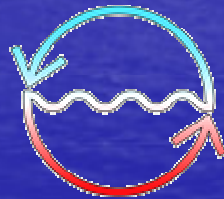


**Oceans of Energy:  
Ocean Thermal Energy  
True Baseload Renewable Energy plus  
Desalinated Water**

**CB Panchal**



**Offshore Infrastructure Associates, Inc.**

**WIREC  
Washington, DC  
March 4, 2008**

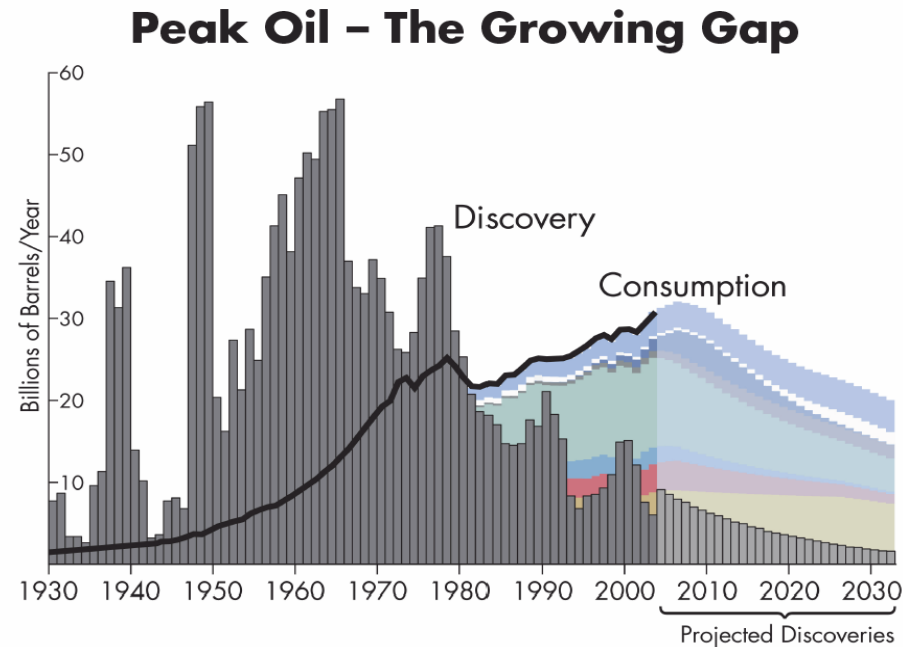
# Presentation Outline

- **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

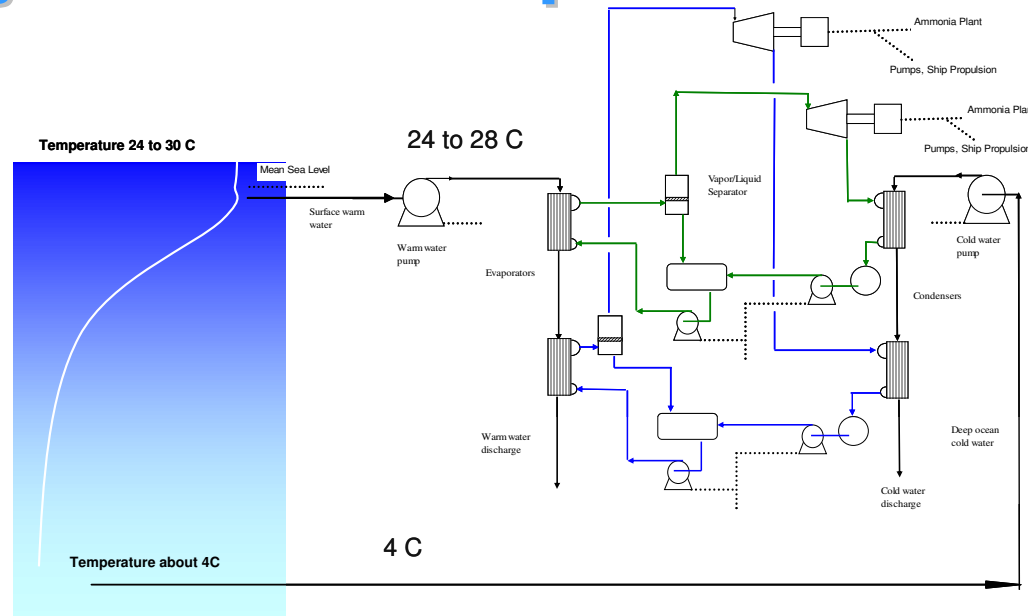
Building **Infrastructure** for Sustainable Energy Supply Using the Current Energy Supply



With impending 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 ( $\sim 7\%$ ), which requires higher capital investment than fossil plants but no fuel cost and no CO<sub>2</sub> 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)



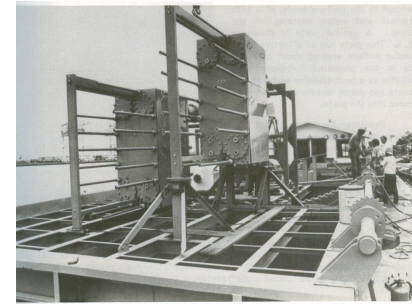
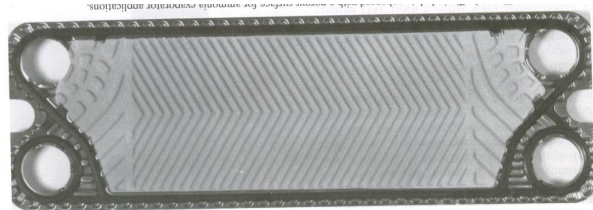
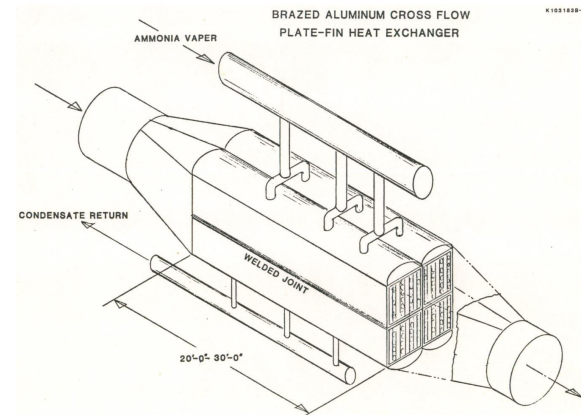
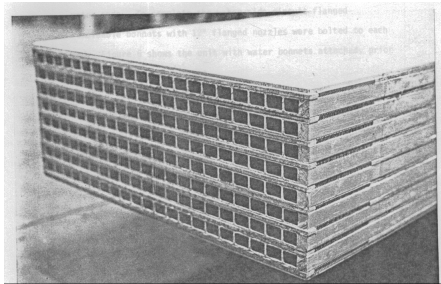
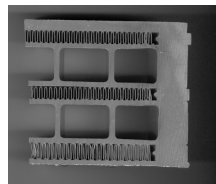
# Major Technical Issues Resolved

- **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**



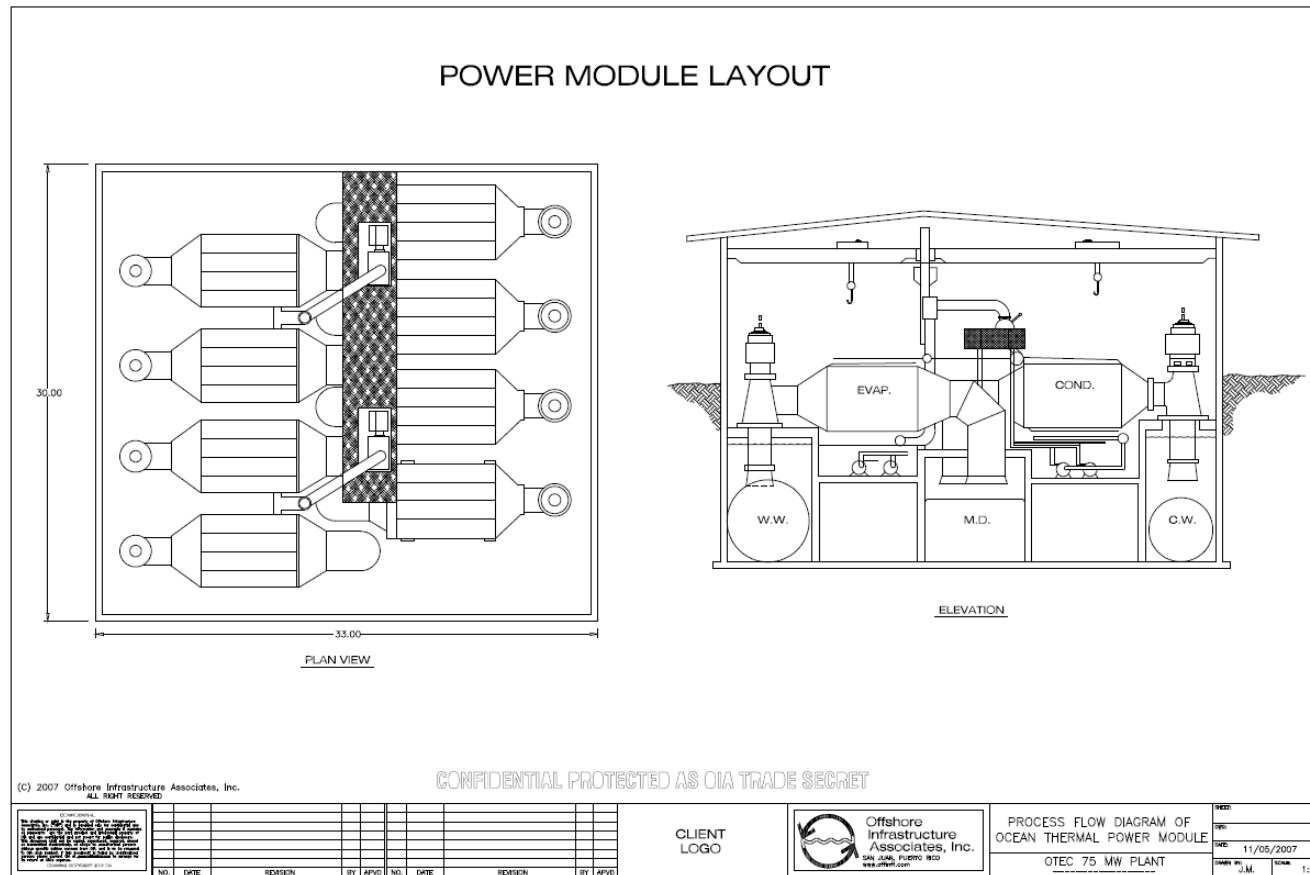
# Modular Heat Exchangers

- 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



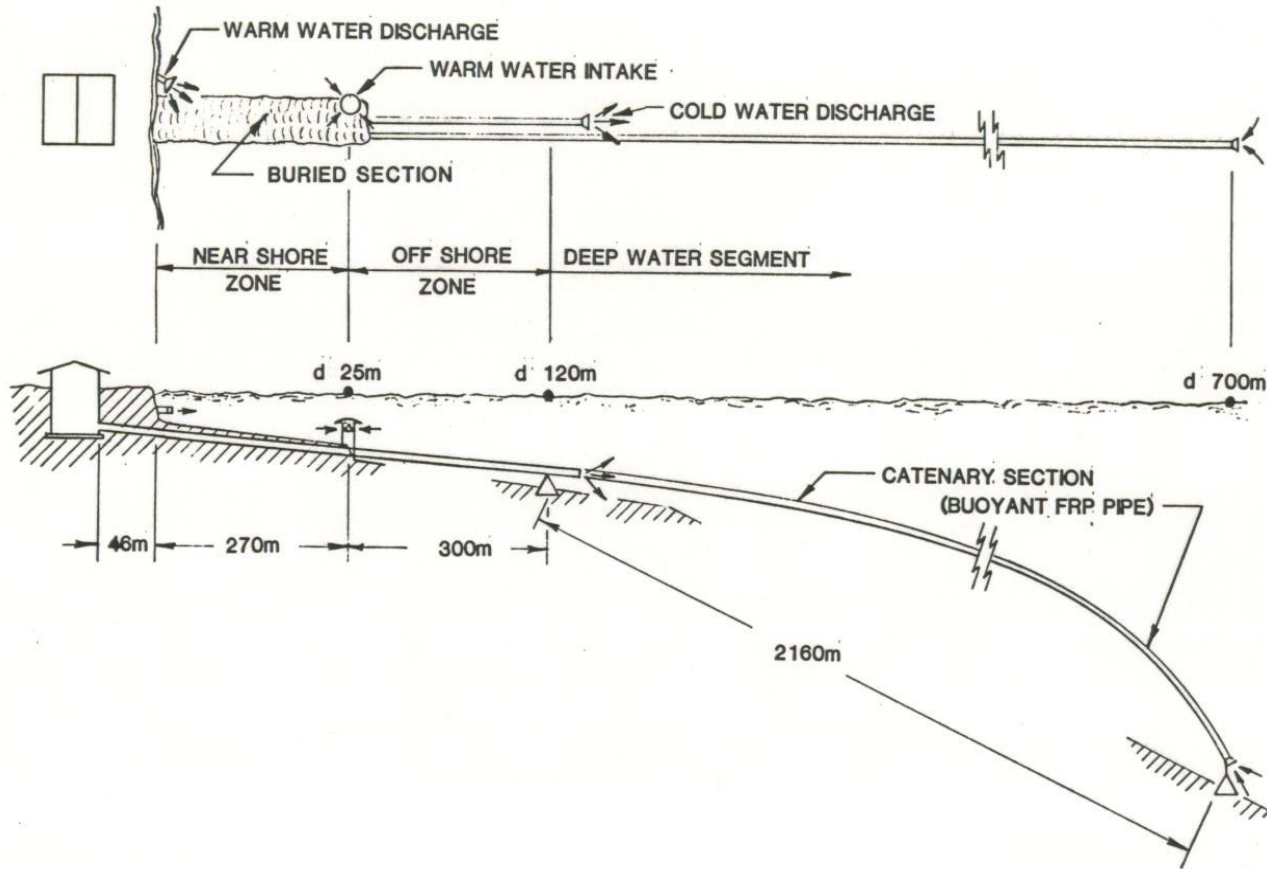
# Power Modules

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*



Intake just prior to initial deployment attempt, 7 Oct.



# Seawater Systems

## *At-Sea Ocean Thermal Plants*

### Cold-Water Pipe

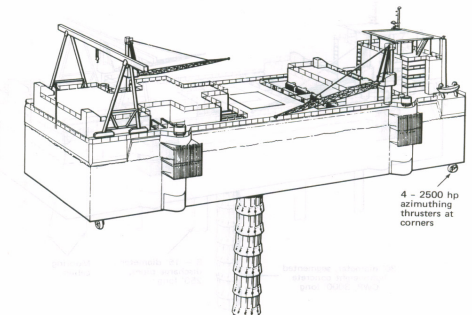
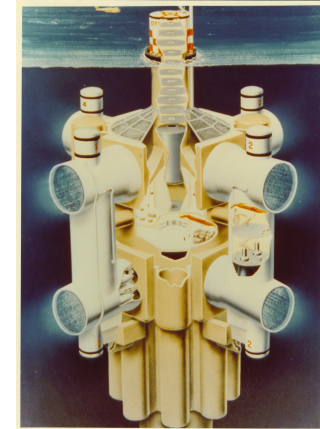
- **Fiberglass Reinforced Plastic (FRP) for larger sizes**
- **High-Density polyethelene (HDPE) upto 2 meter diameter**

### Platform

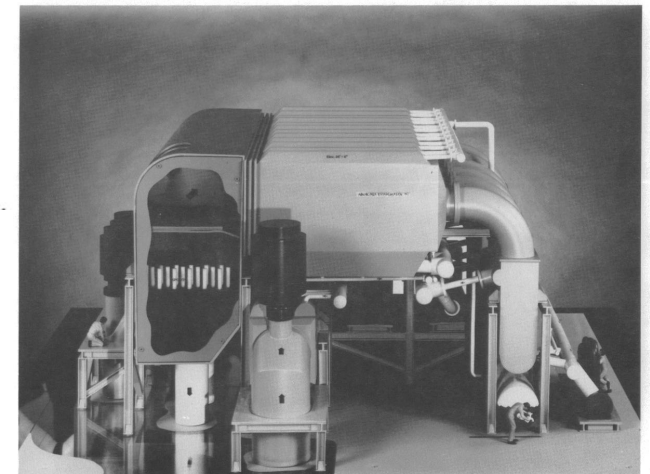
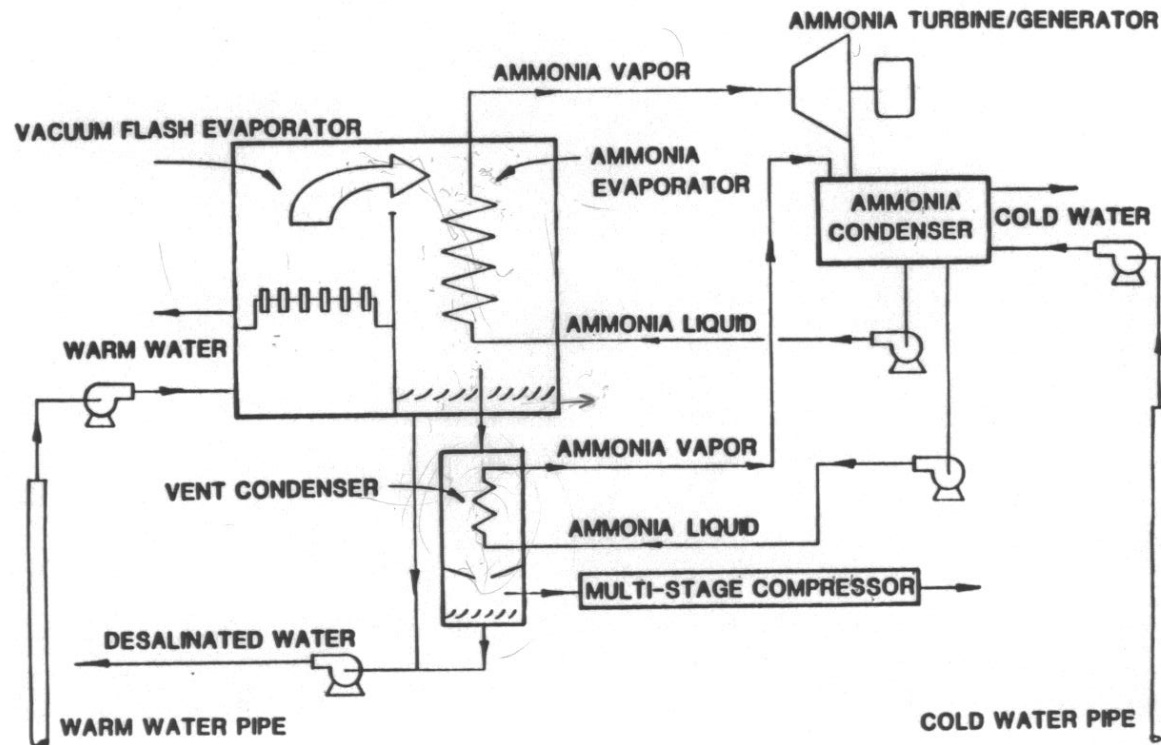
- **Various concepts of platform design for 40MW to 100 MW plants**
- **Promising new platform design concepts**



Measuring Pipe diameter for quality assurance.



# Integrated Hybrid Cycle Power Module

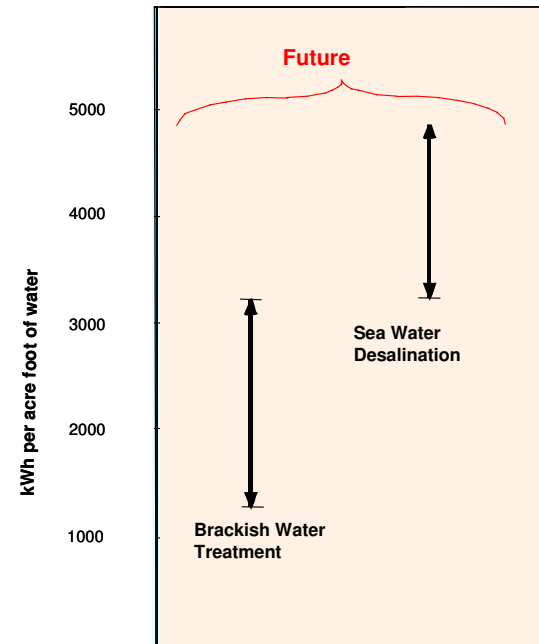
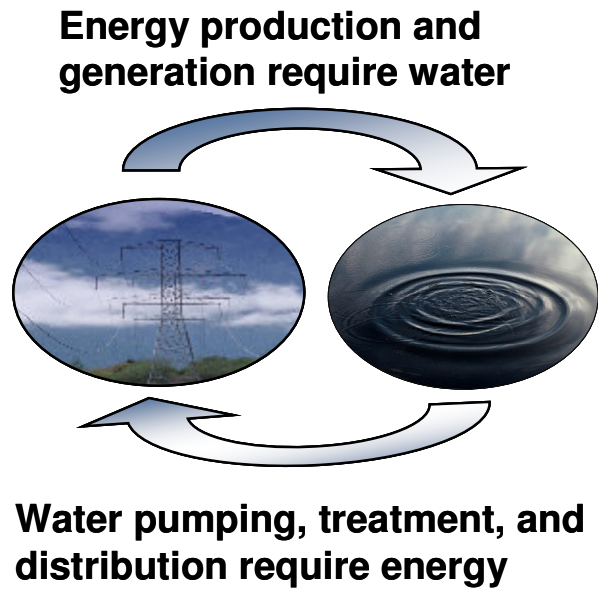


# Strategic Approach to Minimize Technical Risks

- **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**



# Energy-Water Nexus



- **Alternate energy sources (nuclear, ethanol, oil sand) have high consumption of fresh water**
- **OTEC only energy source that can co-produce power (or commodity products – ammonia) and desalinated water**



# Energy-Water Nexus

| <b>Energy Technology</b>                  | <b>Average Water Consumption</b>   |
|---|--|
| <b>Petroleum Refining</b>                 | <b>100 gallons/barrel crude oil</b>  |
| <b>Power generation</b>                   | <b>20 gallons/kWh</b>  |
| <b>Nuclear hydrogen</b>                   | <b>35 gallons/kg of H<sub>2</sub> (1 kg H<sub>2</sub> is equivalent to one gallon of gasoline)</b> |
| <b>Ethanol (not including irrigation)</b> | <b>3 gallons/gallon of ethanol</b>   |
|   |  |

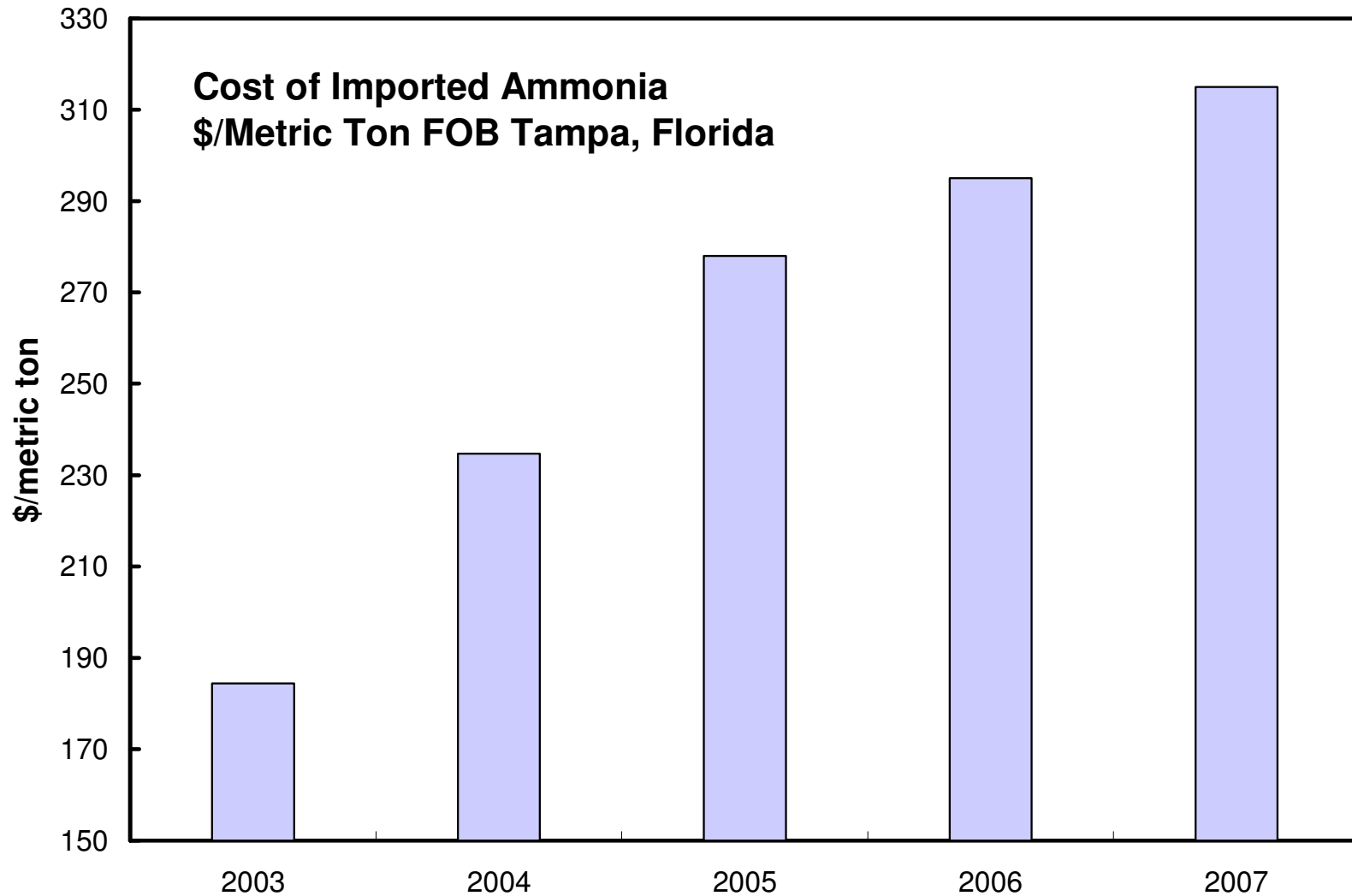


# **Ammonia a Large Commodity Chemical Consumes Large Quantity of Natural Gas**

- **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

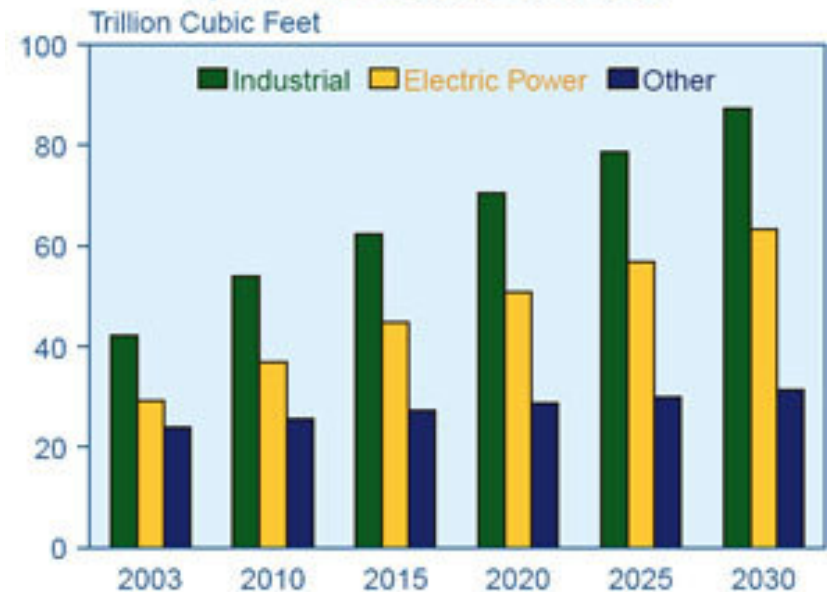


# Ammonia Fuel Cell As Potential for Distributed Power Generation to Displace Natural Gas

## 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



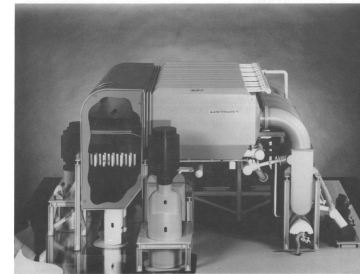
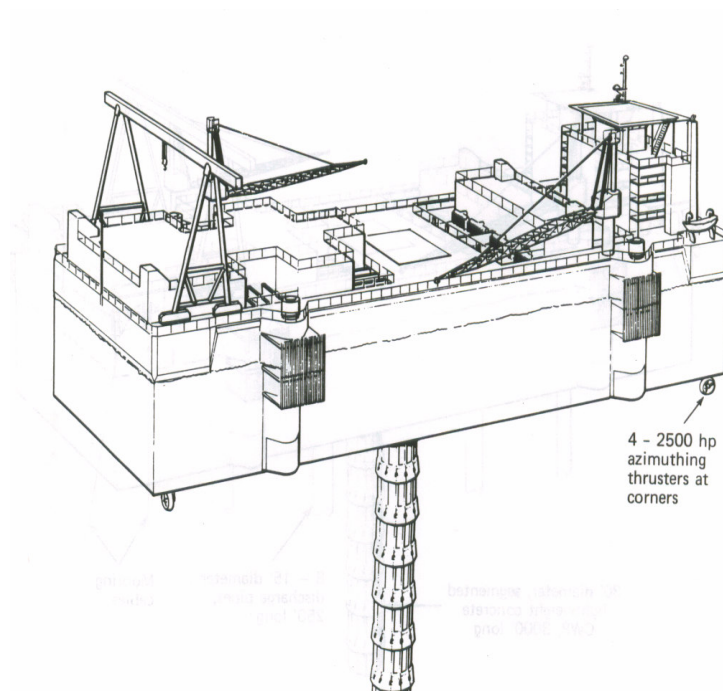
Sources: 2003: Derived from Energy Information Administration (EIA), *International Energy Annual 2003* (May-July 2005), web site [www.eia.doe.gov/iea/](http://www.eia.doe.gov/iea/). Projections: EIA, *System for the Analysis of Global Energy Markets* (2006).



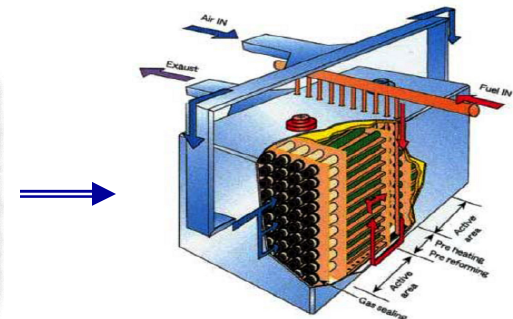
# Ocean Thermal Plantships

## 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

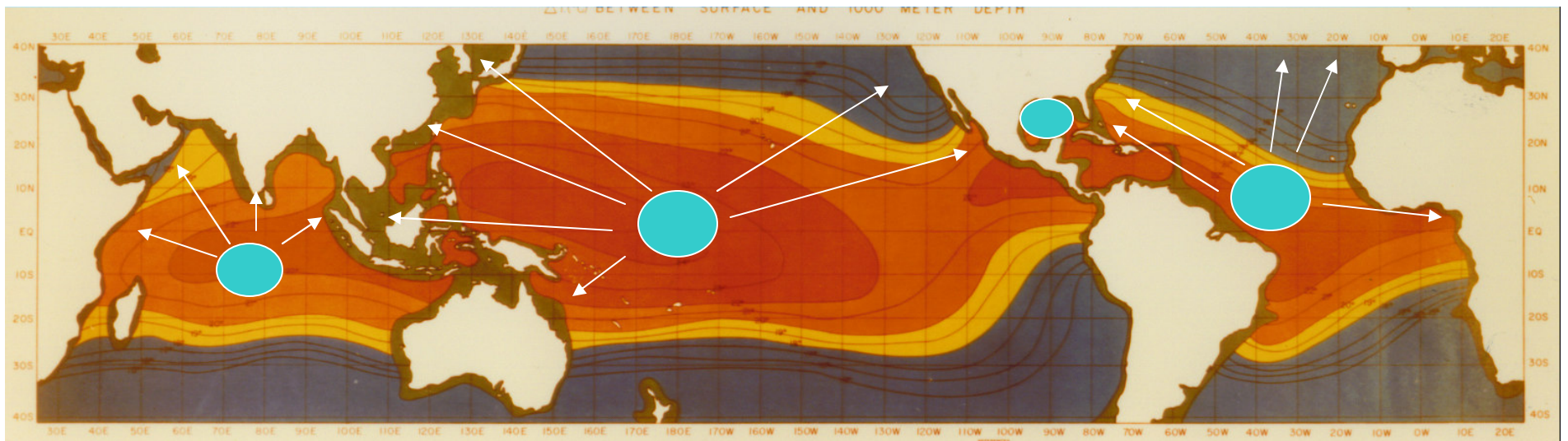


Ammonia



# 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**
6. **Micro-algae production using deep-ocean cold nutrient seawater.**

