Ocean Thermal Energy Conversion (OTEC)

Path to Commercialization: Opportunities and Challenges

Dr. C. B. Panchal

E3Tec Service, LLC

Phone: 410 531 0880

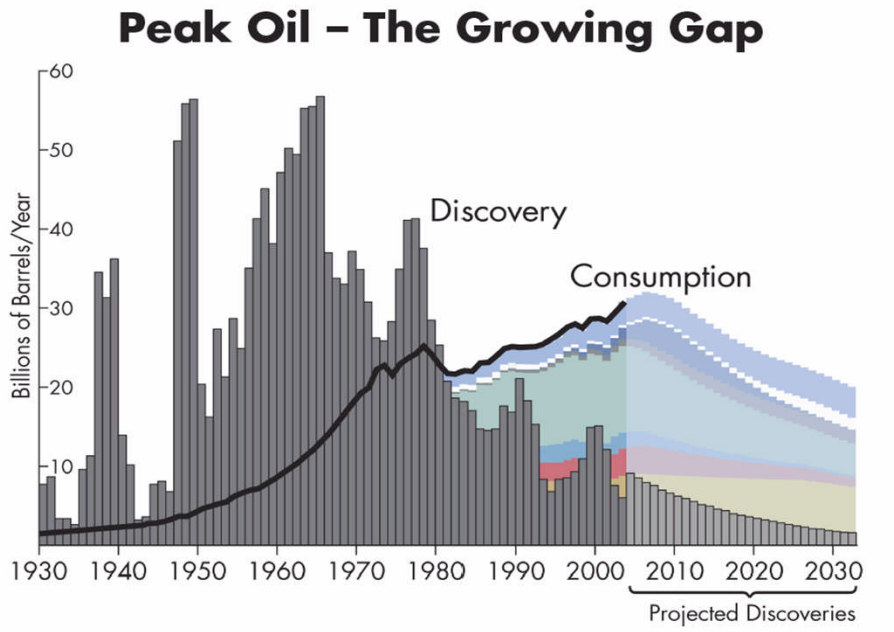
Email: cpanchal@msn.com

LCES-2011, Dalian, China

October 21, 2011

Primary Energy Sources

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

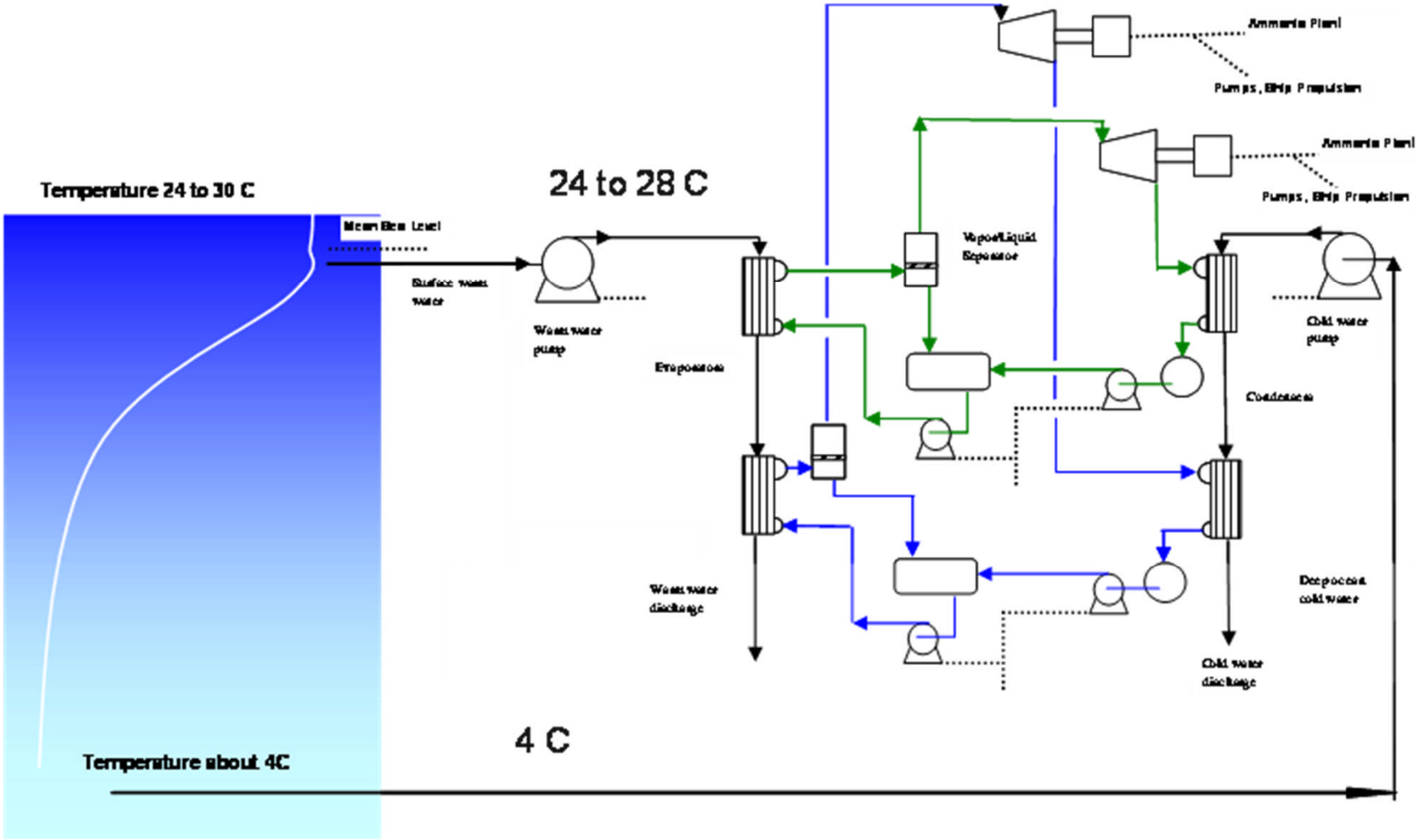


With impeding peaking of oil and natural-gas production, it is important to examine all potential *primary* energy sources of comparable magnitude to fill this gap in the *foreseeable* future

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)

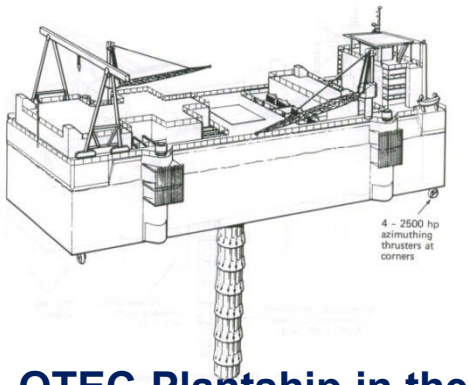
Technical barriers: Mini-OTEC, biofouling, materials, heat exchangers, seawater pipes, environments, OTEC-1, 40 MWe pilot plant designs

Phase II (Mid 1980's through early 2000's)

Technology developments: small plants, water production, mariculture, economic analysis

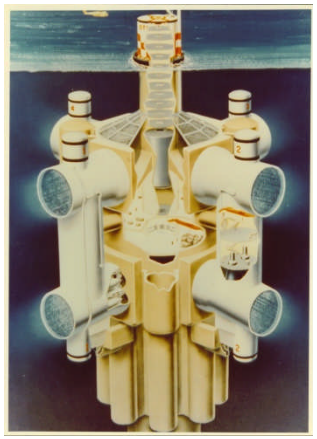
Phase III (Early 2000's and On-going)

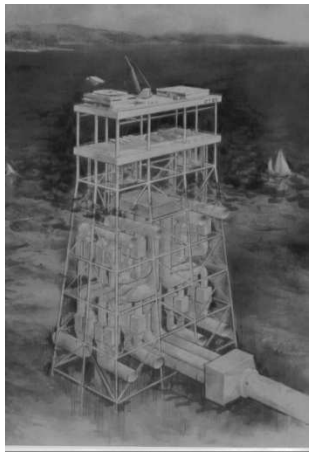
Commercialization: Island and strategic markets, plantships - ammonia as the energy carrier and desalinated water

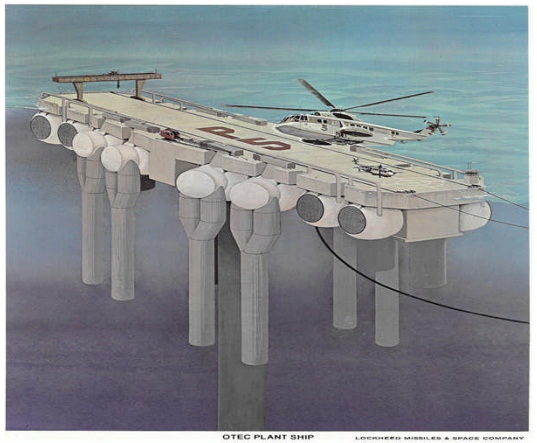


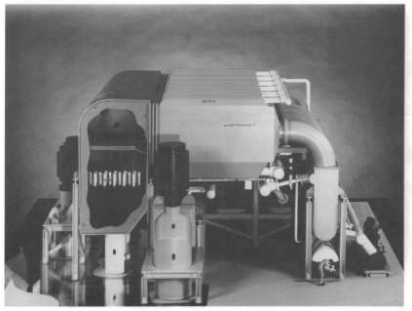
OTEC-Plantship in the Foreseeable Future

OTEC Technology



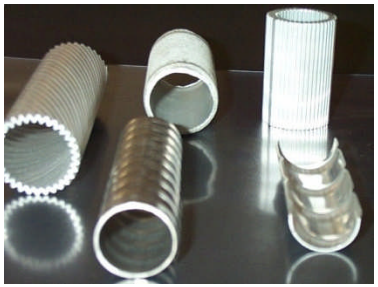


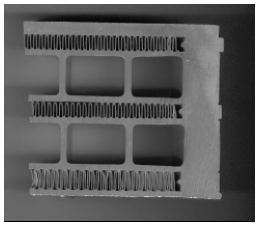


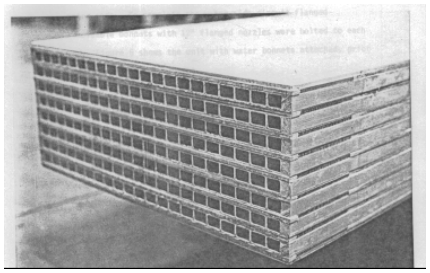


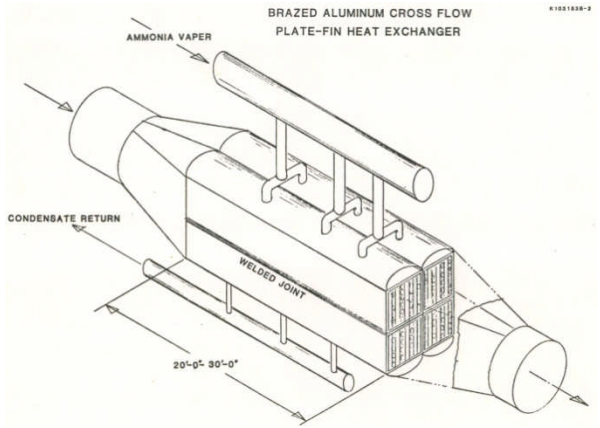
OTEC Technology

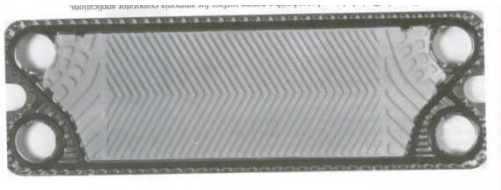
- Initial focus on large shell-and-tube heat exchangers; however, modular heat exchangers ideally suited for ocean-thermal plants
- Leading candidates: Brazed aluminum and titanium welded plate heat exchangers

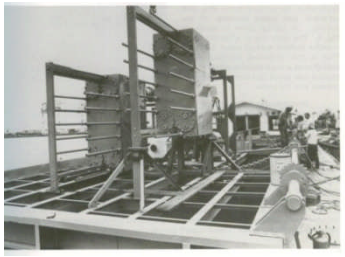












Lessons from Historical Developments

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 techno-economic 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 *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 *reliable* cost estimates and risk management based on WBS**
- **Presently lack of *competitive and credible* system integration *pursued* by major engineering companies**

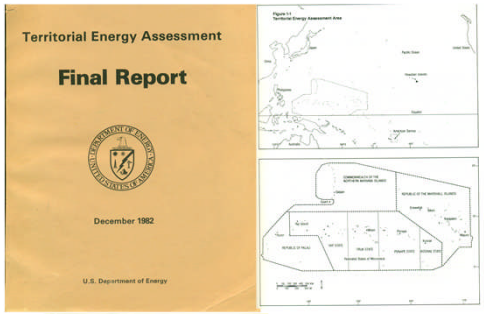
Path Forward to Achieve the Full Potential of OTEC

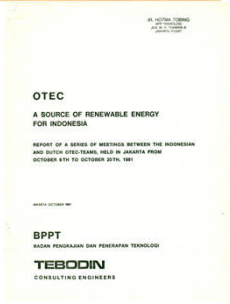
6-Point Visionary Goals of OTEC Commercialization

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

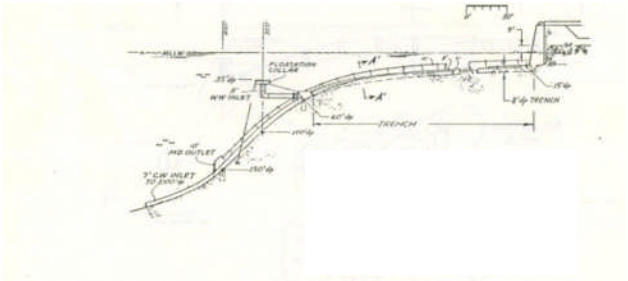
2005 International Mauritius Meeting - Program of Action for SIDS, Energy Sources and Freshwater Resources

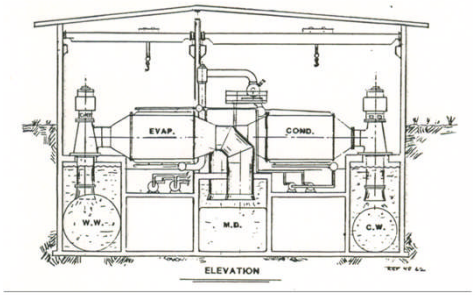


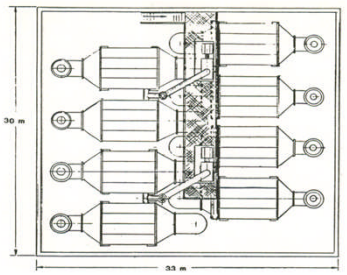


- "consideration be given by the GEF to finance OTEC, particularly in small island developing states (SIDS)"
- Target OTEC Plants for SIDS
  - Medium size 40 to 100 MWe Floating Plants
  - Small 5 to 10 MWe Land-Based plants using HDPE seawater pipes

Global Initiative Needed - ***E3Tec Submitted Proposal (2006) to UN GEF***





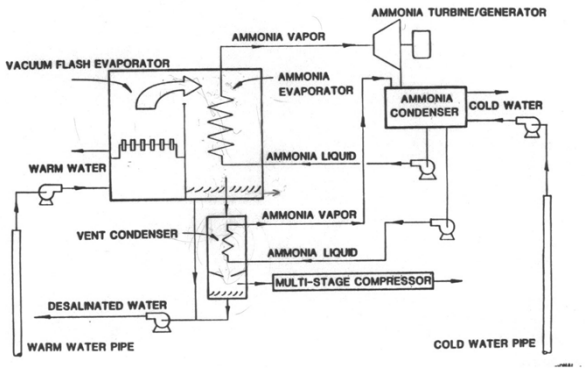


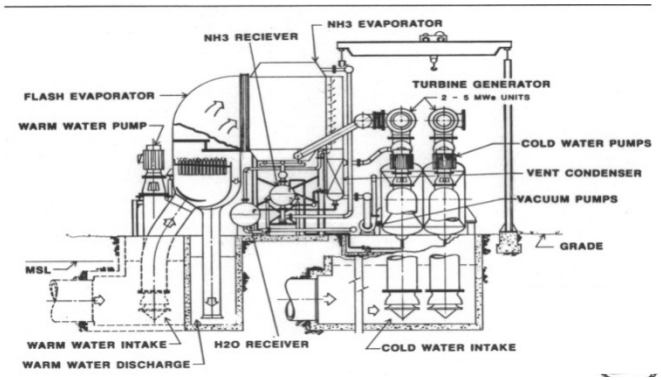
Co-Production of Power and Fresh Water

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

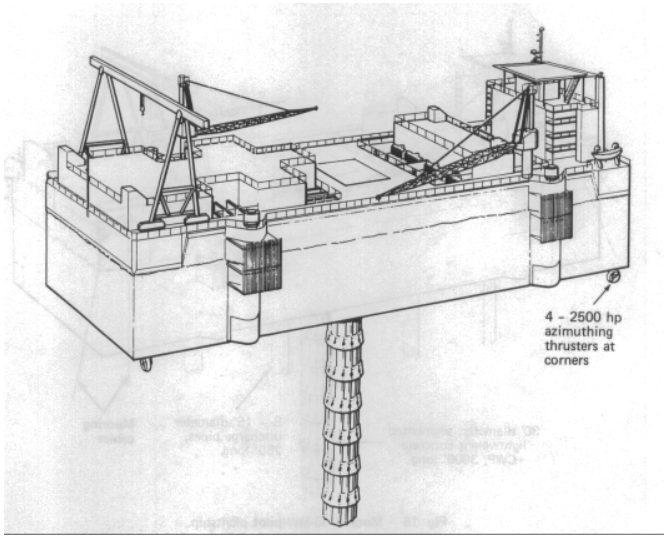
Co-Production using hybrid OTEC cycle can be competitive where cost of electricity is > $0.25/kWh and cost of water > $1/m3

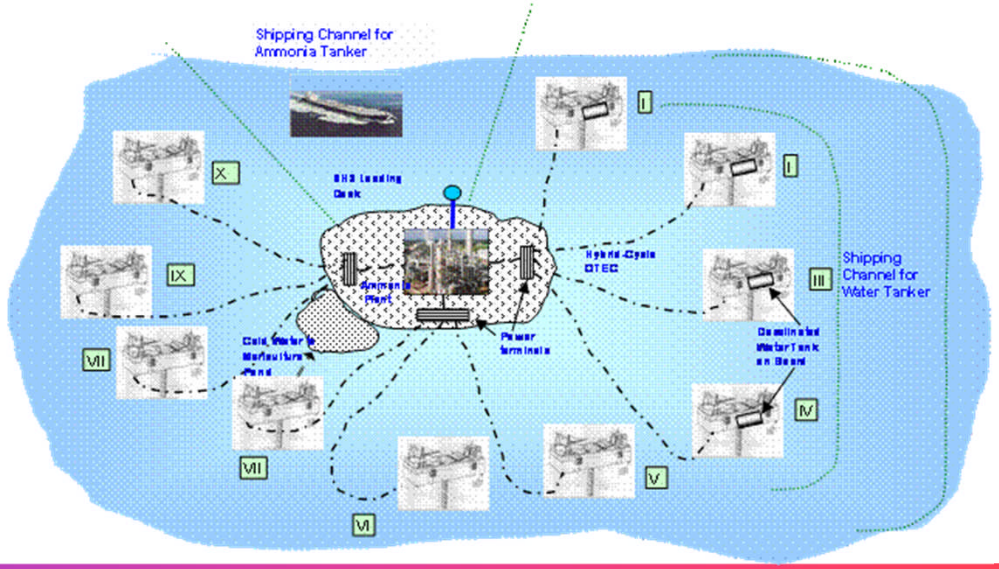




OTEC Ammonia Production

- 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

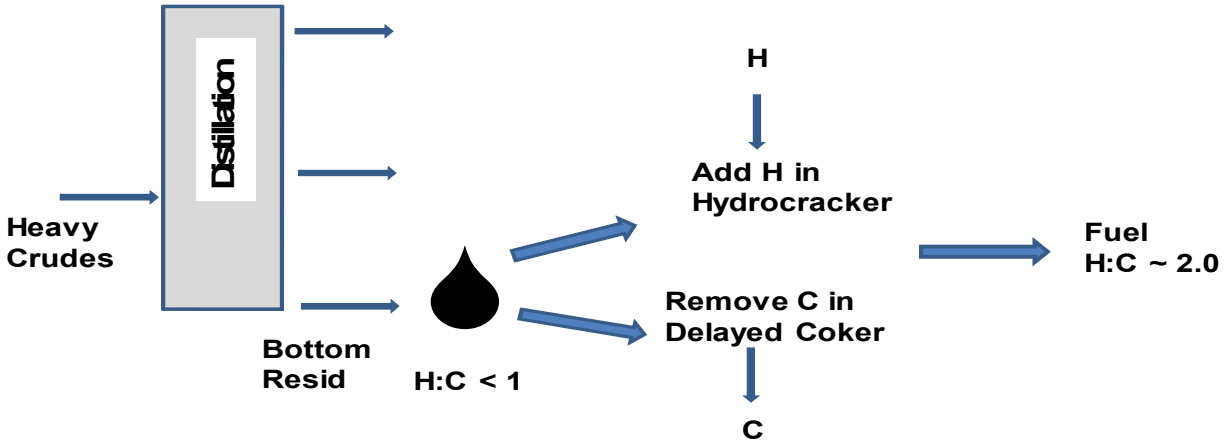




Processing Heavy Crude Oils

Ammonia as Hydrogen Carrier

- 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

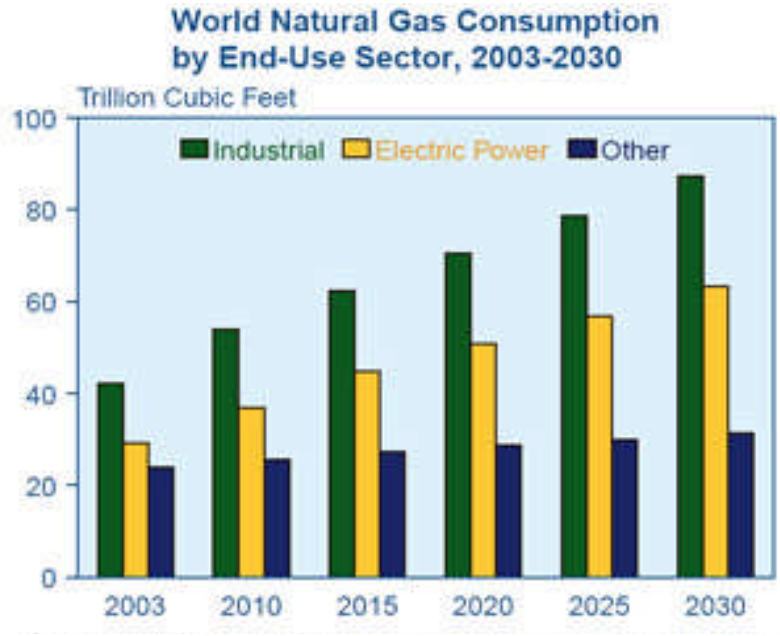


Ammonia Fuel Cell

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 consumptio 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