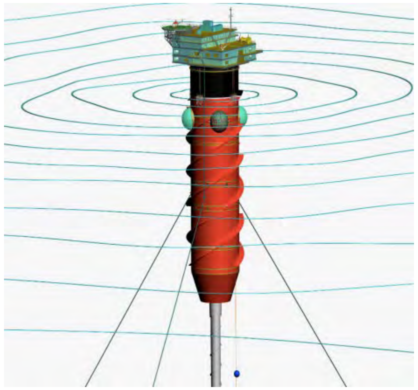
Ocean Thermal Energy Conversion Development Update

A Presentation to The World Bank,
December 2013



OTEC International LLC
An Abell Foundation Company

OTEC – An Attractive Energy Solution

- Renewable Energy – a catalyst for economic growth
  - Wind, Solar, Geothermal, Biomass, Hydropower
  - No single technology provides an "ideal" solution
- OTEC Advantages
  - Base-Load Power (24 hours/day, 365 days a year)
  - High Operating Capacity
  - Reliable and Consistent
  - Operating Cost Efficiency
  - Location Compatibility
  - Valuable Co-Products – SWAC, Mariculture, Fresh Water, Industrial Gases
- Price Competitive (per kWh)
  - Base Load Power
  - Renewable Energy Solutions - level playing field

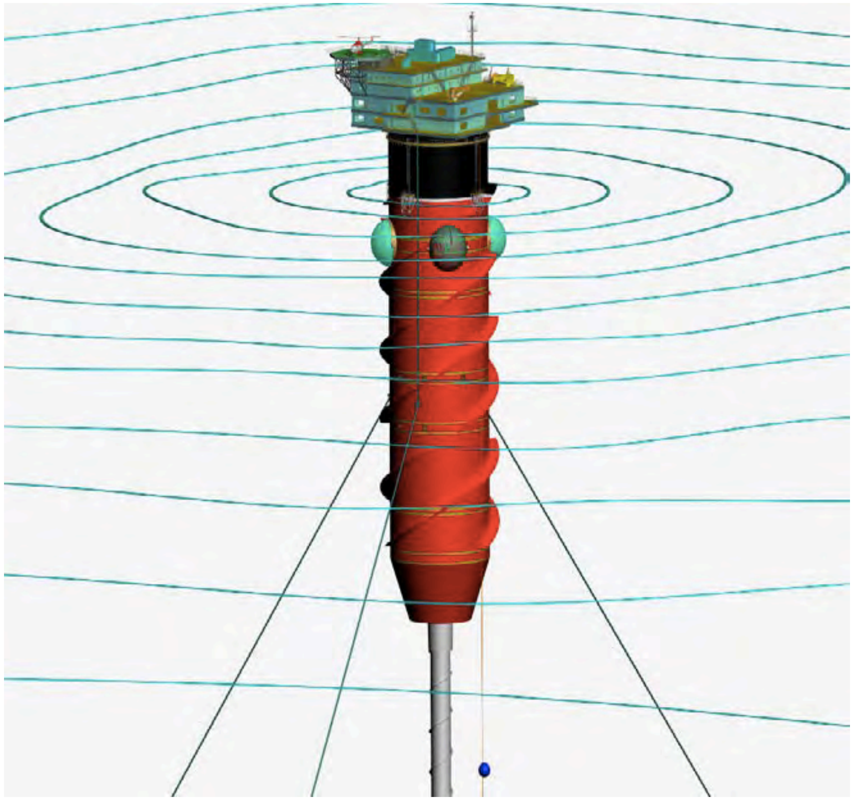
Harnessing Power from the Ocean

Captures Solar Energy

Abundant Natural Resource

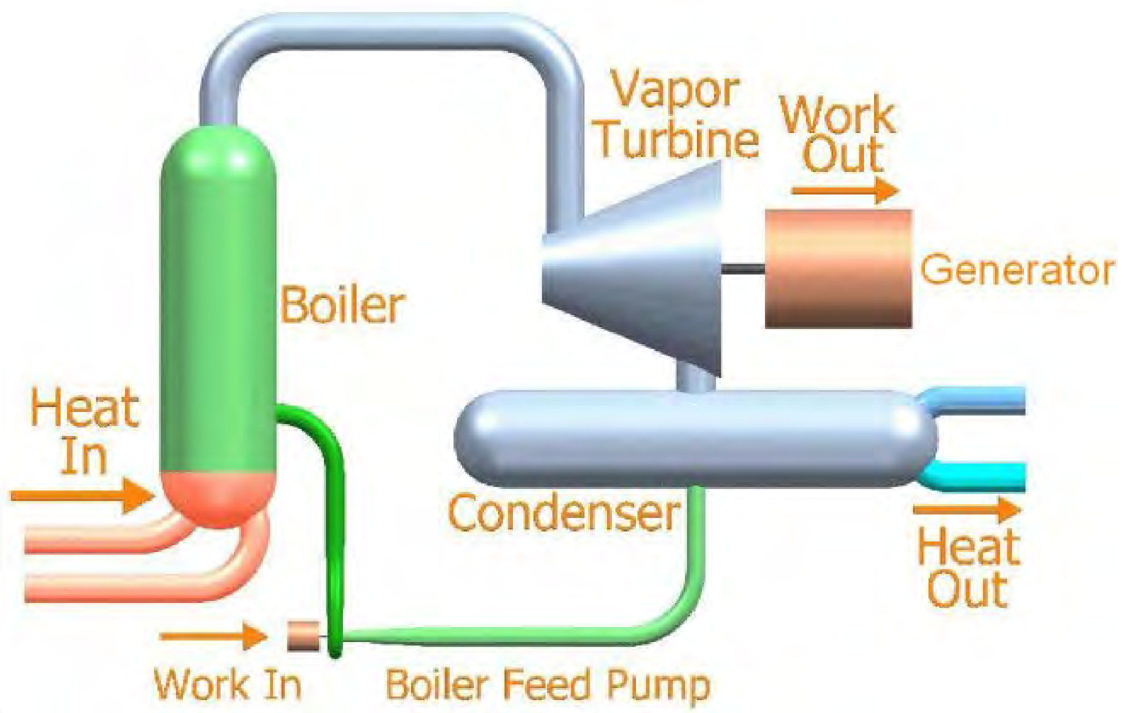
Low Pressure, Low Temperature

Compatible with Environment



OTEC Technology – Fundamentals

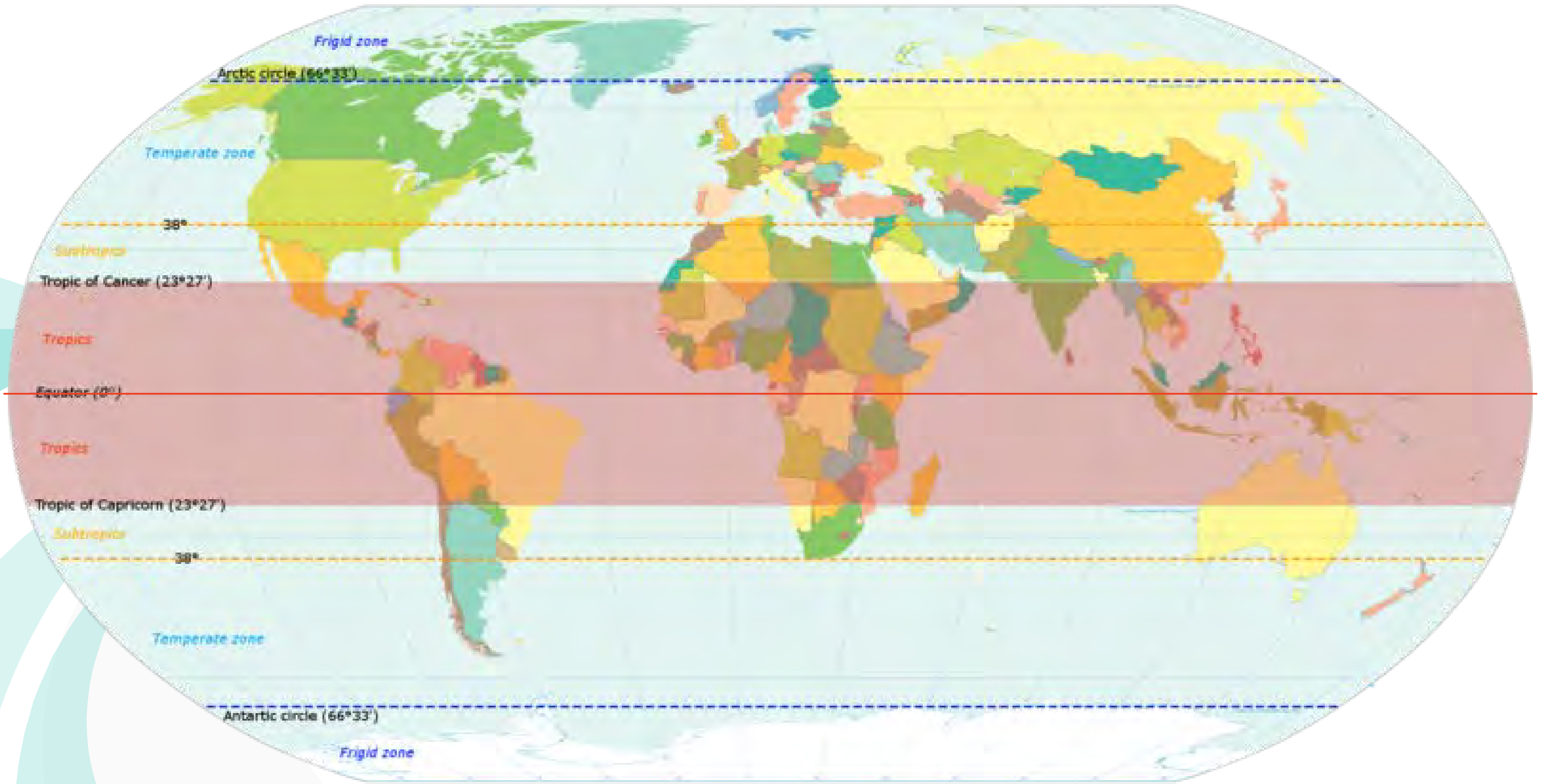
How OTEC Works



Advantages

- Base Load Power
- Reliable
- Renewable/Clean

Geographic Focus – Where OTEC Works



Characteristics of Good OTEC Sites

- Surface ocean temperatures
  - Annual average of 78 degrees or higher; hotter is better
  - Cold season ocean temperatures of 76 degrees or higher
- Close access to cold deep ocean water
  - 40 degrees; typically 3000 feet deep
  - Distance to shore - < 5 miles ideal, < 15 miles acceptable, shorter is better
- Mooring and severe storm assessment
  - Flat shelf, stable bottom
  - Best place in worst storms – wave, wind, current
- Shore side interconnection to reliable T&D system
- High electrical rates; limited base load alternatives

Potential OTEC Markets

On Shore Utilities

- Bahamas
- Barbados
- Belize
- Costa Rica
- Ghana
- Haiti
- India
- Indonesia
- Jamaica

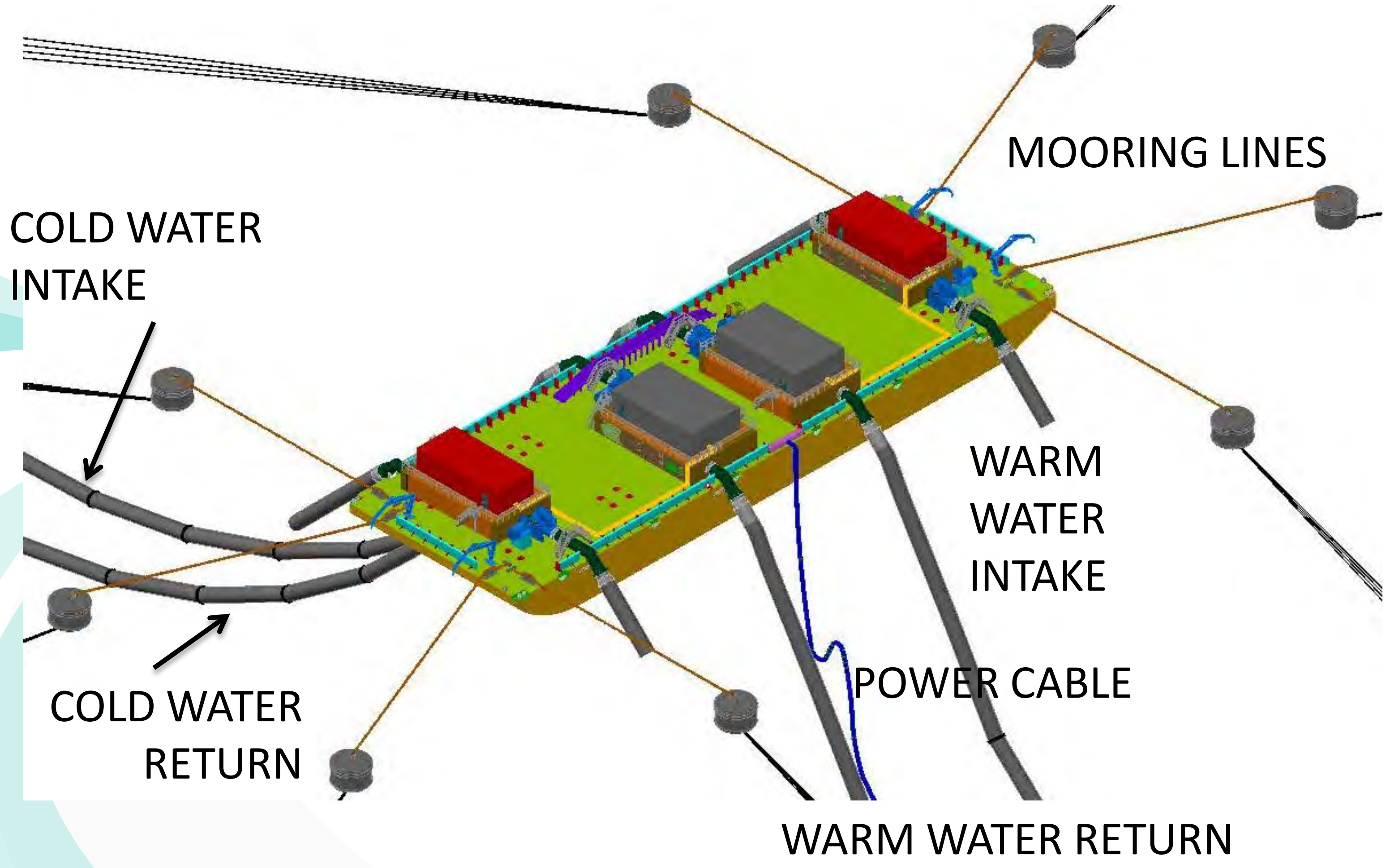
On Shore Utilities

- Malaysia
- Maldives
- Marshall Islands
- Philippines
- Sri Lanka

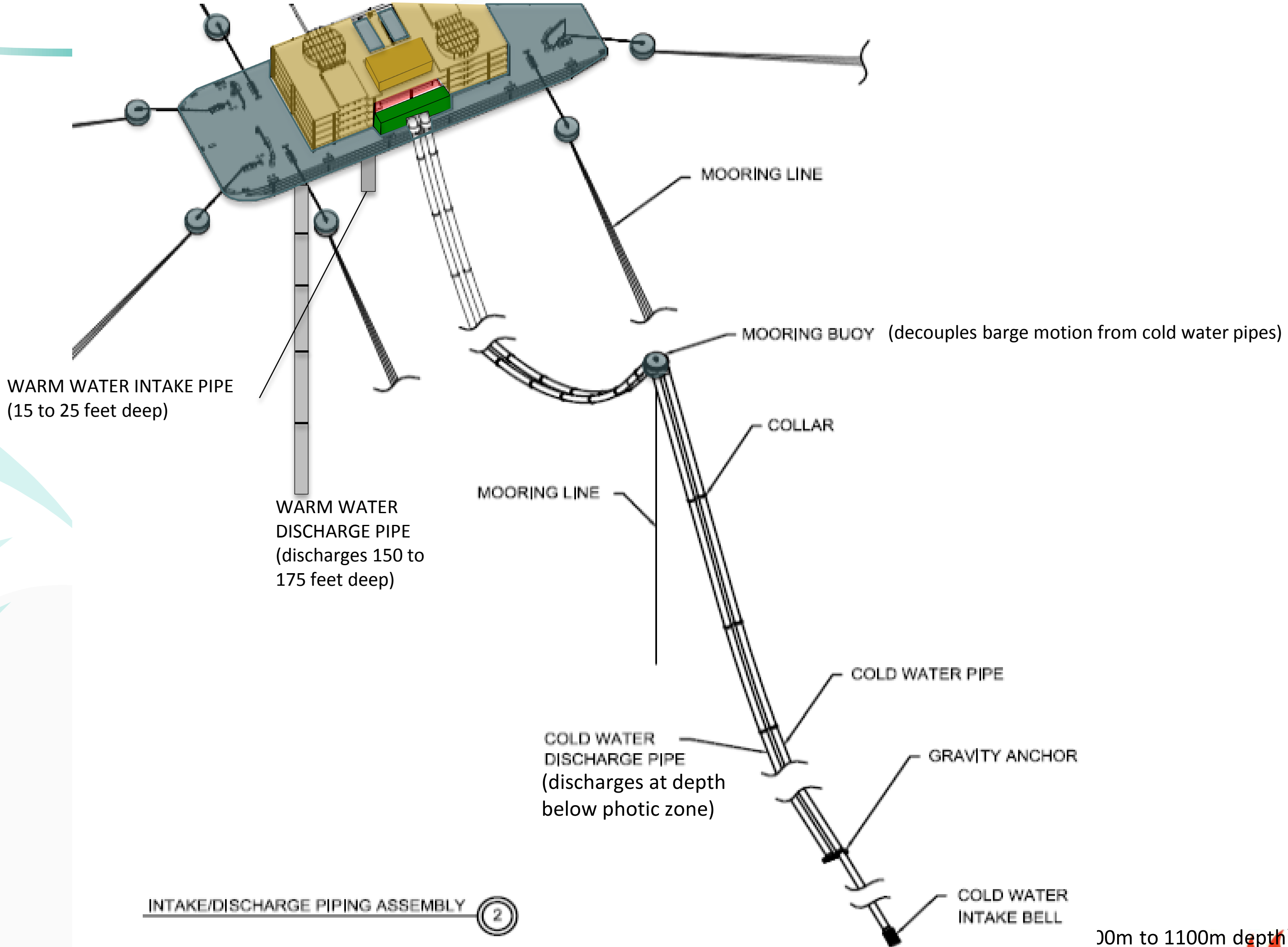
Offshore Oil and Gas Drilling

- Indian Ocean (Australia and India)
- Southern Atlantic Ocean (Brazil)

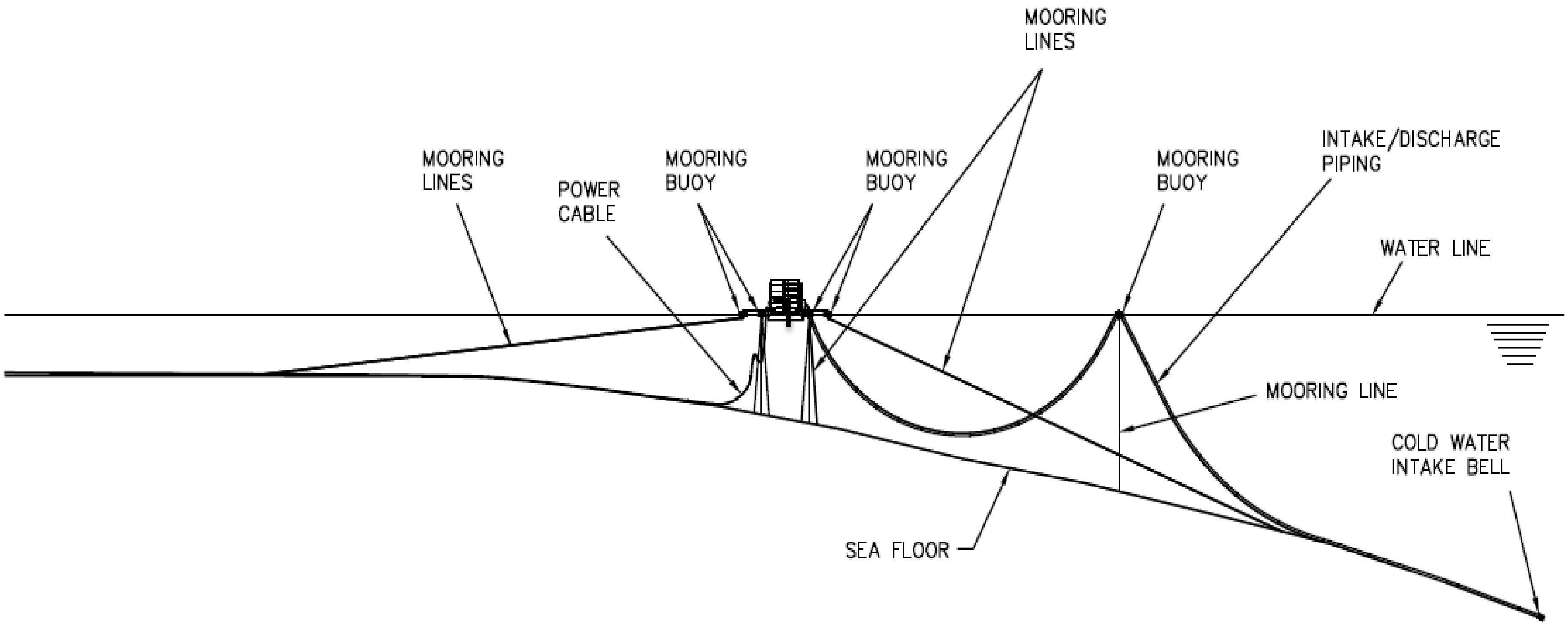
The OTI 5.0MW OTEC Barge Power Plant



Barge Production Plant Arrangement



Mooring System ,Cold Water Pipe and Power Cable Interface With Seabed



“Under the Hood” of OTEC

- Power Block
  - Heat Exchangers
  - Turbines
  - Electricity Generation, Control and Management
  - Pumps, Motors and Variable Frequency Drives
- Platform and Mooring
  - Barge-based up to 5.0 MW
  - Spar-based from 25MW up to 100MW with ABS Approval in Principle/Preliminary Design
- Power Cable and Interconnection
  - Power Cable – 35kV (3.5MW to 25MW plant) up to 138kV (100MW plant)
  - Interconnection/substation – shore-based tie in to utility grid at synchronized voltage and frequency regulation
- Cold Water Pipe

OTEC Development – Failures & Successes

Georges Claudes, 1930, Cuba

Mini-OTEC, Keahole, Hawaii, 1979

Nauru, 1982, 40kW net

OTEC History - Lessons Learned

U.S. government invested over $260 million into OTEC research from the mid-1970s to early-1980s culminating in integrated system pilot projects.

1979 - Mini-OTEC - (93 kW gross) *(Trimble and Potash 1979, Trimble and Owens, 1980)*

- Engineering requirements of an OTEC power system design, construction, and operation at sea were understood at a small scale .
- ***The observed performance of the complete power cycle agreed closely with the analytical predictions.***

1981 – OTEC 1 – (.9 MWe Equiv Gross) *(Castellano, 1981)*

- Heat exchanger cycle in close accord with behavior predicted from model.
- Successful deployment of the bundled 2.2-m-diameter, 670-m-long CWP.
- Successful operation of CWP and heat exchanger in ocean conditions
- Biofouling control with injection of chlorine at amounts well below FPA limits.
- Confirmed that marine engineering aspects of OTEC operation are understood.
- ***The test program provided no surprises.***

OTEC History – Lessons Learned

1981 Japanese Shore-Based OTEC Pilot Plant - Nauru (100-kW)

- The Tokyo Electric Power Company successfully built and deployed a closed-cycle OTEC plant .
- Demonstrated total pilot-plant construction and operation.
- Generated output was used to power the plant and the remaining electricity was used to power a school and other places.
- ***Demonstrated that net power can be generated from a land-based OTEC system and delivered to a real power grid.***
- Provided accurate data on performance of complete power cycle
- **The goals were all successfully accomplished.**

OTEC History – End of U.S. DOE Support

<u>1981 U.S. DOE Program Opportunity – 40 MWe (net)</u>

Avery-Wu *"Renewable Energy from the Ocean"*

- A Program Opportunity requesting cost-sharing proposals for the construction, deployment, and operation of a 40-MWe (net) OTEC power plant that would demonstrate the technical feasibility of OTEC at a large scale.
- With the change of Administration in 1981, no funding was requested to continue the program. DOE support of the program was then terminated.

<u>Economic Barriers to Private Investment</u>

- Historically low stable cost of fossil fuels
- Environmental costs and energy security not valued
- High initial life capital cost vs. life cycle cost
- Original OTEC designs – too big, too heavy, too costly

Recent Challenges & OTI Solutions

- Technical Challenges – Solution
  - Very Low efficiency cycle – high parasitic loss penalties
    Solution: High Efficiency Heat Exchangers
  - High water volumes – high pumping power demand from deep in the ocean
    Solution: Efficient Flow Pattern of System Design
  - Marine environment – Survivability in major weather events; long term corrosion
    Solution: Barge & Spar Designs; Strategic Partnerships
  - Utility Integration – Diversified Generation Sources; Small Island Grids

    Solution: Limited Capacity Battery Storage
  - Environmental Impacts – General and Project Site Specifics

    Solution: Design Mitigations; Strategic Partnerships

Environmental Impacts and Mitigating Strategies

- Cold Water Intake and Return
  - Nutrient-rich water
  - Photic Zone
  - Flow rate
- Warm Water Intake and Return
  - Flow Rate
  - Screening and Stand-off Distance
  - Avoiding Thermal Contamination
- Marine Life
  - Plankton
  - Pelagic Fish
  - Marine Mammals and Reptiles
- Navigation and International Cable Protection Convention

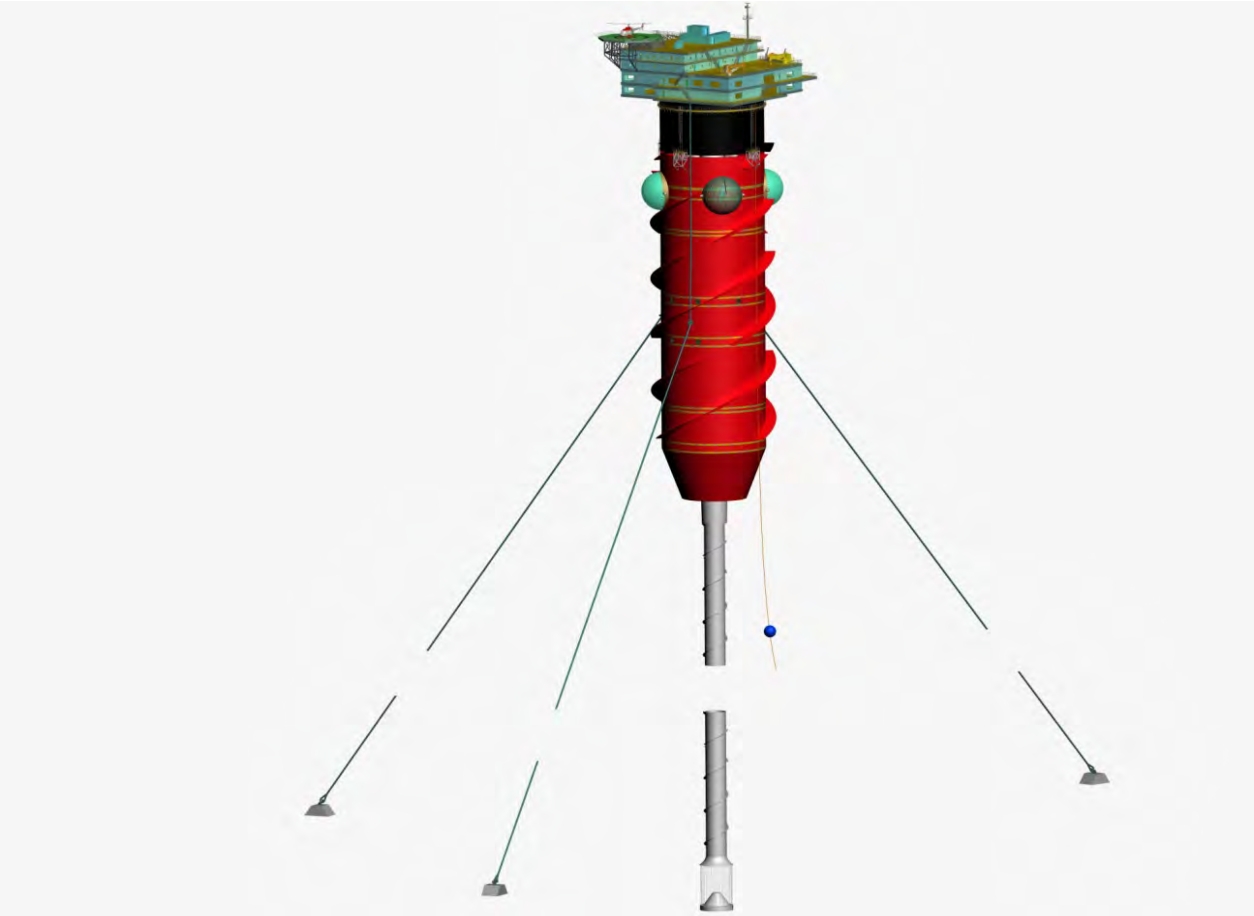
Integrating with Utility Operations

- Issues
  - Interconnection
  - Power Cable
  - Peak/Off-Peak Output (Ramp Rate for Quick Load Pickup and Rejection)
  - Grid Stability and Transients
  - Base Load Generation vs Intermittent Load
- Opportunities
  - Nominal Output with excess during peak demand period
    - Output tracks seasonal changes in ocean temperature – energy demand curve
    - Stored Potential above nominal scheduled energy delivery – Quick Load Pickup
  - Energy Storage
    - Ancillary Service helps stabilize utility and protect OTEC facility
    - Reduced Size as Consequence of OTEC's Stored Potential

OTI Project Pipeline

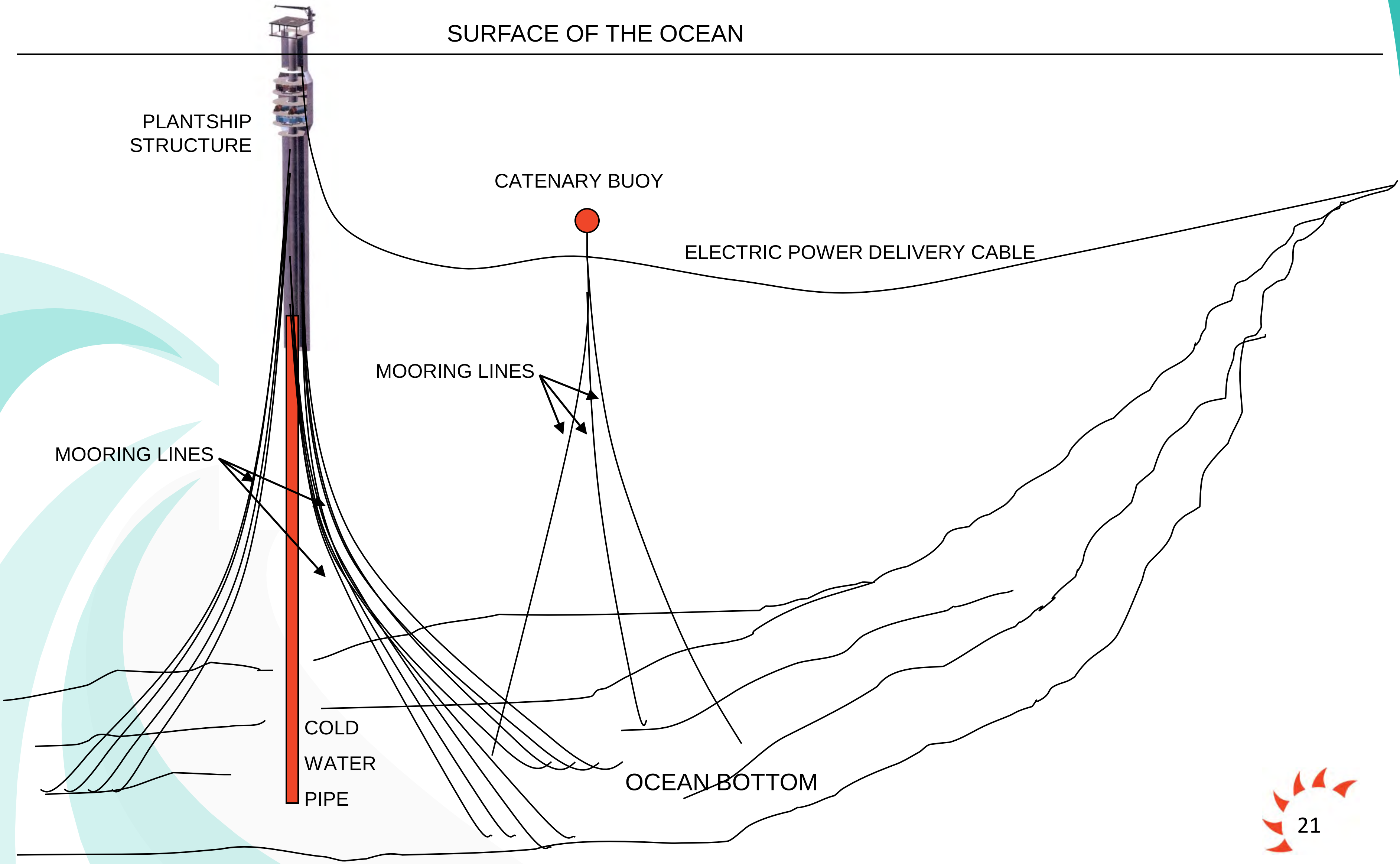
- Kona, Hawaii – 1 MW Research, Development and Demonstration Facility (NELHA)
- Bahamas – Abaco or Eleuthera – 3-5 MW (BEC)
- Grand Cayman – 5 MW (CUC)– Optional Shore-side Piping for SWAC
- Grand Cayman – 20-25MW Production Plant (CUC)
- Oahu, Hawaii – 100MW Production Plant (HECO)

OTI 25-100 MW Off-Shore Power Plant



OTEC Technology

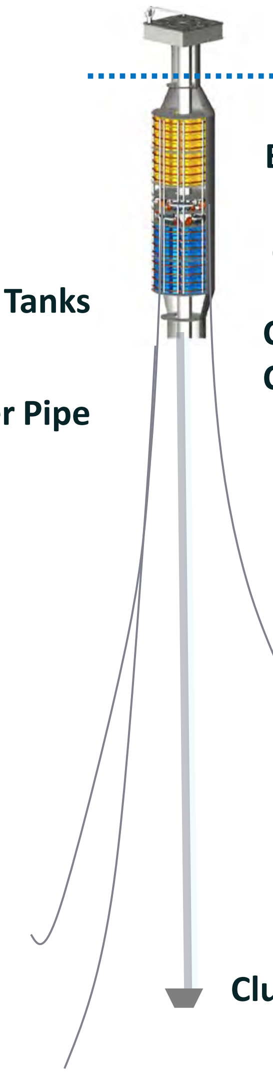
Abell OTEC System on Location



OTEC Technology

Major Subsystems & Components

- Spar
  - Platform
  - Mooring
- Heat Exchangers
- Power Block
  - Generators
    - Switch Gear
    - Transformers
  - Turbines
  - Warm / Cold Water Systems
- Power Transmission
- Cold Water Pipe



OTEC International LLC

- Legacy of 40 years, dedicated OTEC R&D –Anderson technology (2000)
- Current best of class – Off-shore industry and materials
- Engineered systems ready for utility and commercial markets
  - Reduced project risks
  - Lowered development costs
  - Increased OTEC reliability
  - Bottom line focus
- Over 17 U.S. issued and pending patents filed on proprietary innovations ; 44 Internationally
- Independent evaluations – ABS, Black & Veatch
- Project pipeline – 1 MW, 5 MW, 25 MW & 100 MW

Company Sponsor - The Abell Foundation

- Endowed charitable foundation founded in 1953
- Fund innovative solutions to social challenges
- Promote entrepreneurship as economic growth engine
- Early stage investor – Triple Bottom Line focus
- Proven track record
  - Two Successful IPOs: Guilford Pharmaceuticals and Visicu
  - Four Successful Private Dispositions of Emerging Technology Companies
  - Current Investments: PAICE–Toyota License, TRI–Bio-Refinery, Ceratech–Green Cement
- Commercial Projects – will partner with U.S., Asian and local market investors

Other Potential OTEC Projects in Pipeline

- Lockheed-Martin / Reignwood – South China Sea Coastal Resort – 10 MW
- Bluerise NV – Curacao Sustainable EcoPark
- OTE Corp – Bahamas OTEC/SWAC Project
- MAKAI Ocean Engineering – DOE R&D Demo at NELHA < 1 MW – No T&D
- Saga University – Kumejima Island Demo < 1 MW – No T&D

Due Diligence Support

- ShareFile Repository
- Validation and Verification Testing
  - UMD – heat exchangers
  - UDel – Composite Cold Water Pipe
  - CDI Marine Engineering – 1:40 Scale Model Testing of Spar, 1:80 Scale Model Test of CWP
- Independent Engineering Assessments
  - Black & Veatch
  - ABS
  - Horton
- Development Partners
  - UMD, Novelis, Bundy, Fisnar, Resin Designs, DTMP, CDI, Burns & Roe – Heat Exchangers
  - 5D Composites, CDI, UDel – Cold Water Pipe

OTEC International LLC
An Abell Foundation Company

111 S. Calvert Street, Suite 2300
Baltimore, MD 21202 USA
011+ 1+ 410 547 1300
www.OTECI.com