MAKAI OCEAN ENGINEERING

Ocean Thermal Energy Conversion (OTEC)

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NSRP Joint Panel Meeting
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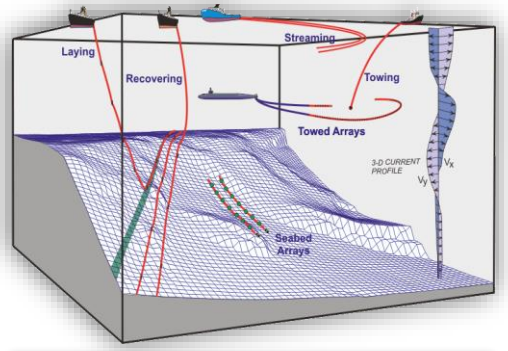
Makai is…

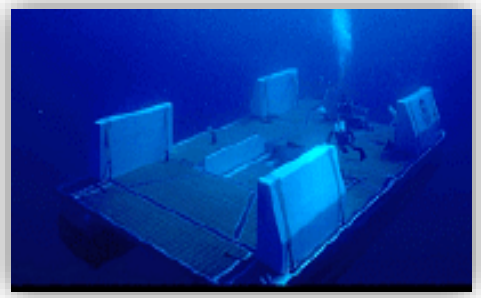
Innovative Ocean Technology Company ● Founded 1973 ● 36 employees

Turning Concepts into Capability for 45 years



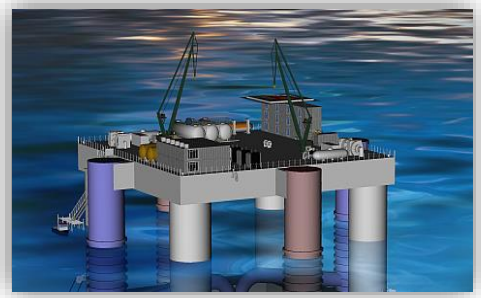
Subsea Cable Software

- World's #1 cable software
- Installed 250k miles



DoD S&T, Ocean Engineering

- Navy underwater vehicles
- Subsea sensor networks



Ocean Energy

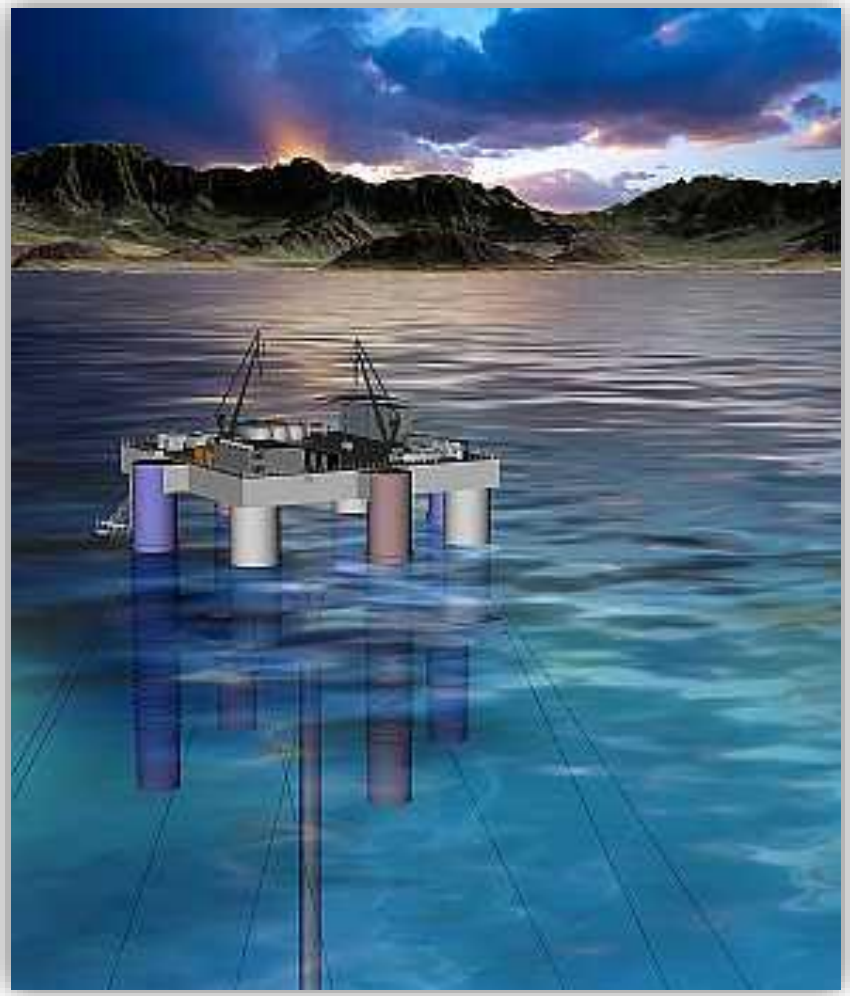
- Pioneers of SWAC/OTEC
- First US Grid Connected OTEC plant

NAVFAC
Naval Facilities Engineering Command
EXWC Engineering & Expeditionary Warfare Center
A DOD Science, Technology and Reinvention Laboratory

Oceans Multiple Award Contract (OMAC)

- Broad Ocean Engineering
- $250M IDIQ

Ocean Thermal Energy Conversion (OTEC)



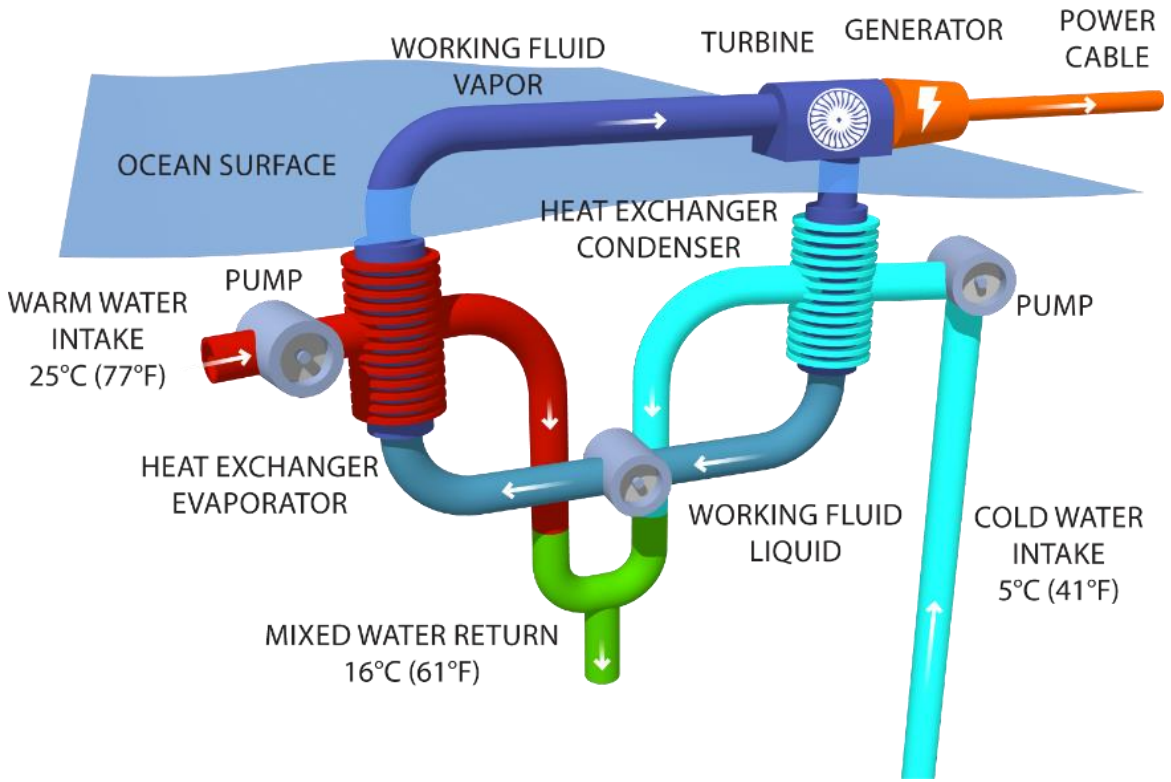
- What is it?
- Makai's role and history
- Lessons learned
- Breakthrough
- Future

OTEC: What is it?

- Process to produce electricity
- Leverages temperature differential between surface and deep seawater
- Seawater temperatures remain near constant
- Provides stable, baseload power unlike other variable renewable energy systems

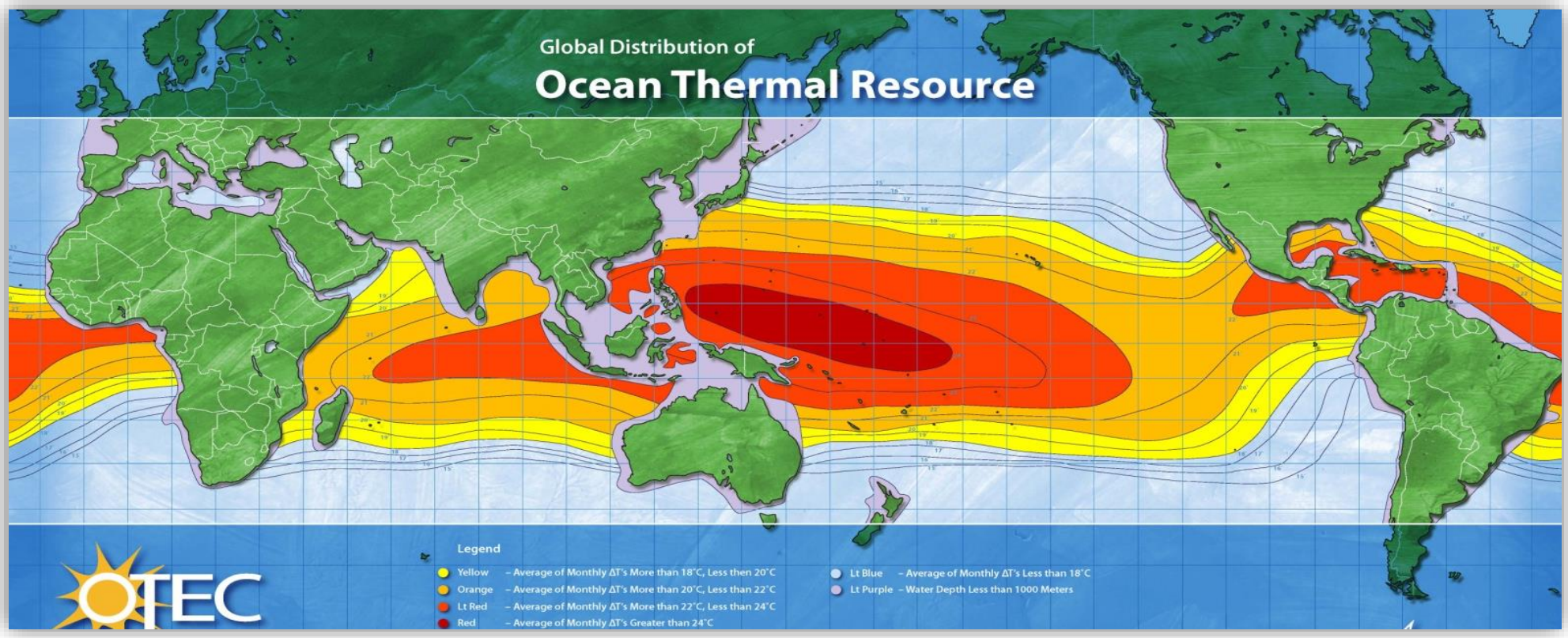
Simple Components

- Heat exchangers
- Turbine generator
- Seawater pumps and pipes
- Working fluid piping and pump



24/7 baseload renewable energy resource

Massive Resource



Surface vs. Deep Water Temperature Difference >20° C (36° F) required

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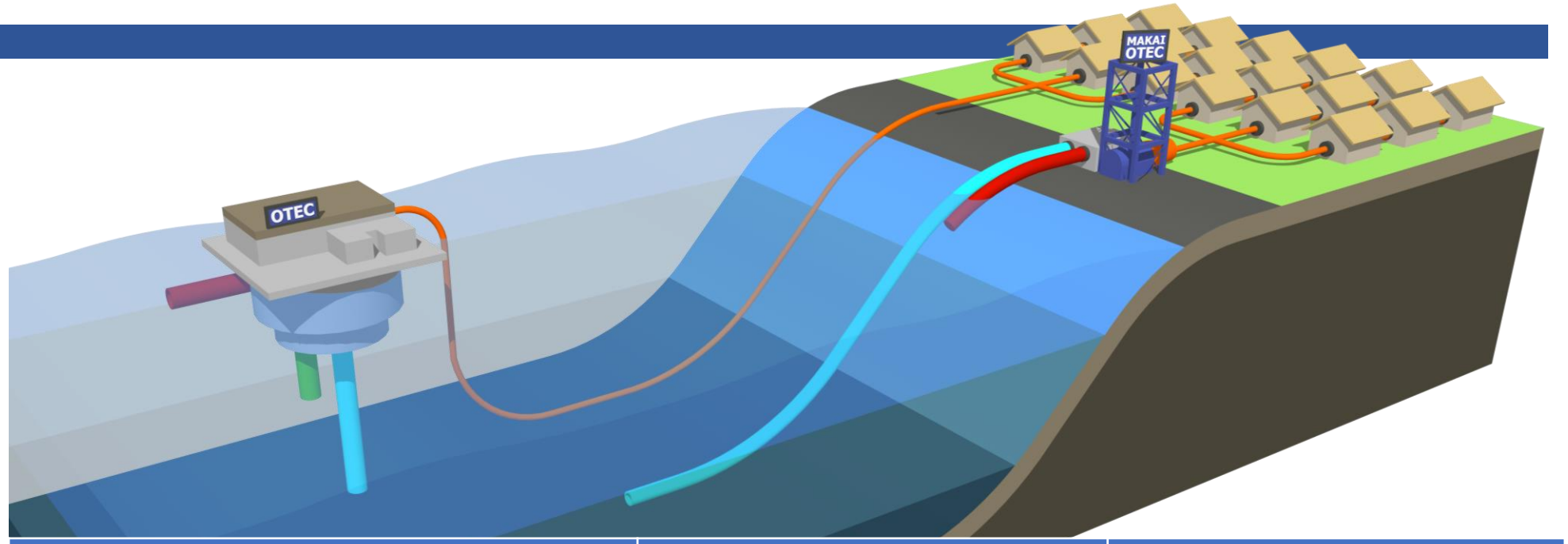
The ocean is a large thermal energy storage tank.

OTEC: Onshore vs. Offshore



	Offshore	Onshore
Plant location	Ships at sea	On land near shoreline
Proximity to thermal gradient	Directly below	No immediate access
Power transmission to power grid	Challenging	Easy to transfer to grid
Cost to build/operate plant		Typically less than offshore
Engineering risk of gathering the resource	Low	High

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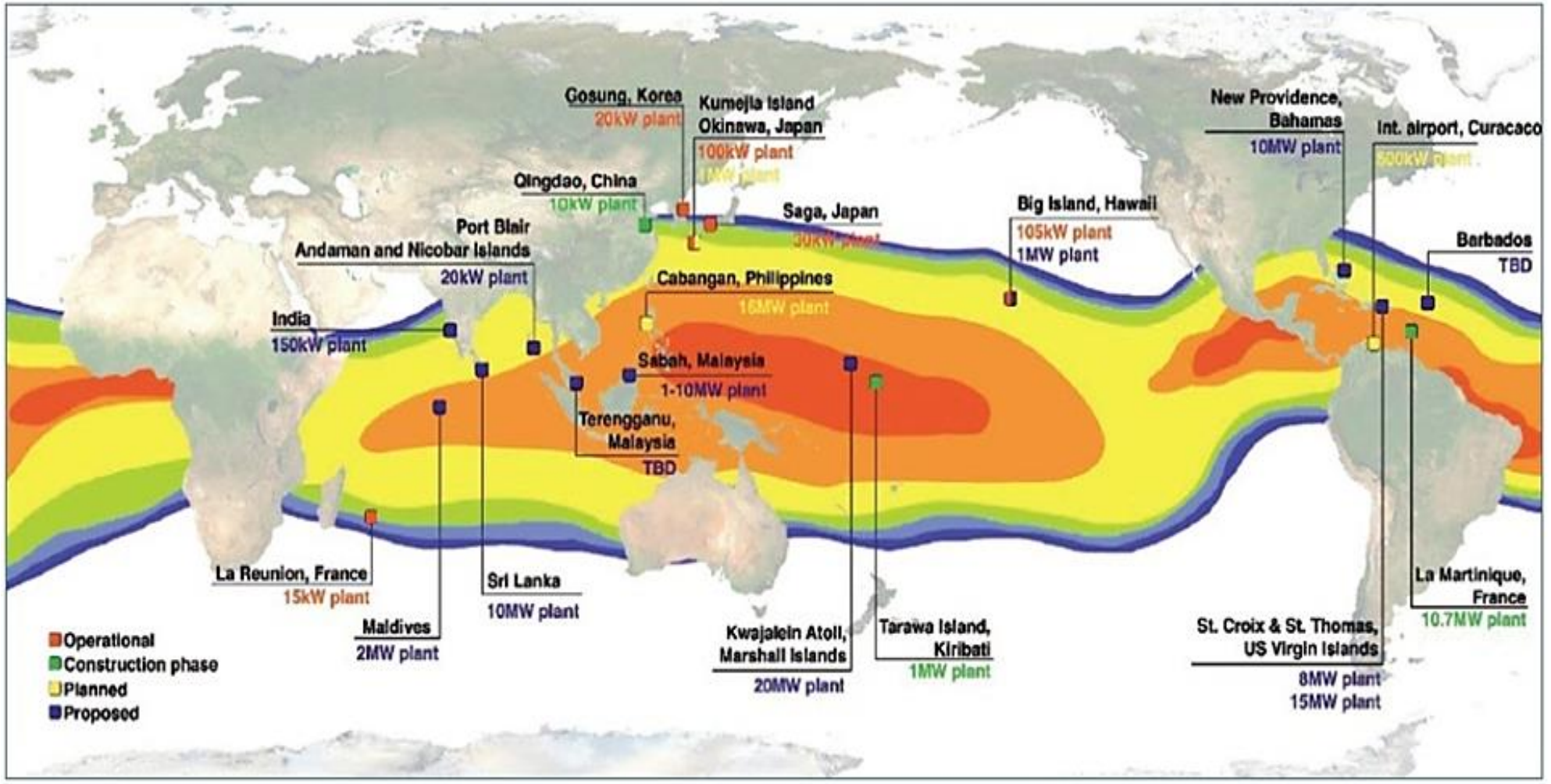
OTEC is only economically viable offshore.

OTEC Plants: Operational, Planned, Proposed



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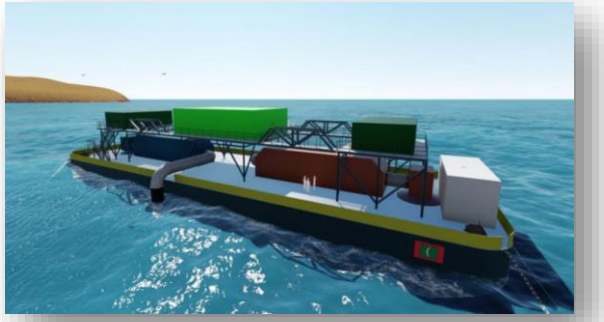
Offshore Floating Utility Scale

Makai

Lockheed Martin

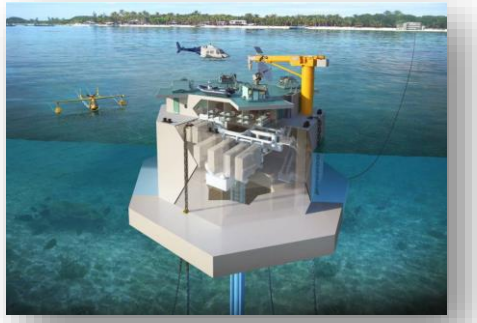
Various designs proposed:

- Barge
- Semi-submersible
- FPSO-style
- Spar

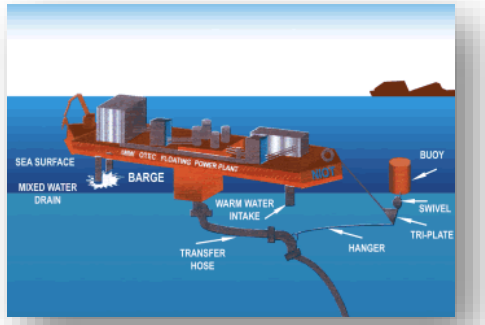


Global OTEC

Naval Energies



KRISO



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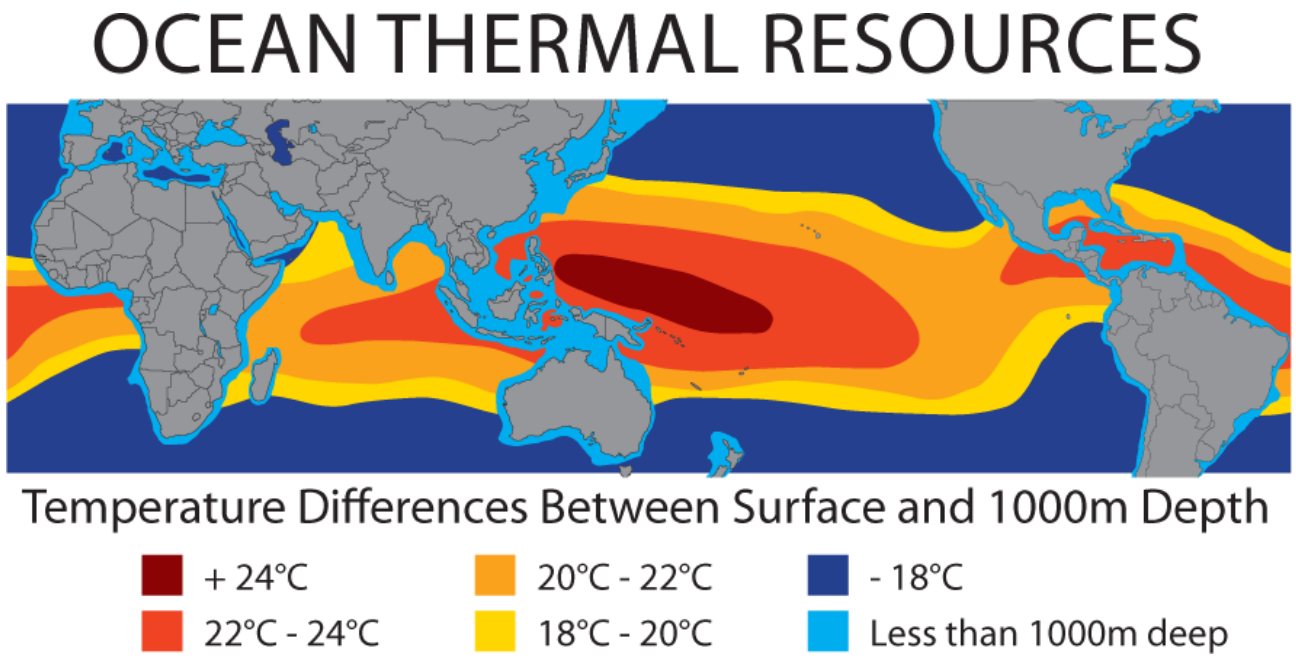
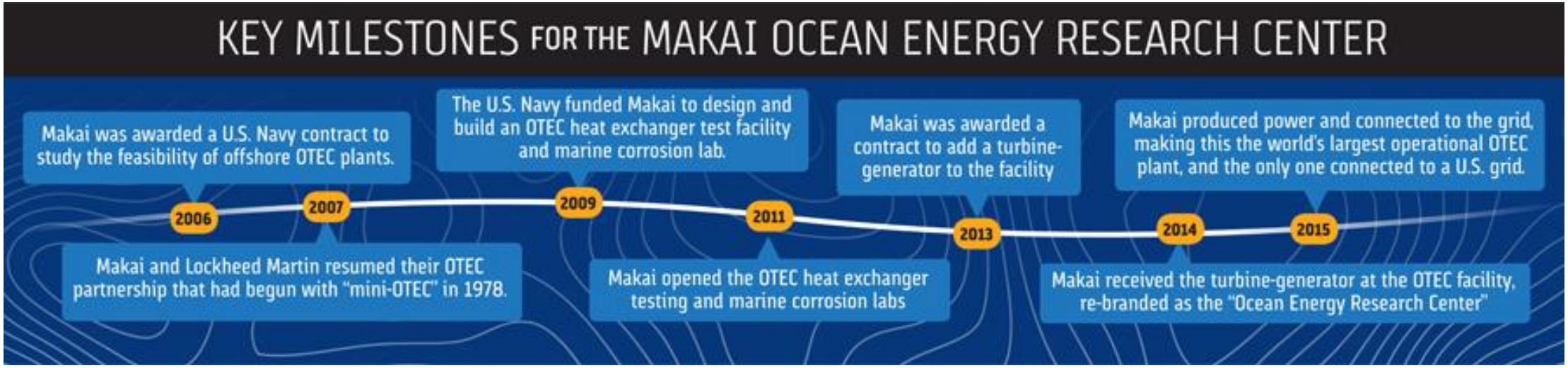
OTEC's Challenges

- High CAPEX
- Vigorous economies of scale
- Has not been built at commercial scale
- Limited to locations with warm surface waters and cold deep seawater
- Onshore OTEC limited to small scale
- Offshore floating pilot plant needed



Makai's Role and History with OTEC



Ocean Energy Research Center (OERC)

- Funded by Office of Naval Research (ONR) in partnership with HNEI

Capabilities

- Corrosion and biofouling studies
- Heat exchanger testing
- OTEC system design and development
- Large diameter pipe development and testing
- Grid-connected power studies
- OTEC Plume modelling
- Advanced heat exchanger manufacturing facility

Marine Heat Exchanger Development & Testing

Heat Exchanger Testing

- Funded since 2009
- Third-party & Makai's own designs

OERC Facility

- ~12,000 gal/min seawater
- High accuracy instrumentation
- Fully automatic controls

OERC for OTEC R&D

Project Goals:

- Develop autonomous OTEC plant controls
- Produce utility-grade electricity
- Gain operational experience
- Improve commercial designs
- Raise visibility of OTEC

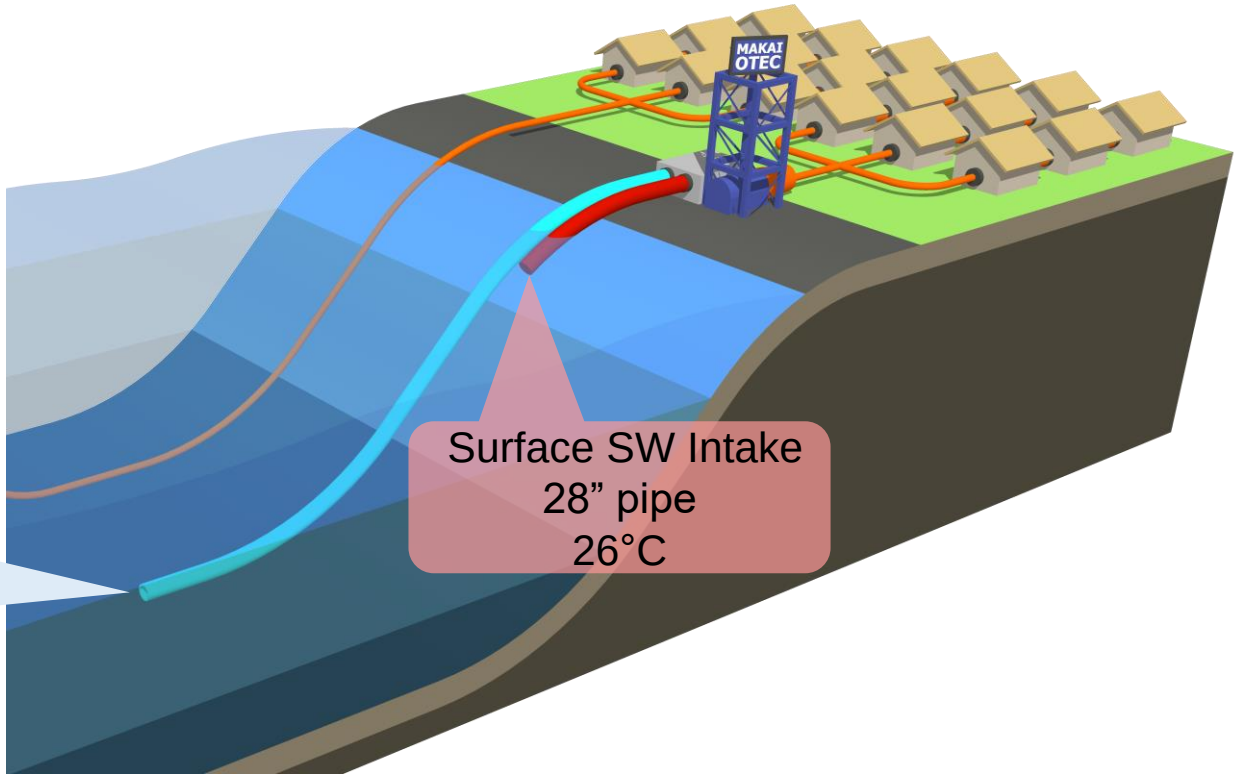
Mission Statement: To reduce the cost of ocean energy

Makai's OTEC Plant

- First U.S. grid connected cc-OTEC plant
- Plant dedicated Aug 21st 2015

Operational Details

- 2 x 2MW thermal duty HXs
- 4,000 gal/min cold and warm seawater
- 105 kW ammonia turbine generator
- Ability to power 120 Hawaiian homes with seawater



Why don't we have OTEC power?

Answer: Economics

- Current designs are too expensive
  - Current designs only cost-effective on the >100 MW scale, estimated at $0.10 - $0.20/kW-hr.
- Large systems still need to be proven viable through demonstration and operation.
  - Offshore pilot plant will not pay investors back.

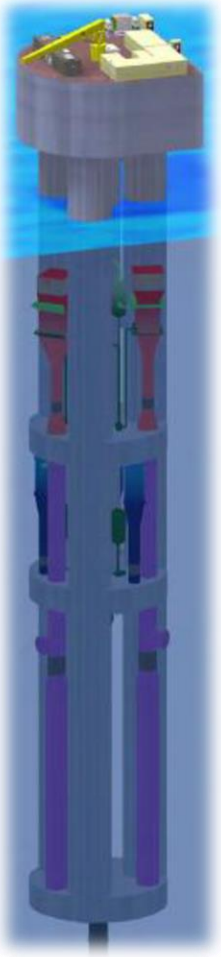
Proposed DCNS 10MW Pilot

How do we accomplish economical OTEC?

Answer: Need a step-change in cost of the system and radically different design

What needs to change:

- Heat exchangers are largest top-side component – reduce their size and cost
- Need an affordable design at a smaller scale (miniature 5 MW system)
- Massive offshore structures are too expensive – minimize their size



Lessons Learned

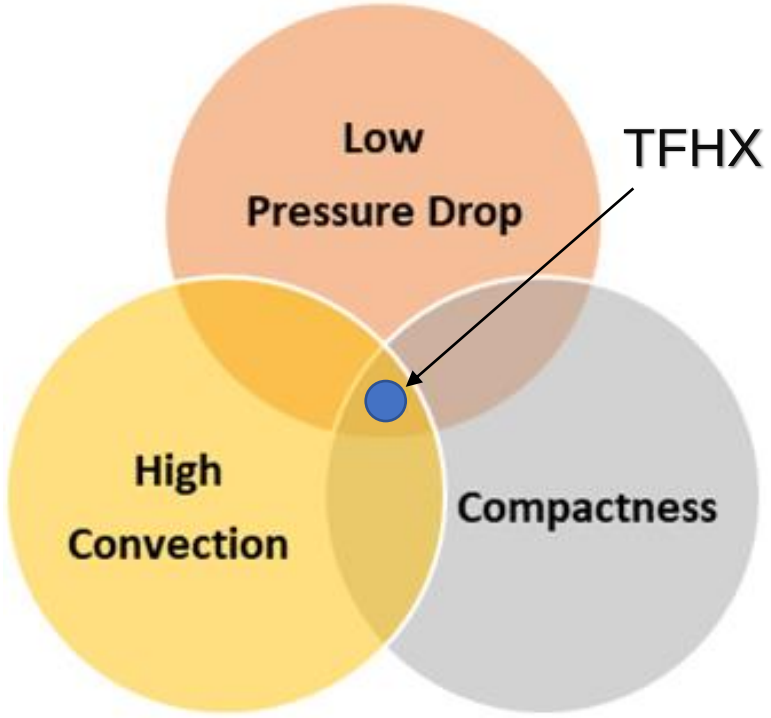
Heat Exchangers have largest impact on OTEC system economics

- Should only use corrosion resistant titanium for condenser
- Compactness directly impacts system size and therefore cost
- Size (volume) is function of waterside-channel geometry, ducting, ammonia manifolds and piping
- Lowest approach temperatures are critical
- Heat exchangers impact the system cost more than any other OTEC component

Takeaway: No heat exchanger on the market meets OTEC's high demands.

Makai's Solution: Thin Foil Heat Exchanger (TFHX™)

- All foil construction, thickness < 0.1 mm
- High efficiency (U values > 11 kW/m2-K)
- High pressure rating (1000 psi tested)
- Self-supporting (no heavy external header plates)
- Low pressure drop < 10 kPa for optimized OTEC
- Custom geometries enable efficient integration into larger systems



The TFHX™ will enable OTEC to reach commercial implementation!

Makai's Thin Foil Heat Exchanger (TFHX™)

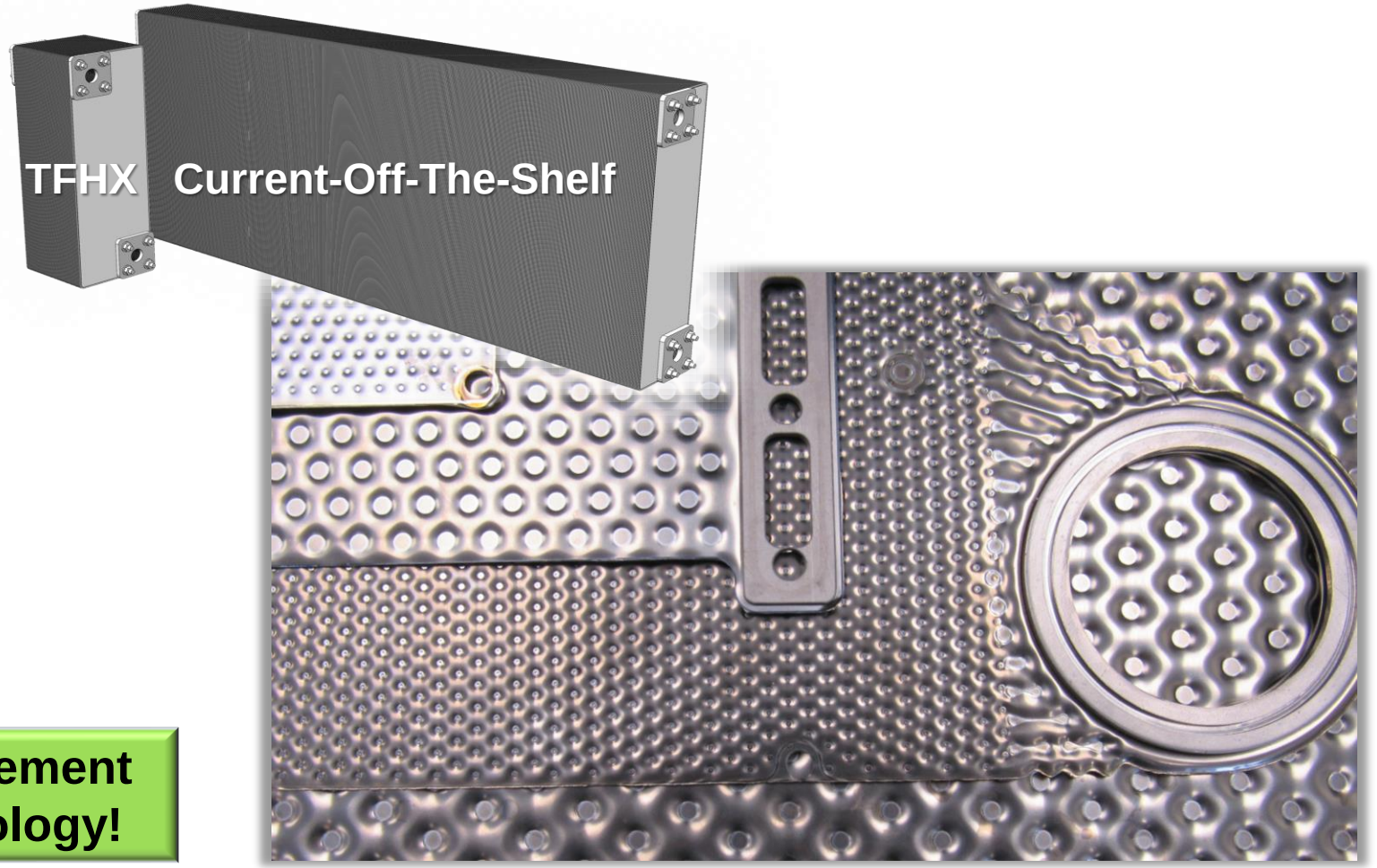
Features

- Ultra-Compact
- Lightweight
- Corrosion Resistant
- Form Fitting

Advantages

- Up to 5 - 8x more compact
- Reduced material costs
- Utilizes unused spaces

True step-change improvement in heat exchanger technology!



Accelerating Commercialization

Performance Testing

- Optimizing for OTEC, aircraft cooling systems, and industrial seawater cooling applications

Reliability Testing

- Burst pressures >500-800 psi
- Fatigue life > 1,000,000 cycles
- High pressure water spray nozzle testing
- Sand blasting, shock and vibration

Fabrication Development

- Automated, high speed fabrication system
- Prototype-scale production

TFHX™ Applications

- OTEC and Seawater Air Conditioning (SWAC)
- Seawater cooling
- Shipboard/keel cooling
- Vehicle cooling
- Vapor cycle systems
- Thermal storage
- Power plants

The TFHX™ is ideally suited for applications requiring optimized SWAP-C

Mahalo

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