OTEC**
 - Located on floating platforms at sea, intake and discharge pipes deployed directly below
 - Electricity generated to shore using power cables
- **Seawater air conditioning (SWAC)**
 - Using cold seawater through a chiller unit onshore to cool

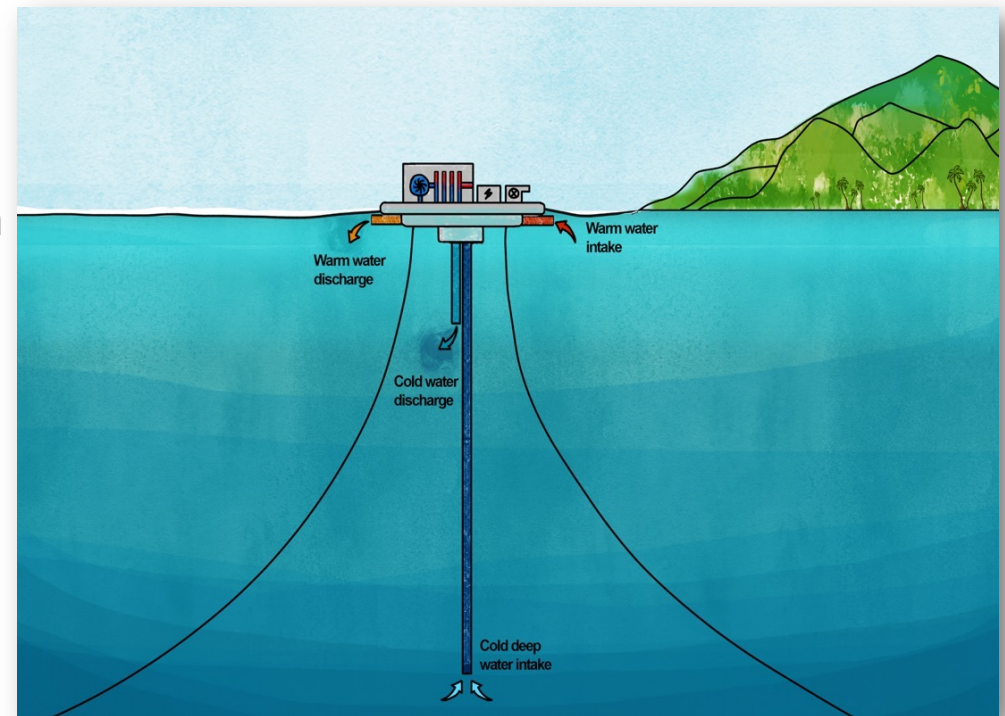


Stephanie King, PNNL



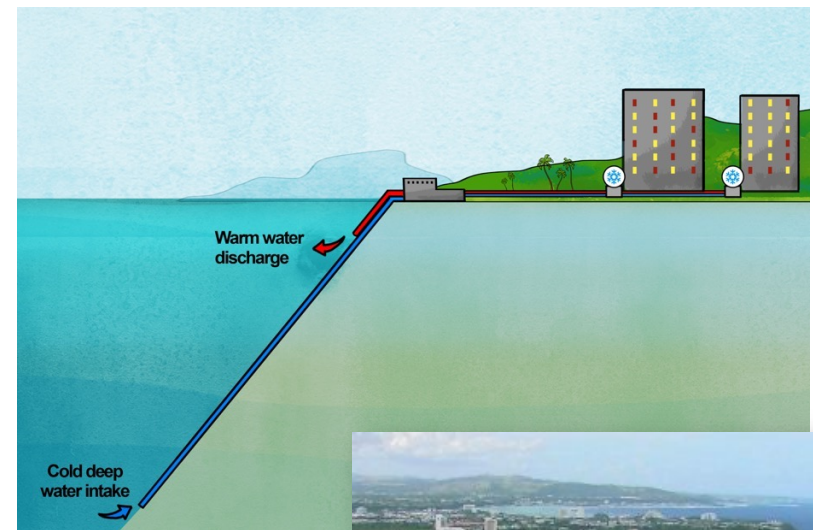
Benefits of using OTEC for Guam

- OTEC well suited for Guam baseload power (grid stabilization, ramping, black start)
- Deep ocean water accessible within few km of shore
- Warm surface temperatures above 27°C year-round for needed temperature differential
- No disturbance of reef needed
- Economic benefits of installation, operation, and maintenance jobs, use of some local vessels



Benefits of using SWAC for Guam

- Air conditioning often accounts for 40-50% of Guam's electric load
- All large hotels clustered around Tumon Bay
- Taking Tumon hotels off grid could provide resilience and capacity for growth
- Distributed system of cold water at shoreline
- Abandoned stormwater collection system runs along the bay
- Individual hotels would tap into cold water for A/C



Stephanie King, PNNL



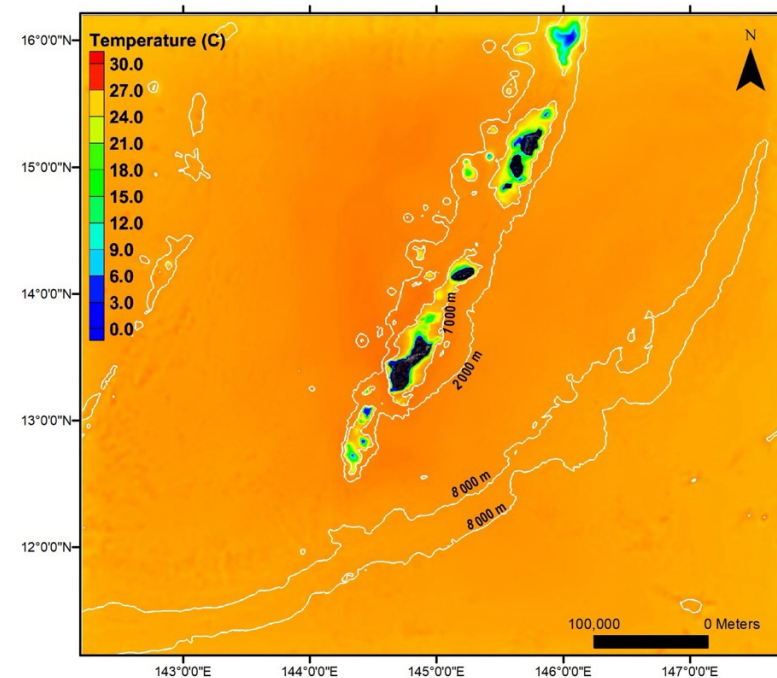
Site selection metrics for OTEC and SWAC

Category of Metric	Metric
Technical feasibility	Adequate resource
	Hazards Assessment
	Suitable landing
	Depth offshore
	Distance offshore
	Seabed condition
	Hook up to electrical grid
	Distribution system for cold water
Economics	Siting, permitting, community engagement
	Cost of additional studies
	Installation costs
	Supply chain upcharges
	Operational costs
	Maintenance costs

Category of Metric	Metric
Environmental concerns	Location of offshore intake pipes
	HDD route
	Shore landing
	MPAs, other designations
	Endangered species
	Other species
	Stability of oceanography
	Hazardous chemicals at plant
Community acceptance	Community engagement activities
	Community members engaged
	Institutions of businesses engaged

Annual averaged temperature differential

- Temperature differential from sea surface to depth
- Averages over 20°C allow for OTEC operation
- Temperature averaged from 20 to 1000m, or to the seabed if the water depth is less than 1000m
- All green color nearshore areas are shallower than 1000m

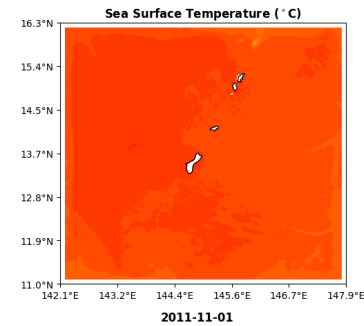


Model validation, using satellite data

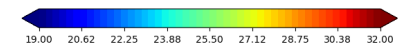
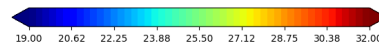
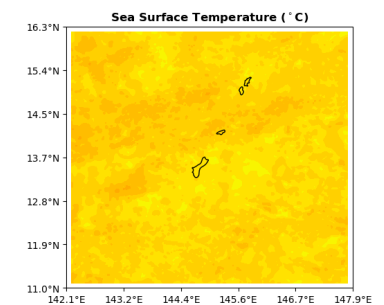
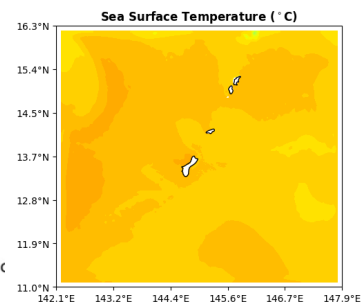
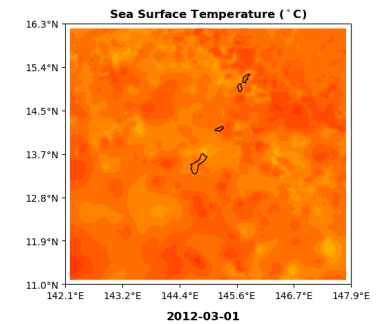
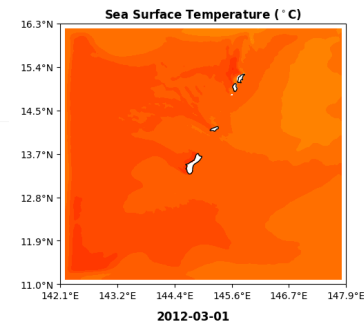
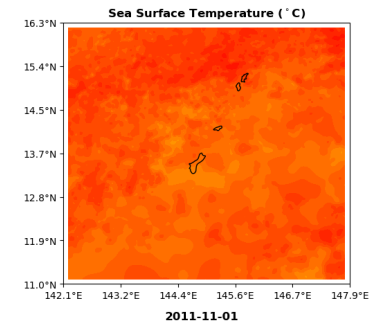
- Satellite (SST) data



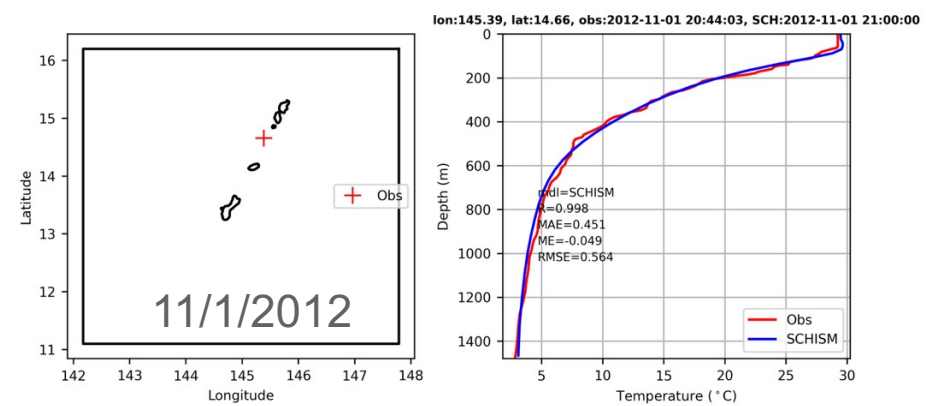
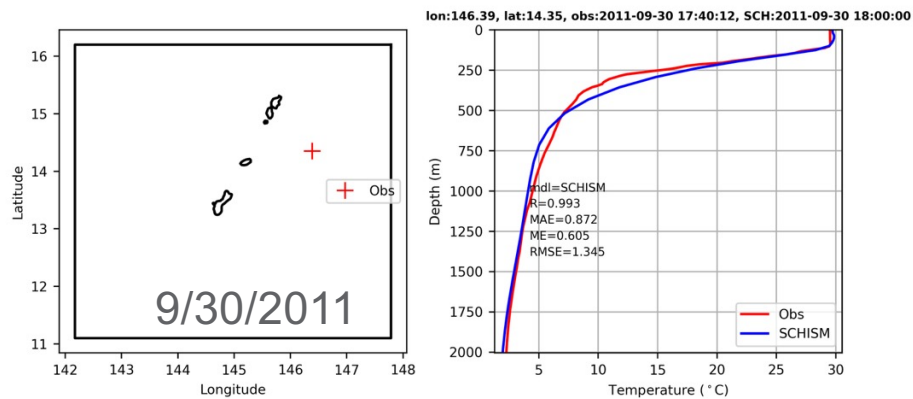
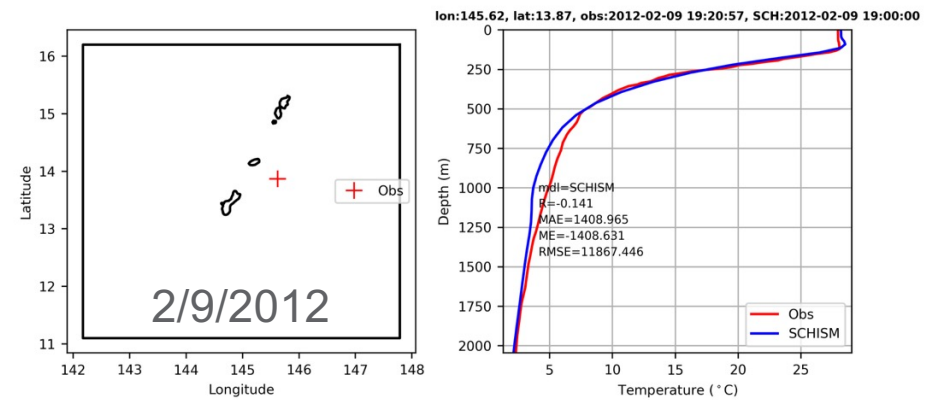
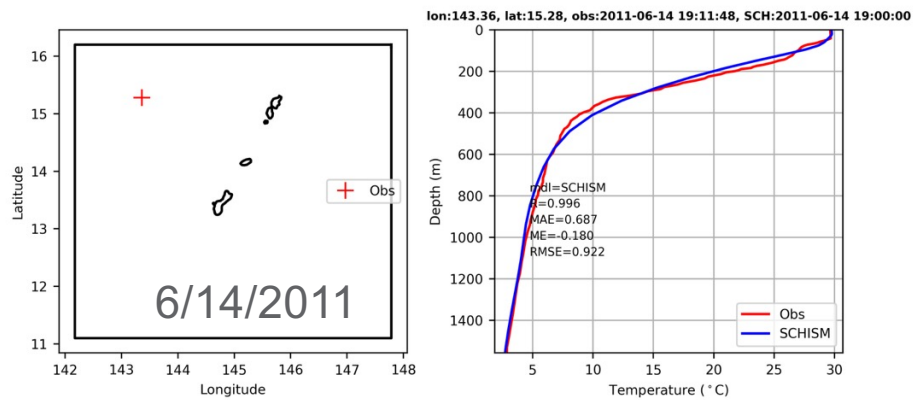
SCHISM
2011-07-01



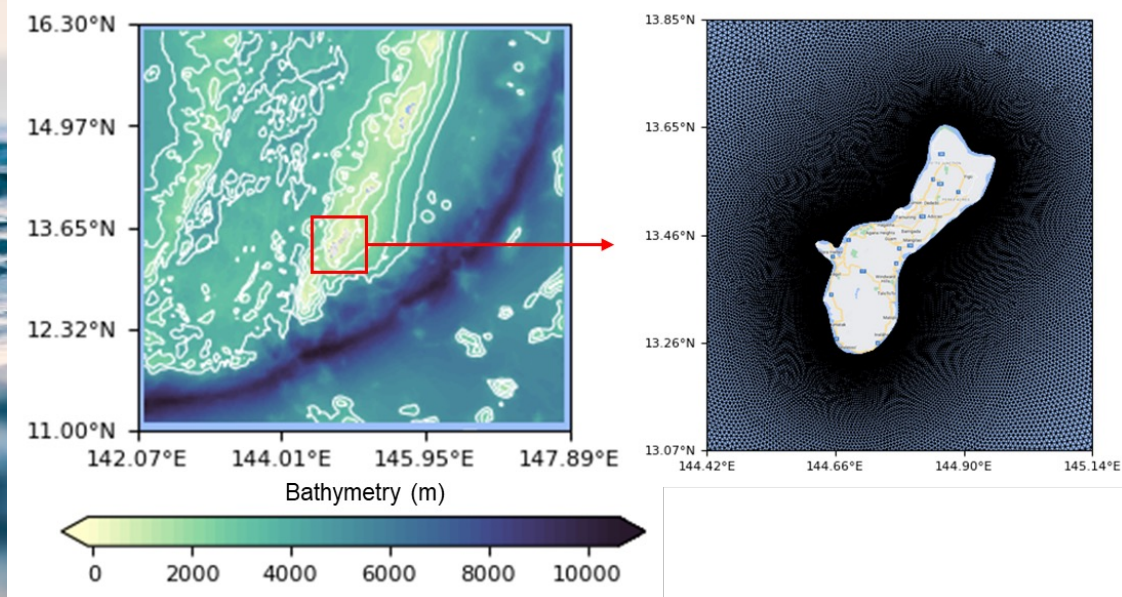
Satellite
2011-07-01



Model validation, using Argo Float temperature profiles

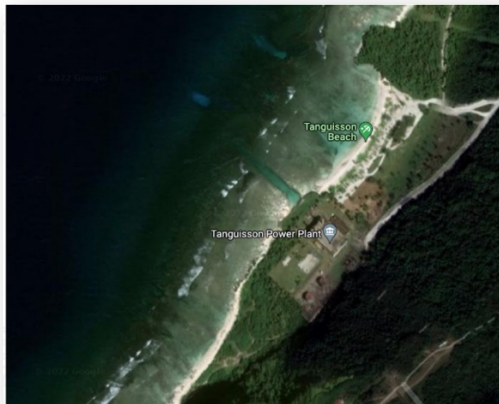


Details of the Model – SCHSM – 8 years simulation



Parameters	Values
# of nodes/elements	~ 63,000 / 126,000
vertical layers	49
Horizontal resolution	~400 m near the coast
Open boundary condition	CMEMS
Surface forcing	CFS v2
Simulation periods	1993 - 2022
Completed simulations	10 years

Potential sites for OTEC and SWAC



OTEC

Tanguisson Beach Area:

- 2 hectares flat seaside land
- 5.5 hectare with steep cliffs
- Site of abandoned power plant
- Grid connection, just below new combined cycle gas plant (Ukudu)
- Planned for LNG landing



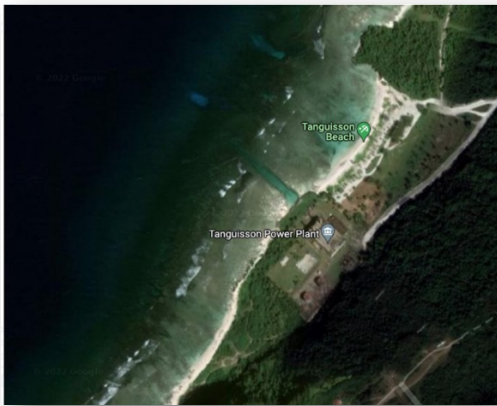
SWAC

South Tumon Bay:

- Site of all major hotels
- Protected by fringing reef offshore, calm lagoon environment
- MPA for bay, shoreward of reef
- Abandoned stormwater collection system runs along Tumon Bay



Potential site for OTEC



OTEC

- Could be onshore, or offshore
- Onshore: HDD under reef to shore
- Offshore: co-located with LNG facility, power cable through existing channel to shore



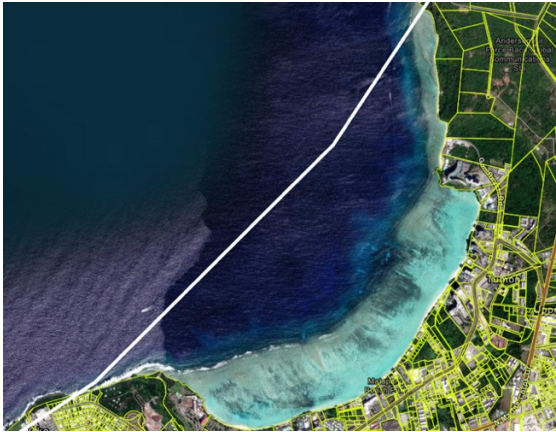
Tanguisson Plant



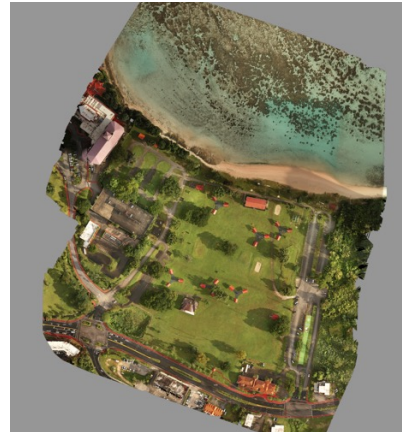
Ukudu Plant



Potential site for SWAC



Old Hospital Point

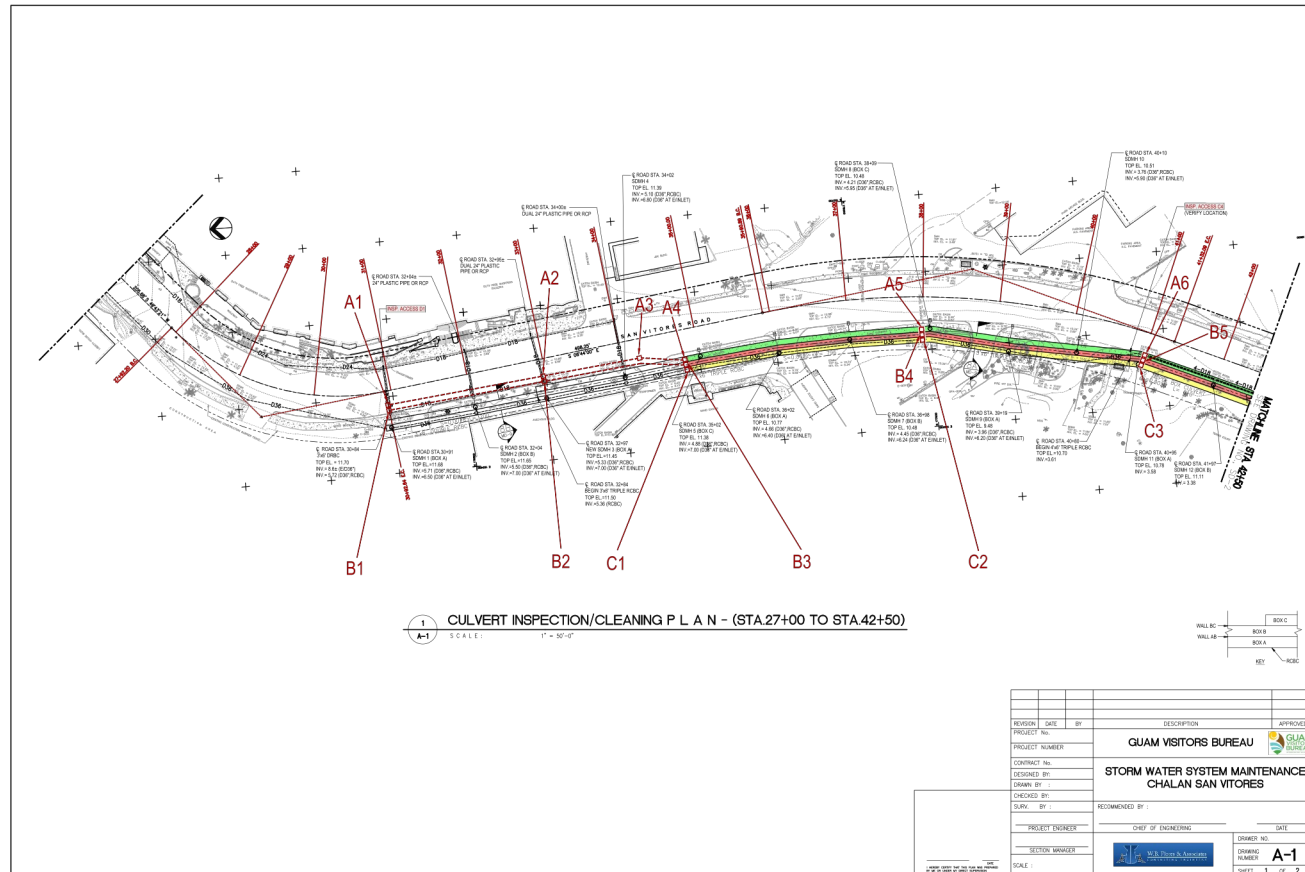


Ypao Beach Park

SWAC

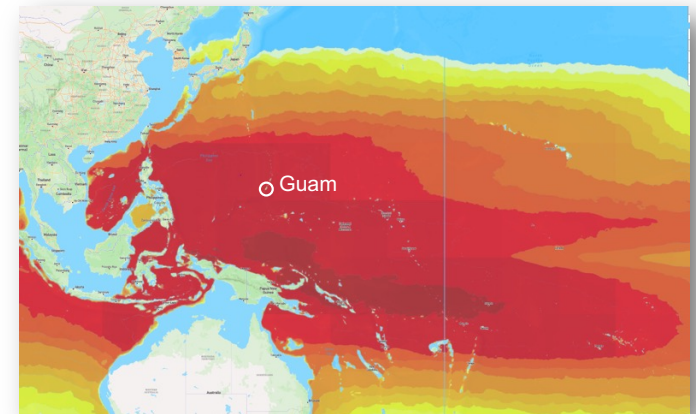
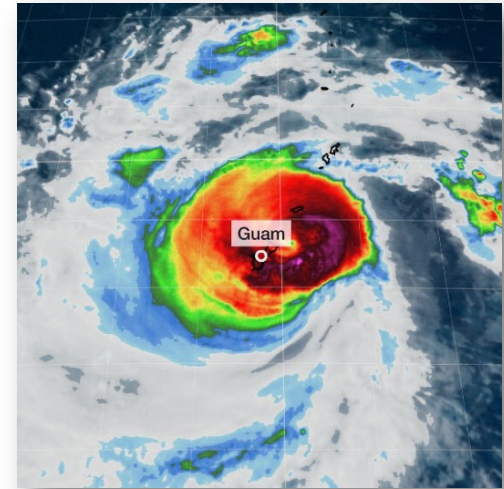
- HDD under reef and seabed
- Two potential land parcels for landfall

Route of stormwater drainage system



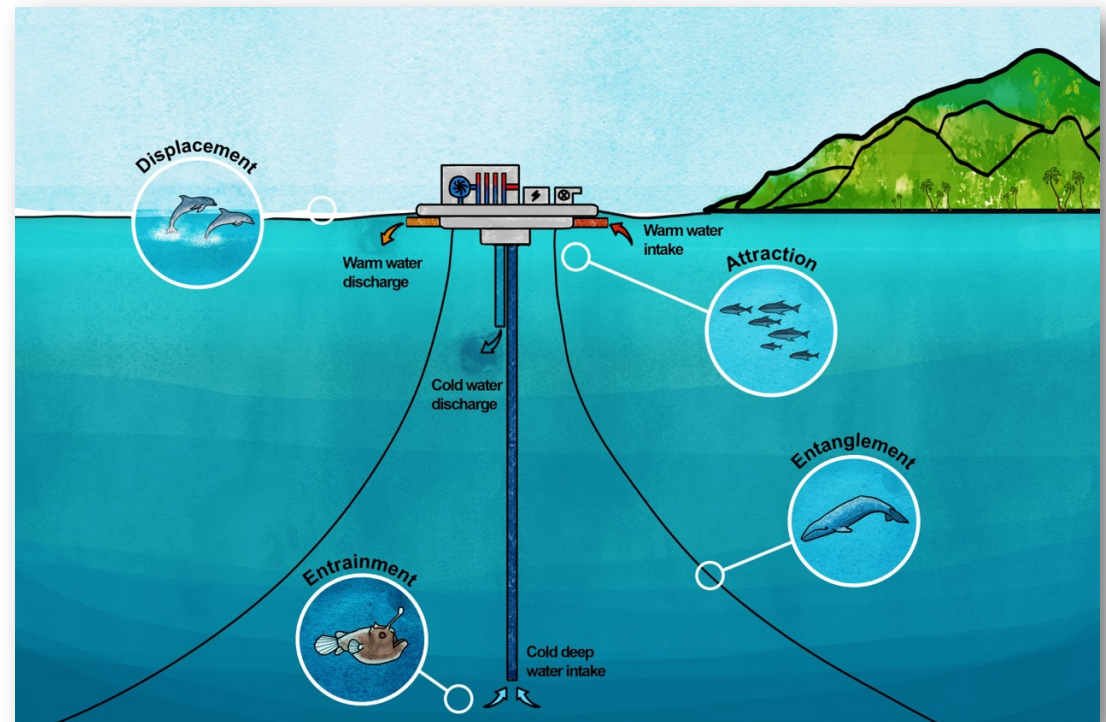
Challenges of OTEC and SWAC for Guam

- More research needed on appropriate locations for siting and to understand/protect marine environment
- OTEC/SWAC plant must withstand natural hazards (e.g., typhoons, earthquake)
- Challenging to install and work at sea
- Materials (e.g., deep-water pipe) must be sourced off-island
- Very high capital costs \$\$\$
- Additional expertise needed for siting, installation, and training locals for ongoing work
- Permitting will have to include consultations with US federal agencies and GovGuam authorities



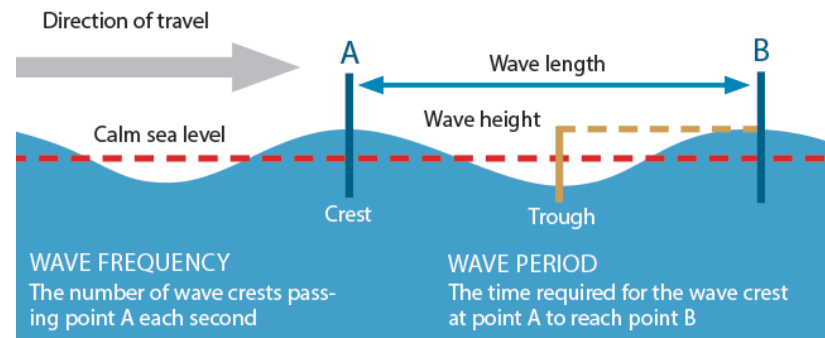
Potential environmental effects of OTEC

- No carbon emissions, fuel consumption, air particulate emissions, or solid wastes
- Large volume of water must be returned at depth to avoid affecting coastal resources, surface organisms, and local oceanographic changes
- Horizontal Direct Drilling (HDD) will bring pipes from the sea to land (avoids coral reefs)
- Very small risk of entraining deep-sea life

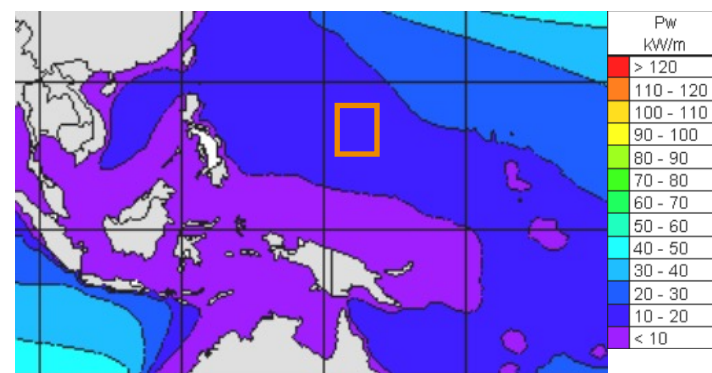


WHAT IS WAVE ENERGY?

- Ocean waves are caused by the wind blowing across the sea surface.
- Characterized by **height** of waves, **period** of oscillation, and **direction** of travel.
- Real ocean waves are “irregular” and contain a combination of waves
- Wave energy conversion is the process of extracting energy from the waves for powering utilities.
- Relatively **consistent and predictable** energy availability



<https://www.boatus.com/app/views/201812/ocean-wave-basics.asp>

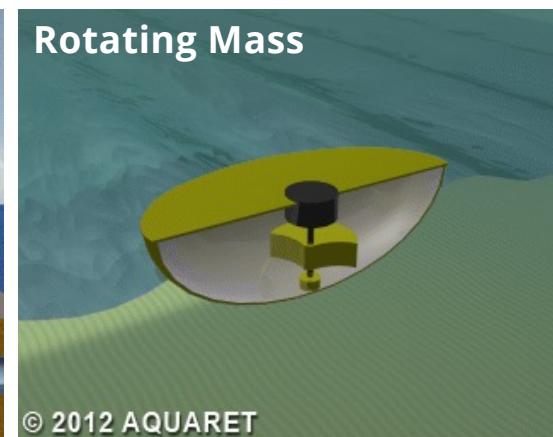
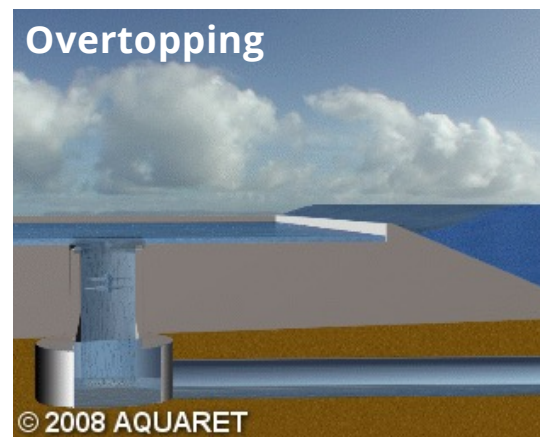
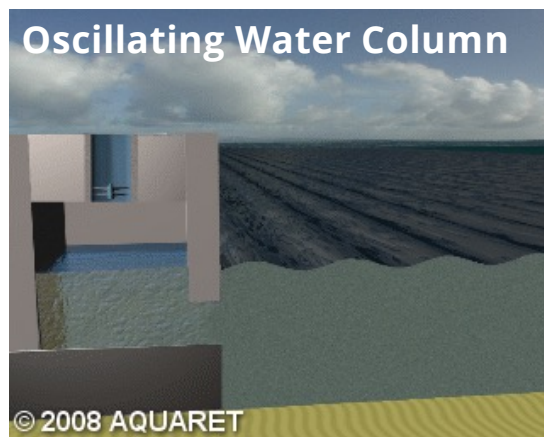
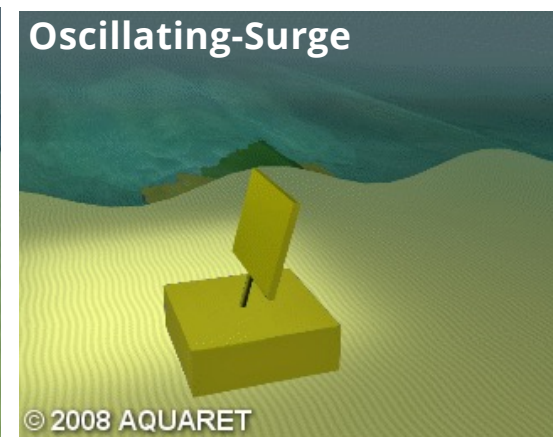


Cornett, Andrew. (2008). A Global Wave Energy Resource Assessment.



WHAT IS A WEC?

- Wave Energy Converter (WEC)
- Wide variety of designs

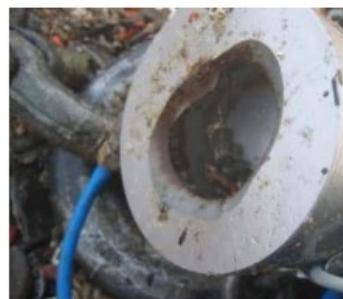
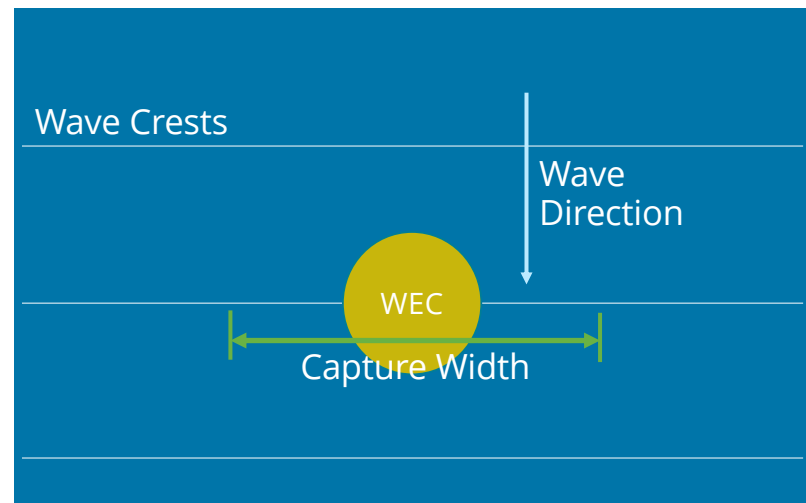


<https://www.emec.org.uk/marine-energy/wave-devices/>

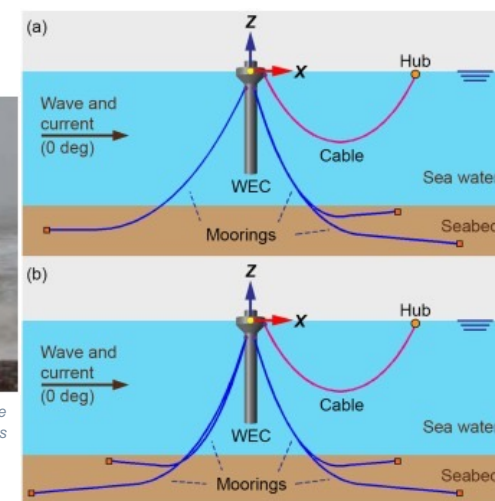


WAVE ENERGY CONSIDERATIONS

- What is important for wave energy converters?
 - Wave conditions
 - Energy
 - Survival
 - Mooring capabilities
 - Cost increases with increasing water depth
 - Benthic habitat
 - Open space
 - Each WEC design requires a certain amount of sea space



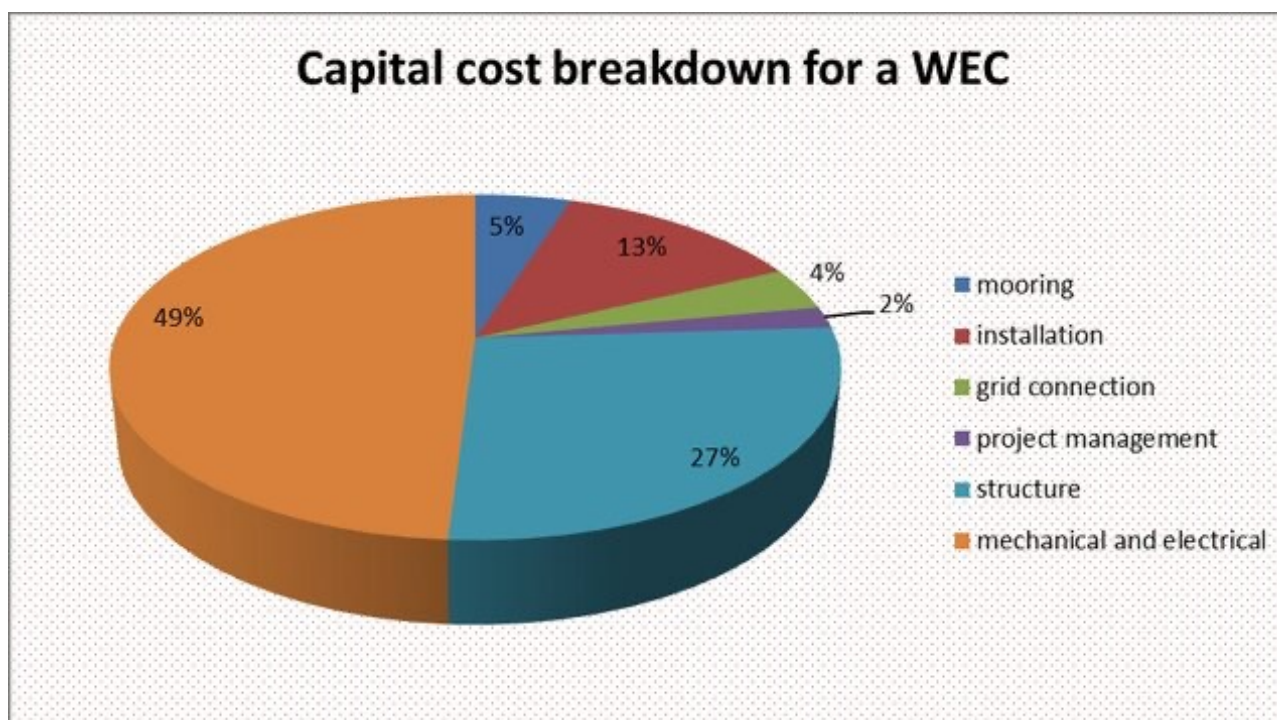
Thies, Philipp Rudolf. *Advancing reliability information for wave energy converters*



Yang, Shun-Han, et al. "Biofouling on mooring lines and power cables used in wave energy converter systems—Analysis of fatigue life and energy performance."

WAVE ENERGY COSTS

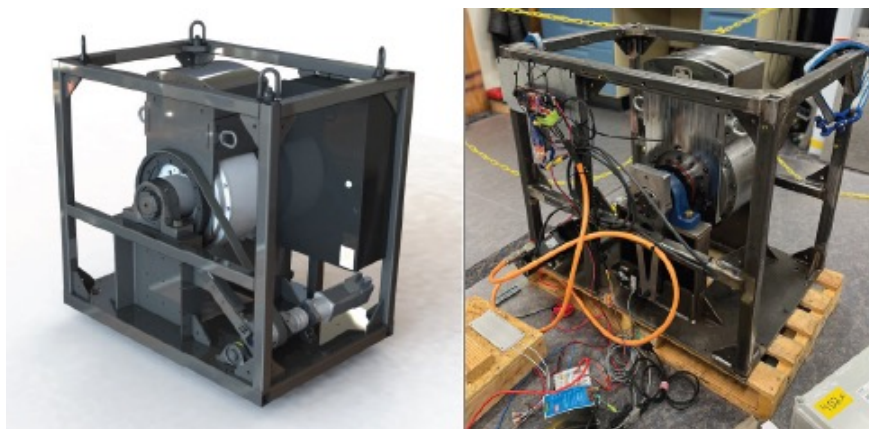
- Capital costs of wave energy are high but vary significantly by type, location, infrastructure, etc.
- Factors that impact wave energy cost:



Bosserelle, C., S. Reddy, and J. Krüger. "Cost analysis of wave energy in the Pacific."

PIONEER WEC- OCEAN OBSERVATION

- Design and Development: The WEC was developed through a collaborative effort between Sandia's Hydrodynamic Energy Systems Department and the OOI, with a focus on the creation of a fully enclosed system that minimizes mechanical failure risks and potential ecological impacts.
- Pitch Resonator Technology: The WEC features a novel pitch resonator design that harnesses energy from the **buoy's natural pitching and rolling motion, ensuring consistent power generation.**
- Integration: The WEC is designed for **plug-and-play installation**, allowing for seamless integration with existing Coastal Surface Mooring (CSM) infrastructure without the need for extensive re-engineering.
- Performance Metrics: **Initial data from the deployment indicates a median power output of 10.2 watts, with an impressive operational uptime of 99% during the first six weeks.** This performance validates Sandia's numerical models and demonstrates the WEC's potential as a stable power source for oceanographic research.

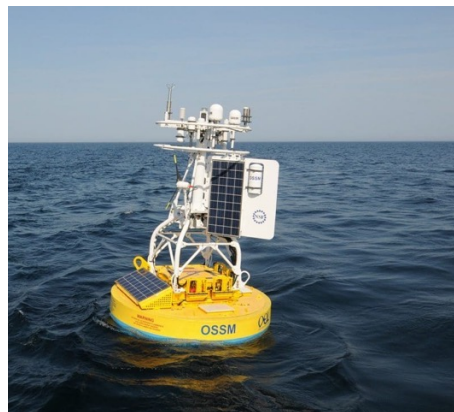


WAVE ENERGY APPLICATIONS

- Suitable for remote, offshore operations. Applications include:
 - Power Generation for Grid
 - Aquaculture systems
 - The current focus of our project. Considering both onshore and offshore archetypes
 - Ocean observation buoys
 - Desalination
 - Offshore military operations
 - UAV charging
 - Seawater mining



<https://www.uog.edu/wp/tpcr/guam-aquaculture-development-training-center.php>



<https://www.who.edu/know-your-ocean/ocean-topics/ocean-tech/moorings-buoys/>



<https://www.pumpindustry.com.au/world-first-wave-energy-technology-to-power-desalination-pumps/>



SUITABLE WAVE ENERGY LOCATIONS FOR NON-GRID APPLICATIONS

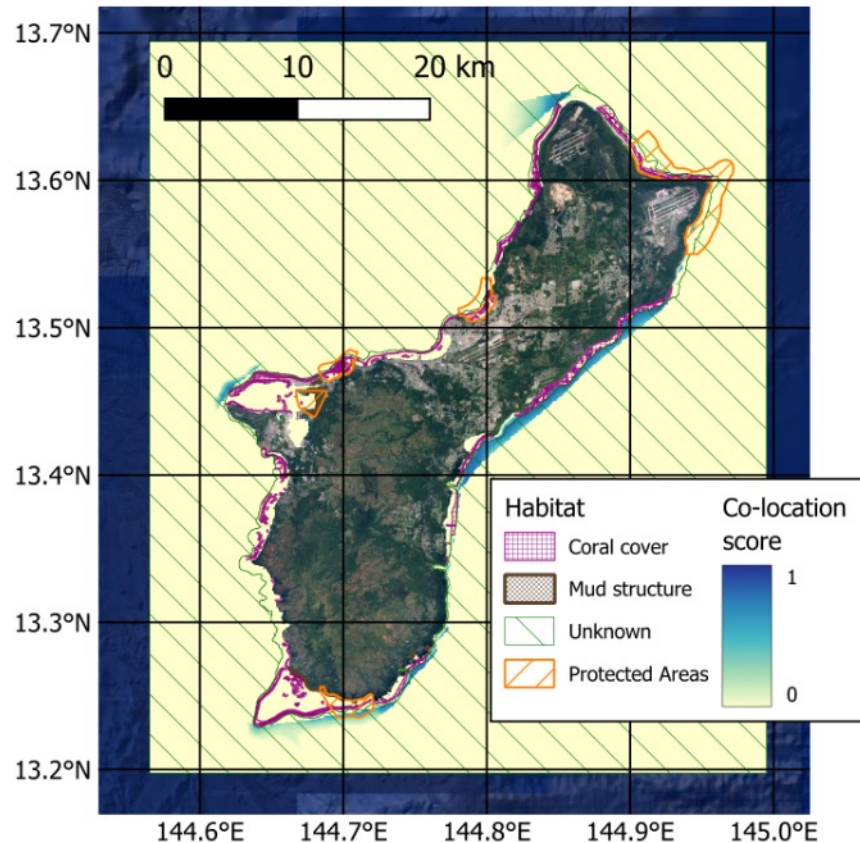
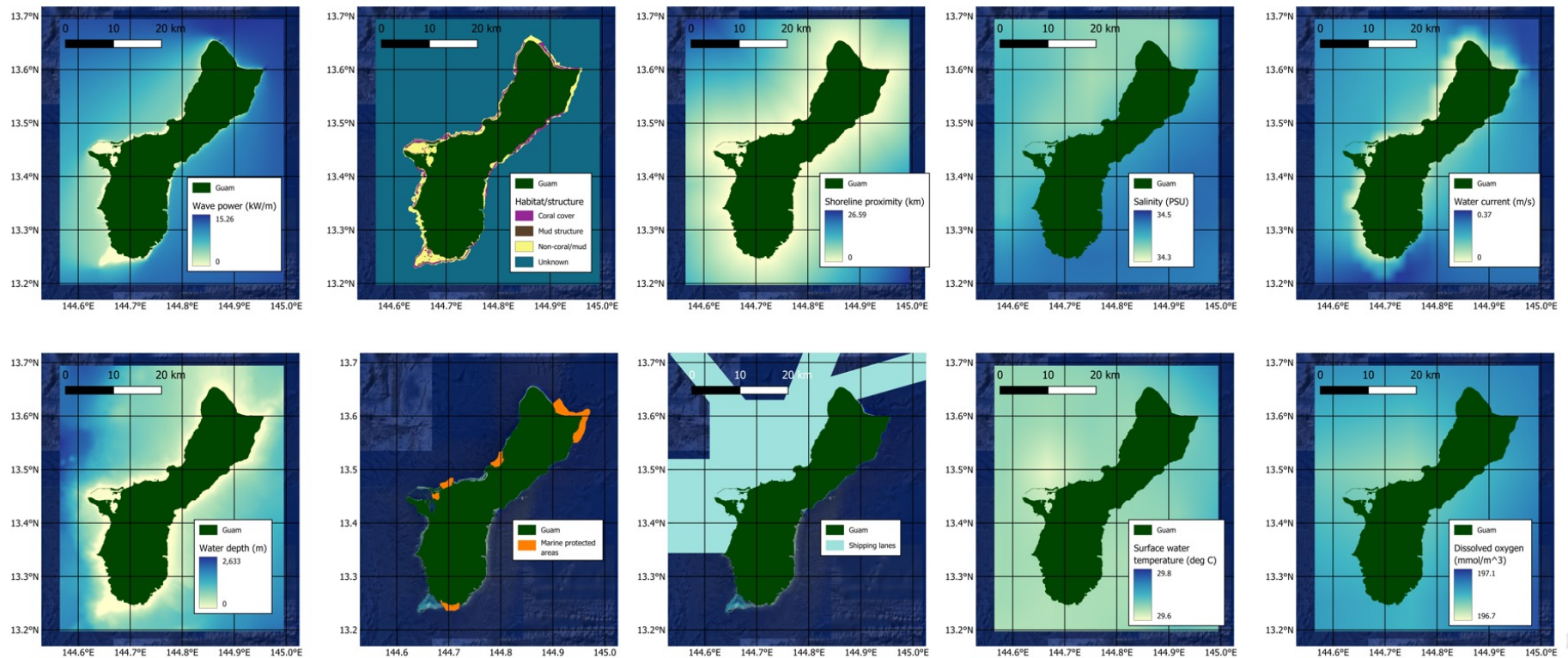


Figure 5-9 Aquaculture co-location scoring. Scoring includes wave power (with minimum monthly average > 2 kW/m and maximum < 15 kW/m), water depth, habitat and seabed structure, shoreline proximity, temperature, salinity, dissolved oxygen, and water current.

- Aggregated data wave power, water depth, habitat and seabed structure, shoreline proximity, temperature, salinity, DO, and water current
- These areas are suitable for aquaculture support, seawater pumping, desalination, and battery-storage integration
 - along the east (notably 13.40°–13.52° N)
 - south coasts
 - near Apra Harbor
 - the island's northeastern tip (near Pati Point)

CO-LOCATION PARAMETERS MAPPED

- Scoring of individual and combined factors
→ Identifies **optimal locations** for both aquaculture + wave energy converters.
- Wave resource is stronger to the north and east
- Water depth increases rapidly offshore
- Marine protected areas and shipping lanes must also be considered



Economic and social challenges

- Biggest challenges to adopting marine energy are financial and political will
 - Reliable energy from OTEC (<10 MW) demonstrated at various test laboratories and developer labs
 - Wave devices still under development
 - High cost of installation (i.e., anchoring, turbines, pipes, cables)
 - Maintenance of equipment to withstand corrosive saltwater and typhoons
- Effects on island's Main Economy – Tourism
 - Construction disruption possible, aesthetic concerns
 - Potential asset as sustainable tourism
- More information needed on operational and maintenance needs
 - How reliable are vital components for long-term operation?



Photo: Luis Vega

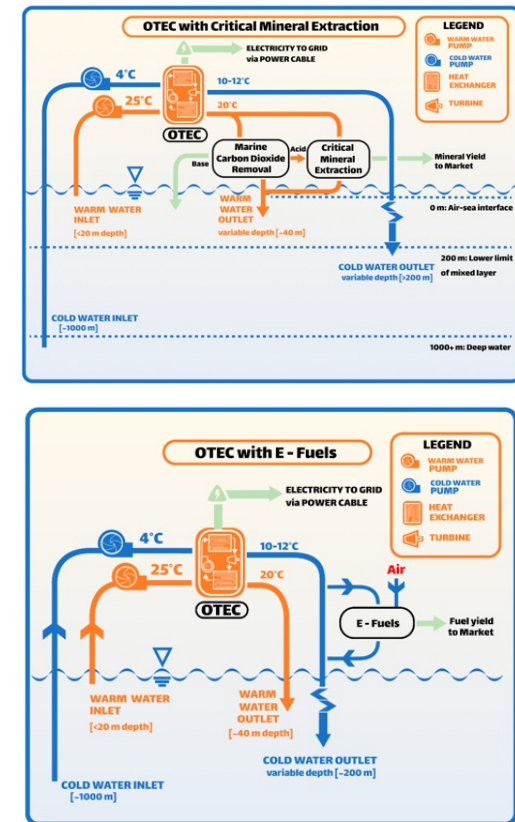
Economic benefits of marine energy

- Scalability of marine energy systems
 - Capacity to generate power to support load demands
 - Ability to store energy in battery storage systems
- Multiple uses of OTEC/SWAC
 - Integrate power into island's electricity grid
 - Provide power and cooling water for aquaculture
 - Could be a source of freshwater for desalination systems
- New skillset for islanders to maintain systems
- University of Guam and island
 - Center for R&D for marine energy as a viable source of power for neighboring islands across Micronesia and western Pacific
- Comparative energy costs:
 - Other renewable energy sources on-island (solar and wind power)



Additional potential advantages of marine energy

- Technological leadership in energy resilience :
 - Deep ocean agriculture
 - Seawater cooling
 - Model grid resiliency and independence
 - Global voice
- Opportunities of developing aquaculture industry:
 - Food security
 - Economic diversification (beyond tourism)
 - Export revenues
 - Extraction of critical minerals from seawater
 - Generation of efuels (hydrogen/ammonia)
 - Investment opportunities
 - New skills and employment opportunities



Copping, A., Farr, H., Rumble, C., Park, K., and Yang, Z. 2025. Feasibility of Multi-Use Ocean Thermal Energy Conversion (OTEC) Platforms. Journal of Marine Science and Engineering, 14(1), 20. <https://doi.org/10.3390/jmse14010064>

Outreach and engagement

- Significant outreach and engagement events
 - 5 townhalls
 - Many individual meetings
- Almost all feedback has been positive – government, community local leaders
- More education and engagement needed to explain energy resilience benefits to government leaders and communities





Next Steps

- Project continues through 2027
- Deeper dive assessment on siting of SWAC, OTEC, and wave
 - Community concerns and interests
 - Community siting inputs
- Assess integration of marine energy on Guam's grid
- Environmental sensitivities
- Permitting process
- Techno-economic analysis



Photo: Allison de Peralta



Thank you!

Contacts:

Dr. Andrea Copping

andrea.copping@pnnl.gov

+1 (206) 528-3049

Megan Anderson

megande@sandia.gov

+1 (508) 677-7858



PNNL is operated by Battelle for the U.S. Department of Energy

