Ocean Thermal Energy Conversion (OTEC)

Path to Commercialization: Opportunities and Challenges

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Primary Energy Sources

Investing the Present Energy Sources for Building Infrastructure for Sustainable Future Low-Carbon Energy Sources

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.
Presentation Outline

- Lessons from OTEC Historical Developments
- Technology Readiness Level (TRL)
- Visionary Pathway to Commercialization
- Technology Opportunities
- Barriers – Technical, Economical and Policy
- Path Forward
OTEC Power Cycle
Three-Phase Developments of OTEC Technology

Phase I (Early 1970’s through mid 1980’s)
Technical barriers: Mini-OTEC, biofouling, materials, heat exchangers, seawater pipes, environments, OTEC-1, 40 MWe pilot plant designs

Phase II (Mid 1980’s through early 2000’s)
Technology developments: small plants, water production, mariculture, economic analysis

Phase III (Early 2000’s and On-going)
Commercialization: Island and strategic markets, plantships - ammonia as the energy carrier and desalinated water
OTEC Technology
OTEC Technology

- Initial focus on large shell-and-tube heat exchangers; however, modular heat exchangers ideally suited for ocean-thermal plants
- Leading candidates: Brazed aluminum and titanium welded plate heat exchangers
Lessons from Historical Developments

General Perceptions

- Not viable for the US continent states

- Too expensive; high technical risks for investors; benefits to only islands/countries in tropical zones

- Mixed messages on capital costs: anywhere from < $5,000/kW to > $15,000 kW for moderate size plants

- Most likely the 1st Commercial OTEC plant would be deployed outside of the USA
Lessons from Historical Developments

Facts of the Matter

- Major *technical barriers* have been removed.
- Many *design studies* have been performed to show technoeconomic viability.
- However, after spending more than $350 million US federal plus industrial R&D funds in 1970’s and 1980’s not a single *pilot plant* was deployed.
- At today’s petroleum costs, OTEC is competitive to *petroleum liquid-fueled* power generation in the island states.
- Co-Production of power and desalinated water favors early commercialization in *niche* market – potentially the Island States.
Technology Readiness Level

OTEC Technology is at TRL 9 as per US/DOE Definition

TRL 9: System Proven and Ready for Full Commercial Deployment –
    Actual system proven successful operations in relevant environment,
    and ready for full commercial deployment

Then Why OTEC is Not Commercialized?

- Large RD&D investments \textit{did not} result into a single pilot, pre-
  commercial or commercial plant
- Rather than improving previous designs, tendency is to develop
  alternate design concepts
- Lack of \textit{reliable} cost estimates and risk management based on WBS
- Presently lack of \textit{competitive and credible} system integration
  pursued by major engineering companies
Path Forward to Achieve the Full Potential of OTEC
6-Point Visionary Goals of OTEC Commercialization

1. Displacement of *petroleum-liquid fuels* for power generation in the *Island States* – **Target 2020**

2. Production of *desalinated water* for regions of critical *water scarcity* – **Target 2030**

3. Displacement of *carbon-based* production of *ammonia* fertilizer – **Target 2040**

4. *Ammonia as hydrogen carrier* for economic processing of *heavy crude oils* and oil upgrading – **Target 2030**

5. *Ammonia fuel-cell* based distributed power generation – **Target 2050**

6. *Ammonia as hydrogen carrier for transportation* (Target 2050+)
OTEC - the Small Island States

2005 International Mauritius Meeting - Program of Action for SIDS, Energy Sources and Freshwater Resources

- “consideration be given by the GEF to finance OTEC, particularly in small island developing states (SIDS)”
- Target OTEC Plants for SIDS
  - Medium size 40 to 100 MWe Floating Plants
  - Small 5 to 10 MWe Land-Based plants using HDPE seawater pipes

Global Initiative Needed - E3Tec Submitted Proposal (2006) to UN GEF
Co-Production of Power and Fresh Water

Scarcity of Fresh Water

- Scarcity of fresh water is globally recognized
- At-sea desalination is likely the major source of fresh water in the foreseeable future
- Renewable energy can play key role in seawater desalination

Co-Production using hybrid OTEC cycle can be competitive where cost of electricity is > $0.25/kWh and cost of water > $1/m3
OTEC Ammonia Production

- Ammonia fertilizer – crucial commodity to world’s food supply
- Global ammonia production ~ 140 million metric ton (MT) per year
- More than 1.8 ton of CO2 emission per MT of ammonia for natural-gas based plants - emission would be higher for coal-based ammonia production
- 100 MWe OTEC plantship using produces about 300 MT/day
- Commercial scale ammonia production possible using Satellite OTEC Plantships
Global hydrogen consumption in oil refineries > 4 trillion standard cubit feet (scf) and increasing at > 7.5% for:

- Increasing H to C ratio of heavy crude oils
- Meeting low sulfur diesel regulations
- Increased consumptions in developing countries China and India

Refineries in the Gulf of Mexico States and California processing heavy crudes with total combined refining capacity > 8 million bpd
Ammonia Fuel Cell

Potential Distributed Power Generation to Displace Natural gas

Illustration using California (2006)

- NG-based power generation 42%
  - 107,000 GWh of 230,000 GWh total
  - 3 billion cfd of NG at 33% thermal efficiency

- NG (2005) consumption:
  - Instate 0.9 billion cfd (7.5%)
  - Import 11 million cfd (92.5%)

- Significant impact on water consumption and supply

Competitiveness of OTEC NH3 Fuel Cell Improves when Costs Associated with LNG Terminal are included in the Cost of Electricity
Opportunities

Decade of Window of Opportunity: 2010-2020

- After significant technology developments between 1970’s and 1980’s, OTEC became nearly dormant
- Small group of entrepreneurs and believers maintained OTEC visibility
- Renewed focus incorporating the recent technical developments with improved OTEC system integration
- Realization of needs for Low-C energy production
- OTEC initiatives from several groups
Barriers
Technical, Economical, and Policy

- **Full potentials** of OTEC is not fully realized
- Strong **negative perceptions** developed previously has not been fully erased
- Lack of an **operating** OTEC plant
Path Forward

Invest Present Finite C-Based Energy Sources To Build Infrastructure of Future C-Free Energy Supply

- Global Roadmap to Commercialize OTEC Plants by 2020
- Global Cooperation for Deploying the First Commercial OTEC Plant
Ocean Thermal Plantships

Global Impact of Ocean Thermal Plantships – Four Strategic Regions