Oceans of Energy:
Ocean Thermal Energy
True Baseload Renewable Energy plus Desalinated Water

CB Panchal

Offshore Infrastructure Associates, Inc.

WIREC
Washington, DC
March 4, 2008
Presentation Outline

• Thermodynamic principle
• Three-phase development of the ocean-thermal technology
• Energy-water nexus
• Ammonia as fertilizer and energy carrier
• Plantships for co-production of ammonia and desalinated water
• Six-point visionary approach of the OTEC technology
Primary Energy Sources
Building Infrastructure for Sustainable Energy Supply Using the Current Energy Supply

With impeding peaking of oil and natural-gas production, it is important to examine all potential primary energy sources of comparable magnitude to fill this gap in the foreseeable future.
Thermodynamic Principle

- Ocean-thermal first-law efficiency is 71.4% (100 MWe net power/140 MWe gross)
- First-law efficiency of fossil plants is 30 to 40% (net power/combustion value of fuel)
- Second-law efficiency of ocean thermal is low (~ 7%), which requires higher capital investment than fossil plants but no fuel cost and no CO2 emission
Three-Phase Developments of OTEC Technology

Phase I (Early 1970’s through mid 1980’s)
- Resolved major technical barrier (Mini-OTEC, Biofouling, heat exchangers, seawater pipes, materials, OTEC-1)

Phase II (Mid 1980’s through early 2000’s)
- Technology developments (Hybrid cycle, open-cycle, economic analysis)

Phase III (Early 2000’s and on-going)
- Deployment (Modular plants for island markets, Plantships for production of ammonia as hydrogen carrier and desalinated water)
Major Technical Issues Resolved

- Net power generation – proved by Mini OTEC
- Biofouling issue resolved with long term R &D
- Aluminum is qualified for heat exchangers
- Developed new concepts of modular heat exchangers
- Deploying experiences of polyethylene cold-water pipes for land-based plants
- OTEC-1 experiences of deploying vertical pipe and at-sea testing of large components
- Testing and design of FRP pipes to support upto 100 MWe ocean-thermal plants
- Design concepts of small and large plants to demonstrate the technical and economic viability
- Platships for delivering energy products to the continent USA and rest of the world with high energy demands
Modular Heat Exchangers

- Initial focus on large shell and tube heat exchangers; however, modular heat exchangers ideally suited for OTEC plants
- Leading candidates: Brazed aluminum and stainless steel plate heat exchangers
Power Modules

An integrated power module is a prime mover of OTEC plants: small land-based as well as large floating plants
Seawater Systems

Land-Based Small Ocean Thermal Plants
Seawater Systems

At-Sea Ocean Thermal Plants

Cold-Water Pipe

- Fiberglass Reinforced Plastic (FRP) for larger sizes
- High-Density polyethylene (HDPE) up to 2 meter diameter

Platform

- Various concepts of platform design for 40MW to 100 MW plants
- Promising new platform design concepts
Integrated Hybrid Cycle Power Module
Strategic Approach to Minimize Technical Risks

- Design methods and systems simulation codes based on 20+ years of R D&D
- Modular design of the power system with validated design methods and commercially available ammonia turbine/generator
- Ammonia as the working fluid with proven thermodynamic and thermal performance
- Aluminum heat exchangers with 20 year service life, proven by long-term R&D, with stainless steel plate heat exchangers as alternate design option
- Fiberglass reinforced plastic (FRP) seawater pipes based on testing of 8’ prototype test section
- Design experiences of offshore oil platforms
- State-of-the-art sensors and monitoring devices
Alternate energy sources (nuclear, ethanol, oil sand) have high consumption of fresh water.

OTEC is the only energy source that can co-produce power (or commodity products – ammonia) and desalinated water.
## Energy-Water Nexus

<table>
<thead>
<tr>
<th>Energy Technology</th>
<th>Average Water Consumption</th>
</tr>
</thead>
<tbody>
<tr>
<td>Petroleum Refining</td>
<td>100 gallons/barrel crude oil</td>
</tr>
<tr>
<td>Power generation</td>
<td>20 gallons/kWh</td>
</tr>
<tr>
<td>Nuclear hydrogen</td>
<td>35 gallons/kg of H2 (1 kg H2 is equivalent to one gallon of gasoline)</td>
</tr>
<tr>
<td>Ethanol (not including irrigation)</td>
<td>3 gallons/gallon of ethanol</td>
</tr>
</tbody>
</table>
Ammonia a Large Commodity Chemical

Consumes Large Quantity of Natural Gas

- World ammonia production ~ 140 million metric ton /yr
  - NG consumption ~ 4,620 billion cubic feet (bcf) /yr at 33,000 scf /MT

- US ammonia consumption ~ 16 million metric ton /yr (~ 50% imported)
  - NG consumption of 496 bcf /yr; (LNG imports of 652 bcf in 2004; projected 1080 bcf in 2010)

- NG-based cost of ammonia:
  - Capital - $1.6 billion for a typical 4,000 MTD
  - $109 /MT Capital @ 10% IRR + $174 /MT @NG cost $5.6/kcf
    (Henry Hub Aug07) = $283 /MT + O&M costs
Cost of Ammonia Linked to Rising Cost of Natural Gas

Cost of Imported Ammonia
$/Metric Ton FOB Tampa, Florida

2003 2004 2005 2006 2007

$/metric ton

150 170 190 210 230 250 270 290 310 330
Ammonia Fuel Cell As Potential for Distributed Power Generation to Displace Natural gas

Illustration using California (2006)

- NG-based power 42%  
  - 107,000 GWh of 230,000 GWh total  
  - 3 billion cfd of NG at 33% thermal efficiency
- NG (2005) consumption:  
  - Instate 873 million cfd (7.5%)  
  - Import 10,895 million cfd (92.5%)
- Significant impact on water supply

Figure 35. World Natural Gas Consumption by End-Use Sector, 2003-2030

Ocean Thermal Plantships

Co-Production of Ammonia and Desalinated Water

Plantships equipped with hybrid-cycle power system to produce desalinated water and new solid-state ammonia synthesis process.

Desalinated water

Ammonia
Ocean Thermal Plantships

Global Impact of Ocean Thermal Plantships
Six-Point Visionary Goals of Ocean Thermal Energy

1. Global displacement of petroleum-based fuels (diesel, fuel oil, naphtha) for power generation;
2. At-sea production of desalinated water for regions of critical water shortages;
3. Displacement of carbon-based for production of ammonia-based fertilizer;
4. Hydrogen supply to allow economic processing of heavy crude oils and upgrading oil sands;
5. Ammonia fuel-cell distributed energy to displace natural-gas fueled power generation and mitigate issues associated with imported LNG; and