ORE 330
Mineral and Energy Resources of the Sea
OTEC
The Ocean as a Heat Engine
The Ocean as a Heat Engine

- The ocean runs the climates of Earth and is a giant natural heat engine
- Cold Water in the poles and warm water in the tropics
- The heat transfer between these areas produces wind, currents, and weather in general over thousands of kilometers
Favorable ΔT Sites

Temperature difference between surface and depth of 1000 m

- Less than 18°C
- 18°C to 20°C
- 20°C to 22°C
- 22°C to 24°C
- More than 24°C
- Depth less than 1000 m
Figure 3. Closed-Cycle OTEC Flow Diagram.
Figure 2. Open-Cycle OTEC Flow Diagram.

1. Warm seawater in
2. Vacuum chamber
3. Desalinated water vapor
4. Warm seawater return to sea
5. Desalinated water vapor
6. Cold seawater in
7. Cold seawater return to sea
8. Dissolved gas

Flow Diagram:
- Warm seawater is pumped into the vacuum chamber (1).
- The water is flash evaporated to desalinated water vapor (2).
- The vapor is expanded in the turbogenerator (3) to produce power (4).
- The condensed water returns to the sea (5).
- Cold seawater is pumped into the vacuum chamber (6) for desalination (7).
- The vacuum pump (8) removes dissolved gas from the system and sends it to the atmosphere.
Products of OTEC
The diagram illustrates a system for extracting fresh water from ocean water. Ocean surface water, with temperatures ranging from 23.3°C to 29.4°C and pressures from 2859 N/m² to 4100 N/m², is ingested and deaerated. After passing through a condenser, which cools the water to 13.9°C, the water is expanded through a turbine to generate steam. The steam is then condensed, reducing the temperature to 7.2°C, and the resulting fresh water is collected.

Key temperatures and pressures:
- Ocean surface water temperatures:
  - 23.3°C: 2859 N/m²
  - 26.1°C: 3375 N/m²
  - 26.7°C: 3487 N/m²
  - 27.2°C: 3603 N/m²
  - 29.4°C: 4100 N/m²
- Condenser temperature: 13.9°C
- Expansion turbine temperature: 7.2°C
- Steam pressure at the turbine: 2874 N/m²
Figure 4: Hybrid OTEC system
# Comparison of OTEC Cycles

<table>
<thead>
<tr>
<th>Cycle</th>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
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<tbody>
<tr>
<td>Closed</td>
<td>1. Smaller turbine</td>
<td>1. Biofouling</td>
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<td></td>
<td>2. More developed technology</td>
<td>2. Material compatibility with working fluid</td>
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<td>3. Large, costly heat exchangers</td>
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<td>4. Complexity and Cost of handling secondary fluid</td>
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## Comparison of OTEC Cycles

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| Open  | 1. Option for producing fresh water  
        2. No large heat exchangers required  
        3. Higher thermodynamic efficiency  
        4. Higher heat transfer coefficients  
        5. Elimination of potentially hazardous working fluid  
        6. Potentially more cost effective and versatile than CC-OTEC | 1. Large turbine and steam duct size  
                                                                 2. Large platform size required  
                                                                 3. Removal of noncondensibles from condenser  
                                                                 4. Need to contain vacuum in large volume  
                                                                 5. Increased parasitic power |
Ocean Thermal Energy Conversion Pilot Plant

- Warm water is drawn into OTEC plant.
- Less than 1 percent of the water is turned into steam by the extremely low pressure in the evaporator. The remaining water is discharged. Steam turns a turbine, which causes a generator to produce electricity.
- Deep ocean water passes through pipes, which cool steam.
- The steam condenses, producing fresh water.
OTEC Plant

Electricity

Steam

Condenser

Cold seawater in

Desalinated water out

Warm seawater in

Cold seawater in

Desalinated water out

Cold seawater out

Air conditioning

Drinking water

Cold-water agriculture
Figure 5: Heat exchanger designs
Figure 8: Benefits of the OTEC system
Lockheed's 10MW conceptual design
Fabricate Pipe On-Site

- Estimate 30 m per day
  - 3-4 weeks for a entire length
- Transportation and deployment is easier but needs good weather window
Cold Water Pipe

- Previous work shows promise, but also challenges

1000m x 10m = Mega-structure!
Delivery to con...

- Cables for now.
  - Longest DC cable runs from Norway to Netherlands (560 km)
    - Rated for 700 MW
Delivery to consumer?

- In the Future…
  Further offshore and larger systems and systems that graze the equator and then ship to consumers. But what do you ship?

Is a hydrogen economy likely?

Figure courtesy of Makai Engineering
5 MWe OTEC Pre-Commercial Plant

OTEC Components

(2) Condenser: 17.5m (L) x 5m ø
(2) Evaporator: 16m (L) x 7m ø
(2) Turbine/Gen.: 14.5m (L) x 3.5m ø
(1) WP Stg Evap.: 15m (H) x 9.5m ø
(1) WP Stg Cond.: 10m (W) x 10m (L) x 12m (H)
(1) Warm Water Inlet: 5m x 3m
(1) Cold Water Pipe: 2.8m ø x 1000m (L) m
(1) Mixed Water Discharge Pipe: 5.5m ø x 50m (L)

Platform

Length = 122m
Breadth = 30m
Depth = 16m
Draft = 9m
Displacement = 32,000 MT
FIGURE 1
Schematic Representation of Deep Ocean Water Usage in an integrated system.

- **Vorn Surface Seawater**
  - 24°-28°C
- **Cold Deep Seawater**
- **DTEC PLANT**
  - 4°C
  - Electricity (Hydrogen)
  - Fresh Water (Open cycle)
- **8°C**
- **INDUSTRIAL COOLING**
  - Condensation: ethanol Freon recycling CO2 Recycling
- **11°C**
- **Homes Hotels Businesses**
- **Potable water Irrigation**
- **Fruits Vegetables Mushrooms**
  - 14°C
- **AQUACULTURE PLANTS**
  - ANIMALS

Note: The diagram illustrates the integration of deep ocean water usage for various purposes, including electricity generation, fresh water production, industrial cooling, and the cultivation of fruits, vegetables, and mushrooms.
And since success is always just around the corner...

Thank you.

The OTEC OWC Wind Turbine Spar Buoy: