Production of Fresh Water using Renewable Ocean Thermal Energy

Ocean-Thermal Desalination (OTD)

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Presentation Outline

- World Water Resources in 21st Century
- Energy-Water Nexus
- OTD for Production of Fresh Water
- Technology Readiness & Economics
- Opportunities and Challenges for Africa
- Path Forward

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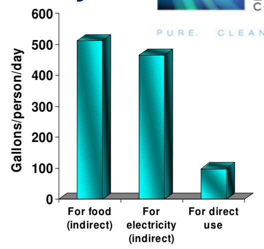
World Water Resources in the 21st Century

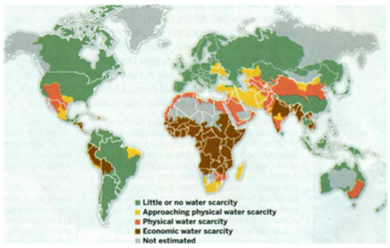


Expanding Water Consumption with Increased Population and Improved Living Standard

Water is Vital Resource That is Facing Three Critical Challenges

- Increasing Population along with Improved Standard of Living
- Increasing Demand for Energy Production and Industry Consumption
- Shifting Global Weather Patterns and Climate Changes Imposing Scarcity of Good Quality Water Where Needed

Island States Face Critical Shortage of Fresh Water with Direct Impact on Human Health



Water Stress Regions
Ref: Chemical & Engineering News, July 2013

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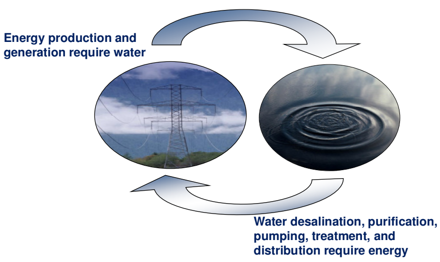
Energy-Water Nexus

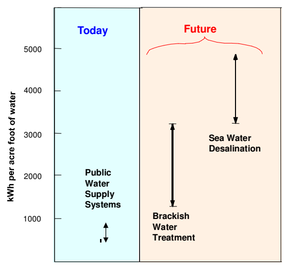
Energy and water are inextricably linked

Water consumption for energy production

- Between 0.5 to 2 gal of water consumption / kWh power generation depending on fuel
- 2 million gal to drill single horizontal well in the “fracking” process
- 3 gal/ gal of ethanol, not including irrigation water
- Hydrogen production will have high water consumption



Power requirements for current and future water supply



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OTD Technology for Water Production

OTEC-RO System

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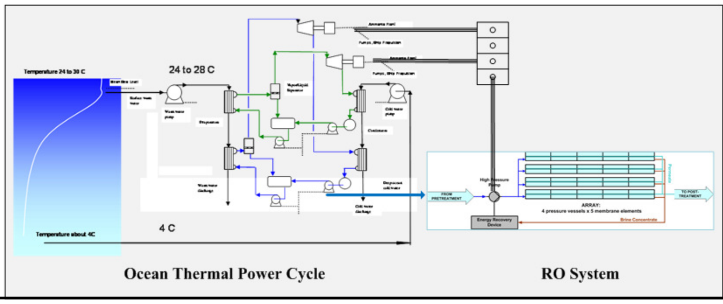
- RO-System operated by OTEC power
- Deep-ocean cold seawater is used in the RO-System that minimizes chemical treatments
- Concentrated brine from RO-system is mixed with return seawater from OTEC plant that minimizes environmental impacts
- RO power consumption 3.5 to 5.0 kWh / 1000 liters with pressure recovery system
- 1 MWe OTEC plant would produce between 4.8 to 6.8 million liter / day of fresh water with no net power



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OTD Technology for Water Production

Open-Cycle OTEC System

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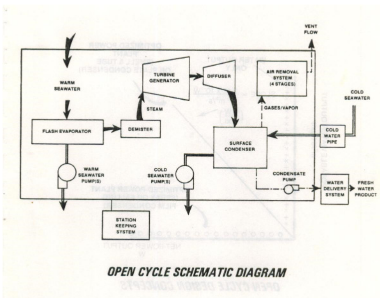
- Flash evaporation of warm seawater and low pressure steam pressure vapor drives the turbine
- Condensation of exhaust low-pressure steam using surface condenser produces fresh water
- Design studies were performed for large scale floating OC-OTEC plants
- Validation tests performed at NELHA using Heat Mass Transfer Apparatus and 210 kW Pilot Unit



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OTD Technology for Water Production

Low Temperature Thermal Desalination System

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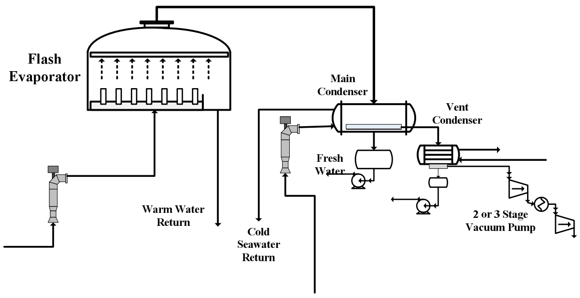
- Open-Cycle system without low-pressure turbine
- In the absence of turbine, larger temperature difference is available for single-stage or two-stage flash evaporation (flash-down) and condensation
- Parasitic power consists of seawater pumping and vacuum system
- Power consumption is 2.4 kWh/m^3 or lower, compared to 3.6 kWh/m^3 required for RO-system
- Parasitic power can be provided by an integrated closed cycle OTEC



Ocean Thermal Desalination (OTD) System

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OTD Technology for Water Production

Hybrid-Cycle OTEC System

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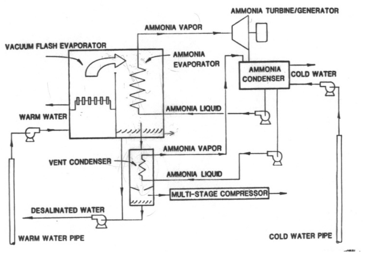
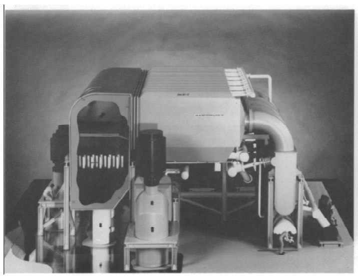
- Spout flash evaporator to generate low-pressure vapor, like in Open Cycle
- Vapor is condensed in compact aluminum heat exchanger to produce fresh water by generating ammonia vapor
- Ammonia vapor runs the turbine and low pressure ammonia condensed in high-performance condenser, like in Closed Cycle
- Biofouling is eliminated
- Typical water production rate is 3.0 million liters/day per MWe net power





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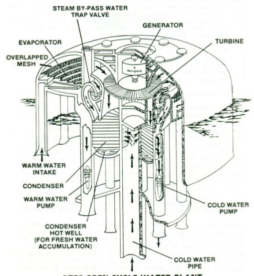
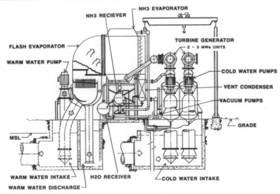
Technology Readiness

- Performance test data for components and integrated systems
- Validated design methods developed based on performance data obtained at NELHA
- Design Studies:
  - 100 MWe floating open-cycle OTEC Westinghouse
  - 10 MWe hybrid-cycle plant by Argonne Lab
  - Other design studies
- Technology Readiness Level (TRL) can be considered at TRL-7 "Integrated Pilot System Demonstrated – System/process prototype demonstration in an operational environment."



OTEC OPEN CYCLE WATER PLANT ILLUSTRATING MESH TYPE SEPARATOR



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Economics of Seawater Desalination

- Global production of desalinated water 40 million m^3 / day of which nearly ½ are multi-stage thermal (mostly in the Middle East counties) and remaining are RO systems for brackish and seawater (SWRO)
- Economic merits of OTEC-water production should be based on SWRO in terms of energy consumption, carbon credit, environment impacts and O&M costs

Type	SWRO		
Production Capacity	10 million liters /day		
Total Installed Costs (TIC), $	14,845,100	14,845,100	14,845,100
Annual Levelized Costs			
Depreciation over 10 years, $	1,484,510	1,484,510	1,484,510
Electric Power, kW	1500	1500	1500
Electric Rate, $ / kWh	**0.15**	**0.25**	**0.35**
Energy Costs, $	1,782,000	2,970,000	4,158,000
O & M and Membrane Replacement Costs, $	1,406,500	1,406,500	1,406,500
Total Annual Cost, $	4,673,010	5,861,010	7,049,010
Cost of Water, $/m3	**1.42**	**1.78**	**2.14**
$/Kgpd	**5.36**	**6.73**	**8.09**

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Economics of OTD

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- Design studies show that small scale OTD can be competitive to SWRO powered by diesel engines
- Floating OTD can be competitive and overcome environment impacts of land-based SWRO powered by natural gas
- Design studies are required to evaluate the relative merits of different OTD technologies
- Economic merits can be significantly improved if land-based OTD is integrated with waste heat sources from utility and industrial plants

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Opportunities for OTEC-Water Production in Africa

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- Based on recent studies, some of the African Countries are facing scarcity of fresh water and the situation is expected to get worse by middle of the 21st century
- Some of the African countries have high level of education and potential of skilled labor that can be utilized for design and deployment of OTD plants
- Potential market of exporting premium bottled water to Europe from floating OTD plants from west African countries
- Integrated OTEC plants of simultaneous power and water for sustained energy and water supply have high potentials in Africa

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Challenges for OTEC-Water Production in Africa

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- Government, NGO and investors in Africa may or may not be familiar with potentials of OTEC and wait till OTD is commercialized in other countries
- Africa faces physical water scarcity combined with limitations of economic resources
- Production costs of OTEC water must be significantly reduced
- Distribution system is lacking in many African countries for distributing fresh water produced by floating or land-based OTD plants

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Path Forward

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- Feasibility design studies to evaluate techno-economic viability of OTD in African Countries
- Development of strategic alliances within Africa and with private as well as government organizations from other countries
- Strategic alliances with Small Island Developing States (SIDS) that are facing similar crisis of sustained water supply
- Approaching NGO and UN for initial funding for feasibility studies and developing centers for water supply in African and SIDS countries

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