Case Study of Ammonia Production in the Island States Using Ocean Thermal Energy Conversion (OTEC)

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Investing Existing *Finite* Carbon-Based Energy

& Material Sources on Future *Sustained* Energy

& Material Supplies

OTEC-NH_3 Can Play a Key Role in Abatement of Global CO_2 Emissions

Overview of OTEC Technology Status

Phase I (Early 1970's through mid 1980's)

<u>Resolved major technical barriers</u> (mini-OTEC, biofouling, heat exchangers, seawater pipes, materials, OTEC-1 pilot plant)

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

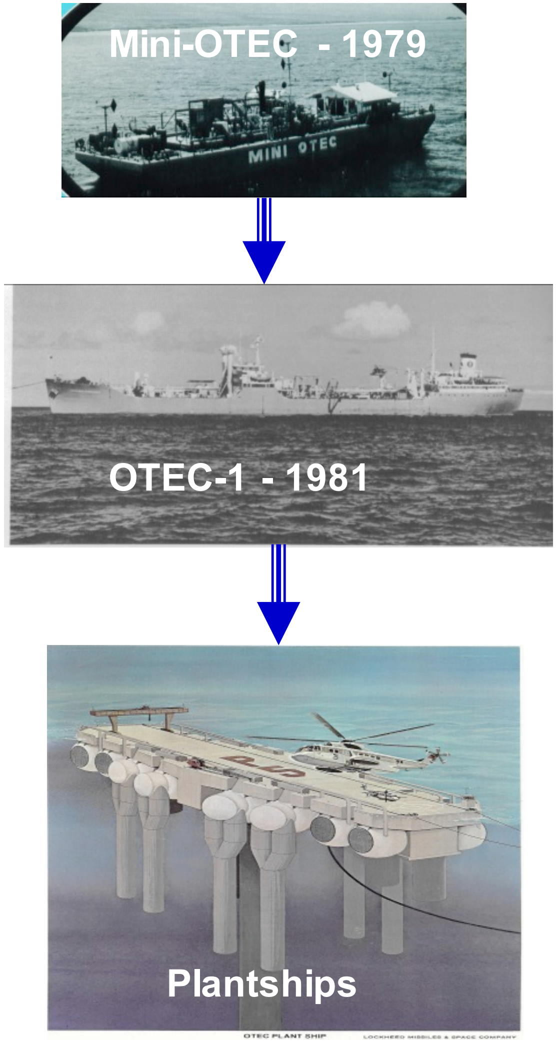
<u>Technology developments</u> (closed cycle, hybrid cycle, open cycle, mariculture, economic analysis)

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

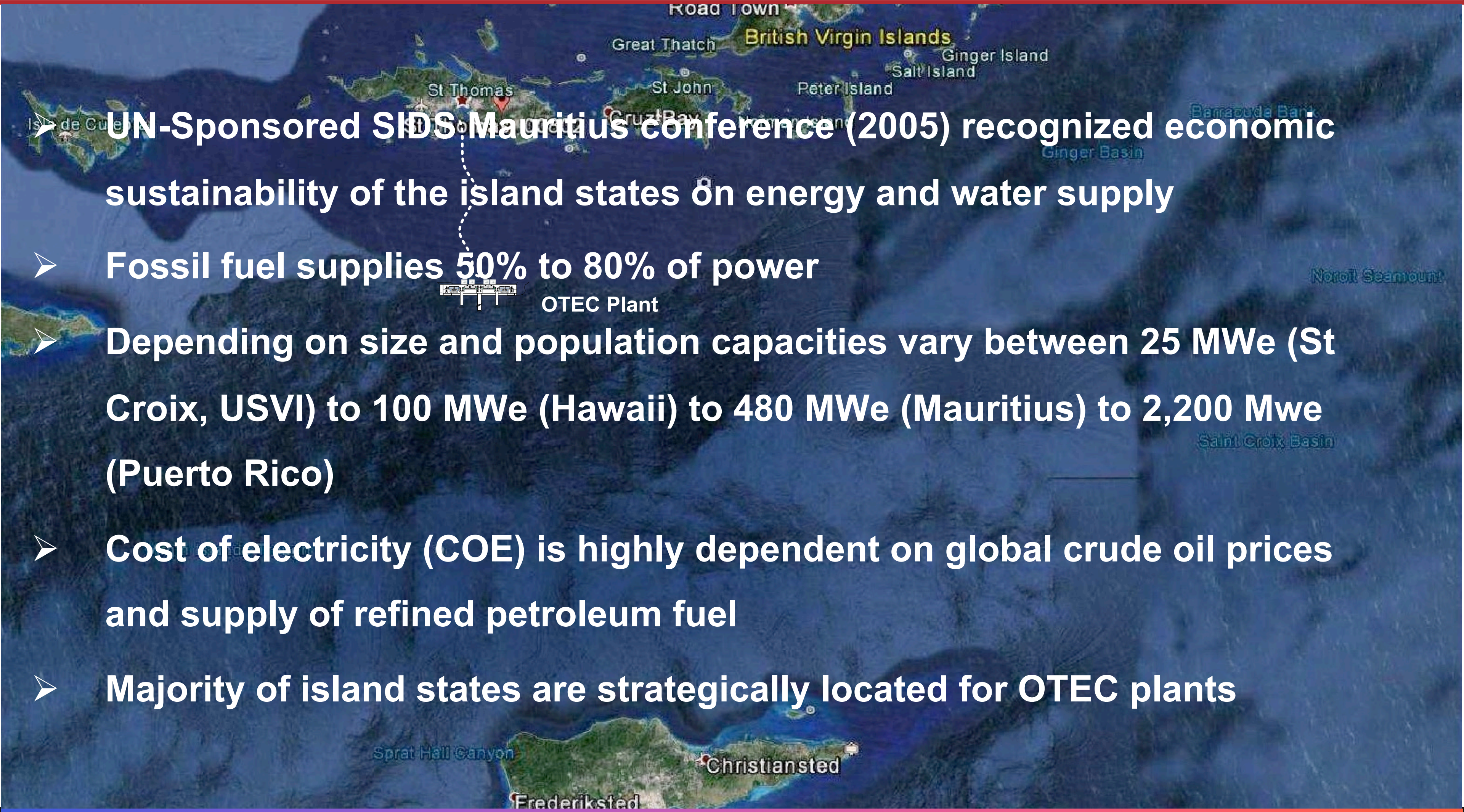
<u>Feasibility Design Studies</u> (modular plants for the island states, production of ammonia as hydrogen carrier, desalinated water and seawater air-conditioning)

Phase IV (2010 and on-going)

<u>OTEC plants for the Island States</u> (co-production of power and desalinated water, utilization of deep-ocean cold water for air-conditioning and mariculture)

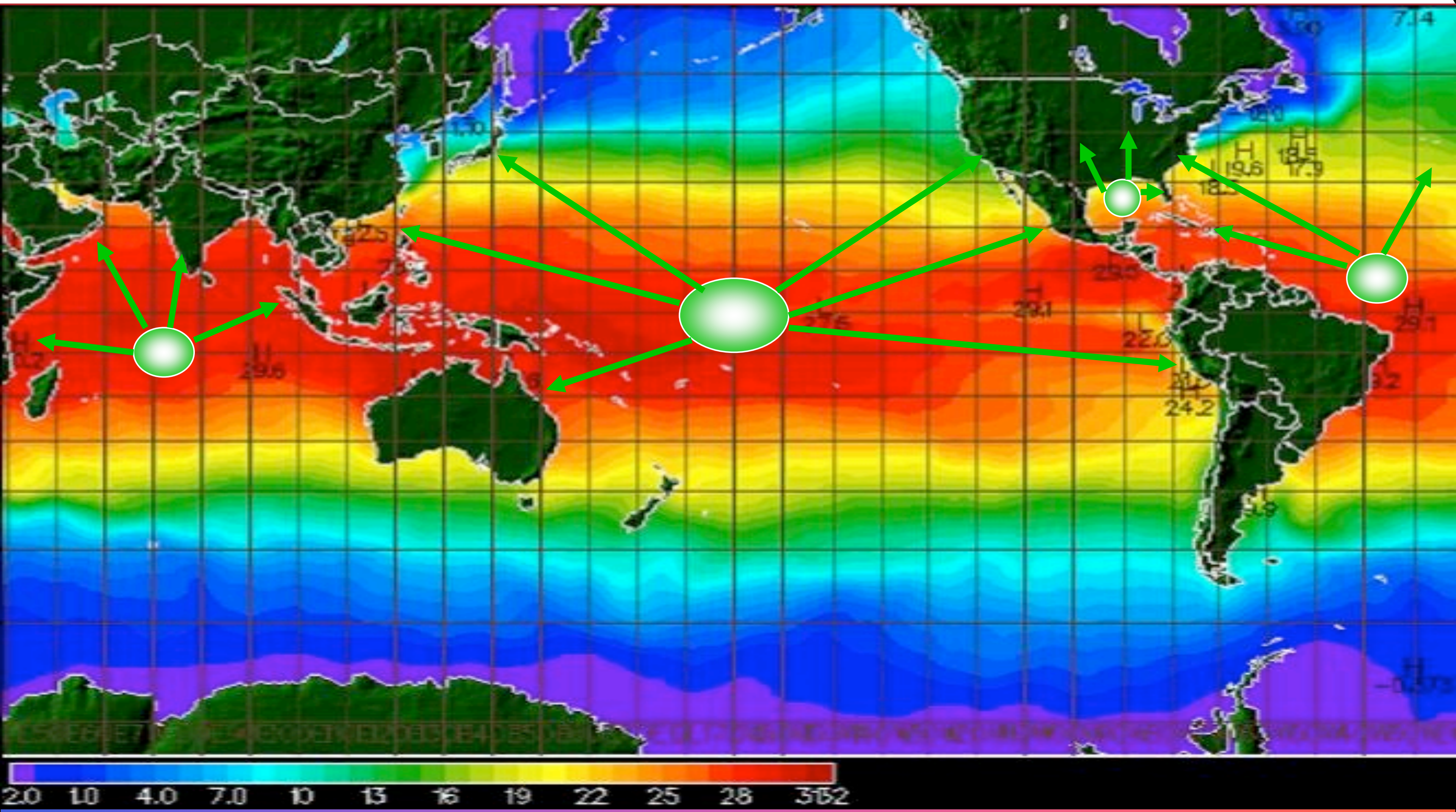


Electricity Production in the Island States



- UN-Sponsored SIDS Mauritius conference (2005) recognized economic sustainability of the island states on energy and water supply
- Fossil fuel supplies 50% to 80% of power
- Depending on size and population capacities vary between 25 MWe (St Croix, USVI) to 100 MWe (Hawaii) to 480 MWe (Mauritius) to 2,200 Mwe (Puerto Rico)
- Cost of electricity (COE) is highly dependent on global crude oil prices and supply of refined petroleum fuel
- Majority of island states are strategically located for OTEC plants

Majority of Island States are Strategically Located within OTEC Resources



OTEC Power Cycle

Design Parameters of 75 MWe Floating OTEC Plant

Flow Rate, MMkg/hr

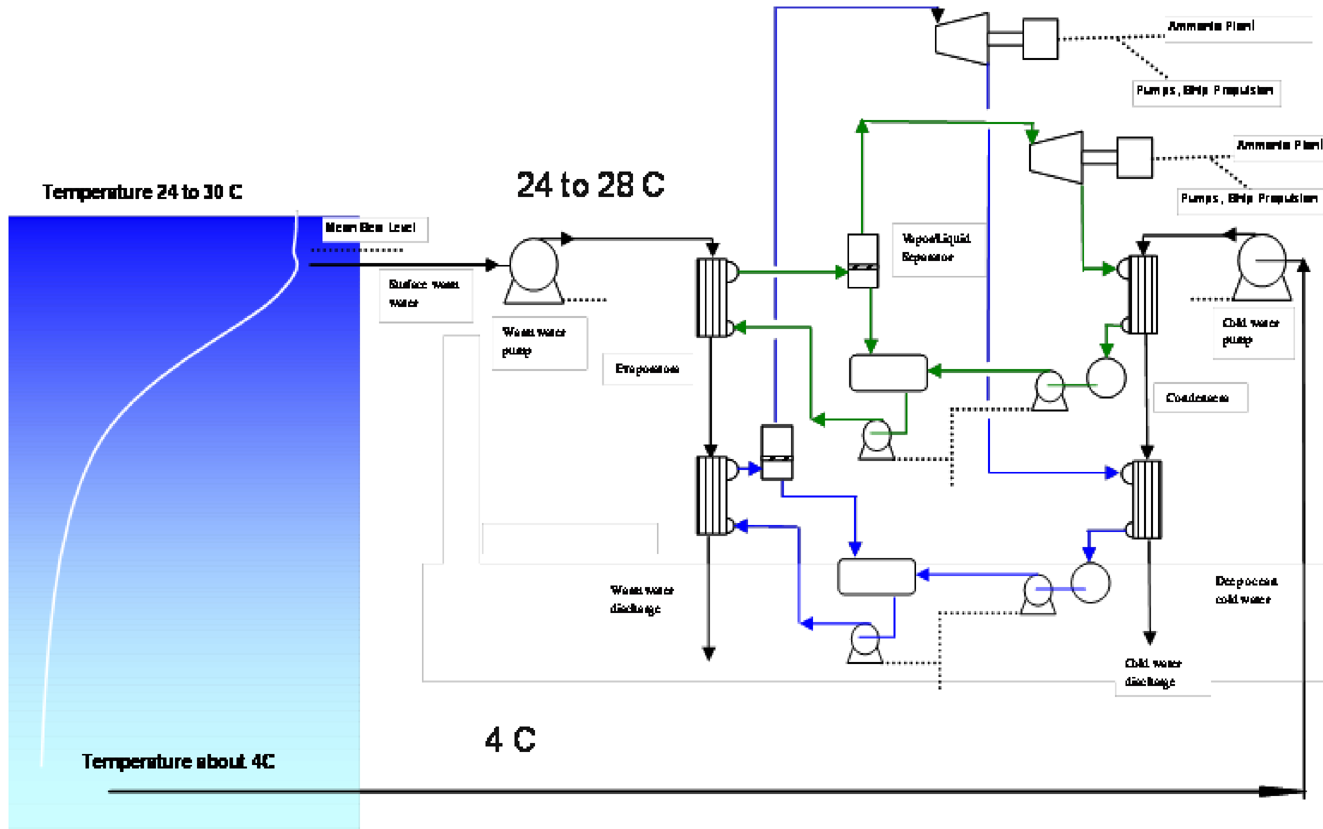
Warm Water	990
Cold Water	690
Ammonia	10

Temperatures, C

WW Source	27.0
WW Return	23.8
CW Source	5.5
CW Return	9.9
Ammonia	
Inlet to Turbine	22.1
Turbine Outlet	11.2

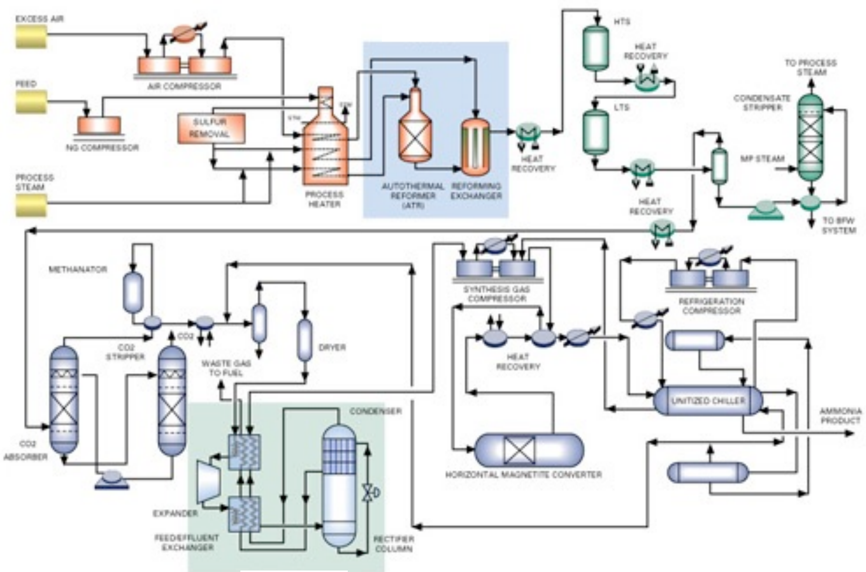
Power, MW

Gross	106
Parasitic	31
Net	75



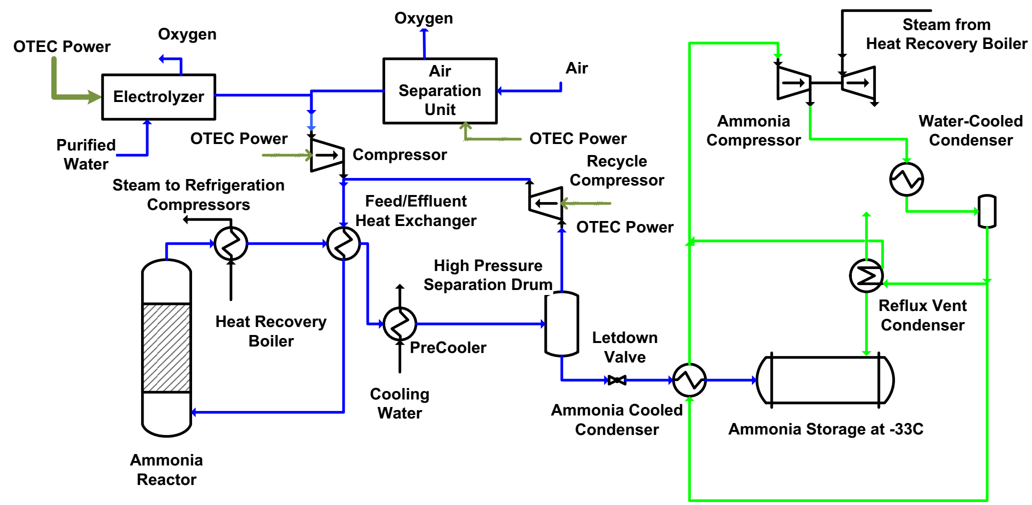
Two-Stage OTEC Power Cycle

OTEC-Ammonia Process



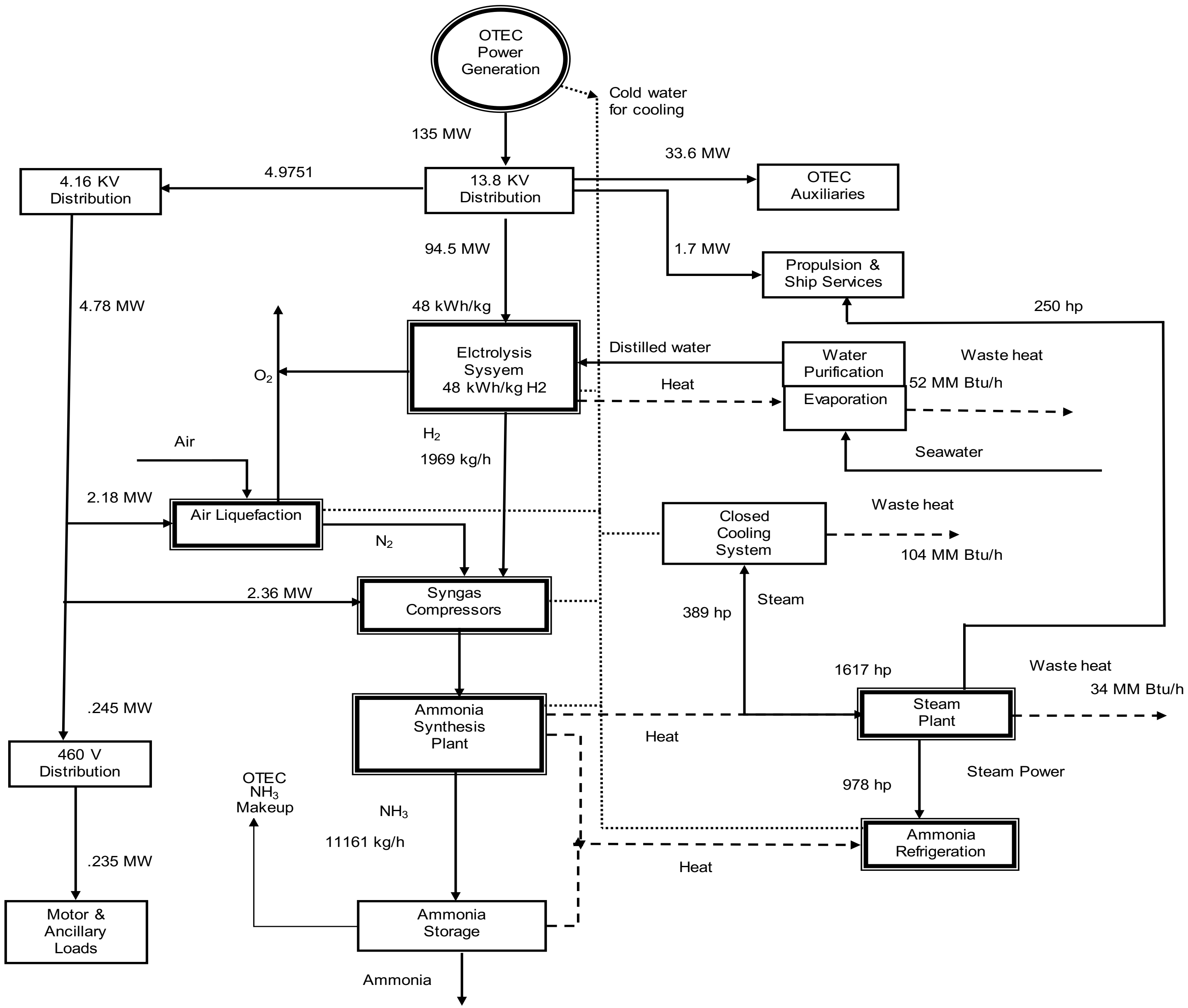
Commercial H-B NG Based NH3 Process

OTEC H-B Based NH3 Process



Ref: OTEC Plantship for Production of Ammonia as Hydrogen Carrier, Argonne National Report, 2009

OTEC-Ammonia Energy Profile



OTEC-Ammonia

Island Case Studies

- **Hawaii**

  Floating OTEC-Ammonia Plant and At-Sea Production of Ammonia with OTEC Satellite Plantship

- **Puerto Rico**

  Floating OTEC-Ammonia Plant

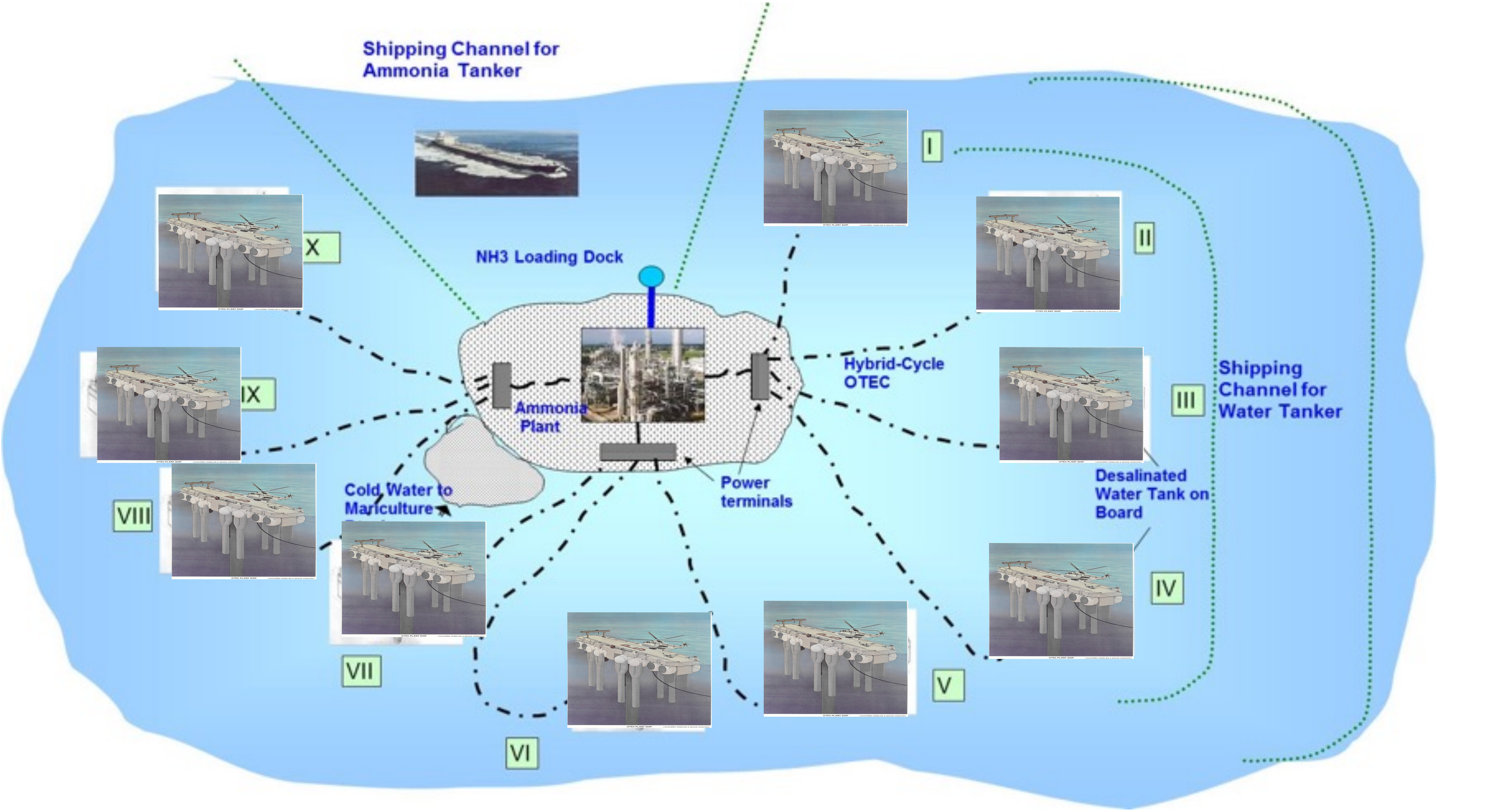
- **Island of USVI**

  Land-Based Small OTEC-Ammonia Plant on the

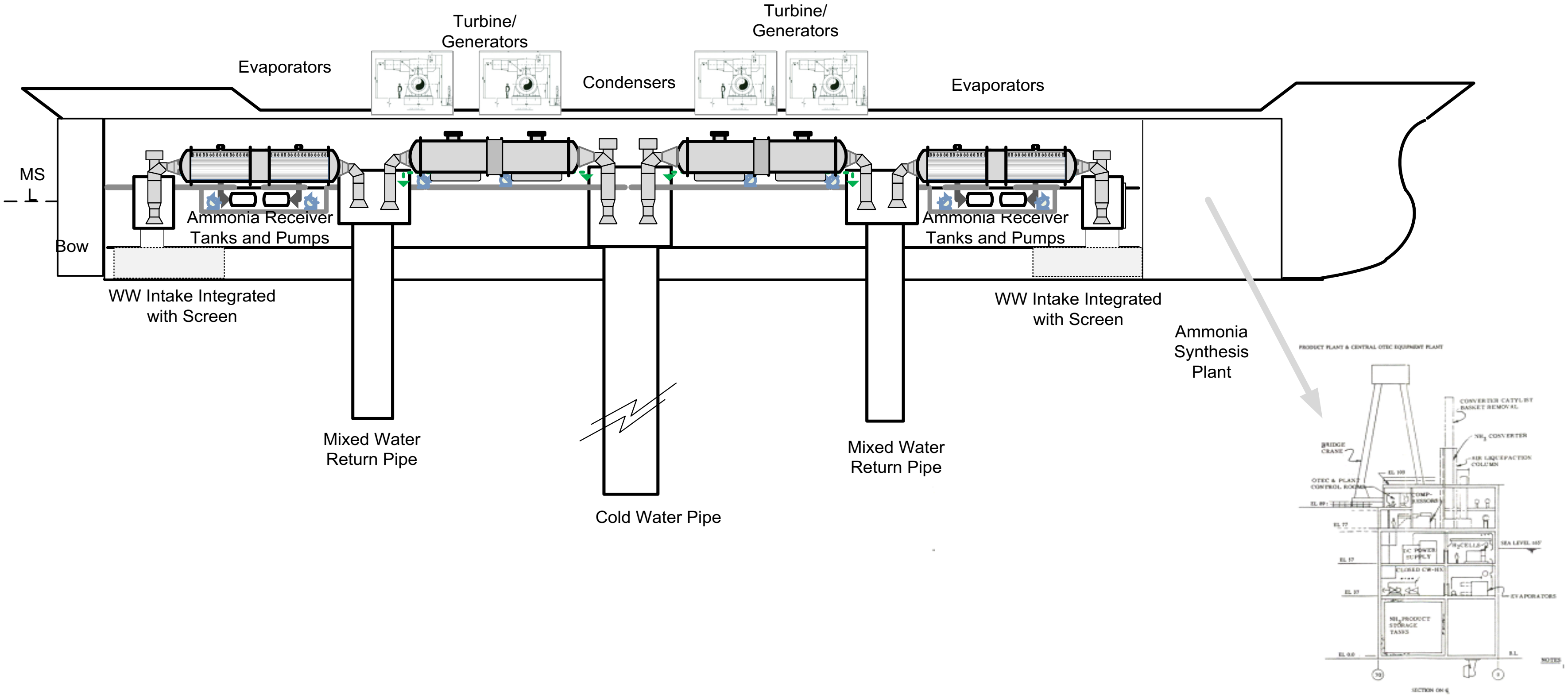
Goal: Achieving Economic Competitiveness of OTEC-Ammonia

OTEC-NH_3 Satellite Plantship in Hawaii

Commercial Scale ~ 3,000 tonne/day NH_3 production with co-production of desalinated water



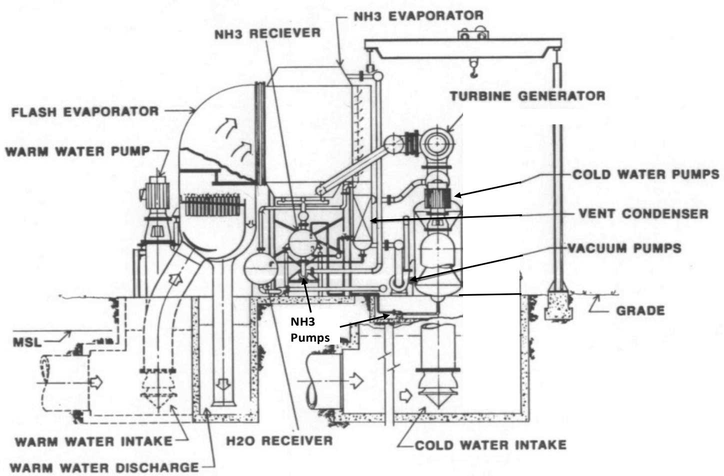
Floating OTEC-Ammonia Plant off the Coast of Puerto Rico

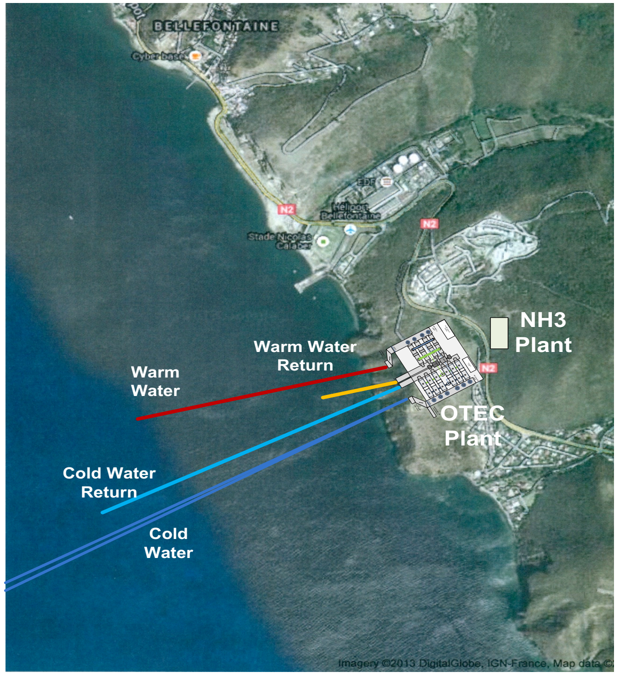


- **75 MWe with NH_3 capacity of 200 MTD with provision of disconnecting CWP and move the platform in the event of hurricane**
- **NH_3 Cost of Production (COP) 835 \$/tonne using SSAS with potential reduced COP for 3rd generation OTEC plants (*Does not include C-credit*)**

Land-Based Hybrid OTEC-Ammonia Plant on the Island of St. Croix, USVI

Plant Capacity	
NH_3 (SSAS Process)	34 tonne/day
OR	
H_2 (Water Electrolysis Process)	5.0 tonne/day
Water Production	23 million liters/d
Water Production Credit	1.3 to 1.6 $/k-liter
NH_3 cost	400 $/tonne
H_2 cost	3.0 $/kg





OTEC-Ammonia off the Coast of Hawaii

Near Term:

- **Distributed power generation with micro-grid with NH_3 as H_2 carrier and fuel-cell power generation –** ***Balancing between renewable energy and 24/7 baseload, OTEC-NH_3 will have sustainable power supply***
- **NH_3 as H_2 carrier for fuel-cell vehicles in Hawaii and California**

Long Term:

- **Large-scale (3,000 tonne/day) OTEC-NH_3 plant-ship for NH_3 as green-fuel for maritime transportation**
- **NH_3 supply to the west coast**

Hawaii is strategically located as NH_3 filling station for sea-going maritime transport

OTEC-Ammonia in Puerto Rico

Near Term:

- **Distributed power generation with micro-grid with NH_3 as H_2 carrier and fuel-cell power generation –** ***Balancing between renewable energy and 24/7 baseload OTEC-NH_3 will have sustainable power supply***

Long Term:

- **NH_3 as H_2 carrier for fuel-cell vehicles**
- **NH_3 fuel for the agriculture equipment**
- **NH_3 supply and/or NH_3 as H_2 carrier for the Gulf Coast Industry**

The Recent Hurricane Exposed the Vulnerability of Power Generation and Distribution

OTEC-Ammonia in USVI – Land-based Plants

Near Term:

- Co-production of NH_3 and desalinated water - *Beneficial impact on the resort and tourism*
- Potential competitive NH_3 by taking credit of desalinated water

Long Term:

- NH_3 fuel for the agriculture equipment
- NH_3 as H_2 carrier for fuel-cell vehicles
- Distributed power generation with micro-grid with NH_3 as H_2 carrier and fuel-cell power generation for increasing use of electric vehicles (EV)

Sustained Supply of Fresh Water is a Critical Issue for USVI

Global CO_2 Abatement

	C-footprint
NG-Based Haber-Bosch (H-B) Process	1.8 to 2.8 tonne CO_2/ T NH_3
Petroleum-Based (H-B) Process	1.3 to 1.5 X NG-Based Process
Coal-Gasification Based (H-B) Process	1.5 to 2.0 X NG-Based Process
OTEC- NH_3 Process	C-footprint of OTEC-NH3 plant

The Production of NH_3 is about 200 million tonne/yr and Increasing at about 6%

With CO_2 Emissions of 360 million tonne/yr at Average of 1.8 tonne/tonne NH_3

OTEC-NH_3 Economics

	NH_3 Cost $/tonne	H_2 Cost $/kg
Floating single plant 200 tonne/day*	**$ 835**	
3rd generation satellite plantship with 3,000 tonne/day capacity can be competitive with accounting for CO2 Capture and Sequestration (CCS) costs		
Land-based Hybrid-cycle with co-production of water**		
NH_3 35 tonne/day (SSAS process)	**$400**	
H_2 210 kg/hr (electrolysis)		**$3.0**

** First-of-a-kind design using titanium heat exchangers*

*** 3rd generation design using aluminum heat exchangers and water credit of $1.6 /m3 (i.e.~ $6.0/thousand-gallon)*

Techno-Economic-Environment Opportunities

- OTEC-NH_3 is at Technology Readiness Level (TRL – 7) of

  Integrated Pilot System Demonstrated

- OTEC-NH_3 Can be Competitive when CO_2 Capture and Sequestration (CCS) Costs (> $120/tonne CO_2) are Incorporated into the Market Price of NH_3
- Coproduction NH_3, Desalination and Power can be Economically Viable
- OTEC-NH_3 as Hydrogen Carrier for the Gulf-Coast Industry
- OTEC-NH_3 Plant-ship in the Pacific Ocean can be Green-Fuel Hub for Seagoing Maritime Transportation
- OTEC-NH_3-based H_2 for US Army and Navy Island Bases

Techno-Economic Challenges

- Capital Intensive OTEC-NH_3 Plants with Uncertain Economic Risks of Large Floating Plants
- No Operating Commercial OTEC-NH_3 Plants to Evaluate Techno-Economic Merits
- Cyclic Nature of Petroleum Prices with Uncertain Future Projections

There is a risk of losing the present momentum with low energy prices

Path Forward

- OTEC-NH_3 Techno-Economical Roadmap by a Committee Representing Global Stakeholders
- Quantified and Credible Long-term Techno-economic and Environment Merits of OTEC-NH_3 for the Island States
- Involvements of Global Organizations Including U.N. Small Island Development States (SIDS) program
- Cost-shared Deployment of the First Five OTEC-NH_3 Plants on the Island States

Majority of Island States are Strategically Located within OTEC Resources