Ocean Thermal Energy Conversion (OTEC) : Electricity and Desalinated Water Production

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Visionary Perspective

- Solar energy absorbed by oceans is $\approx$ 4000 x humanity annual consumption;
- Less than 1 % of this energy would satisfy all needs.

  [@ thermal $\rightarrow$ electric conversion $\approx$ 3 %]

Engineering Perspective

- Ocean's vertical temperature distribution:

  Two layers with $\Delta T \approx 25\ ^{\circ}C$ in equatorial waters…

  heat source and heat sink required to operate heat engine

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OTEC Concept

- Ocean Thermal Resource (fuel)
- Cold Water: @1000 m depth

  4 °C to 5 °C
- Warm Water: Tropical seas at "surface"

  24 °C to 30 °C

What is known about OTEC Technology?

- Continuous production of electricity and desalinated water has been demonstrated with experimental plants:

MiniOTEC
(1979)

50 kW CC-OTEC

Nauru (1982)

100 kW CC-OTEC

210 kW OC-OTEC Experimental Plant

(1993-1998)

Desalinated Water Production (1994-1998)

What is known about OTEC Economics ?

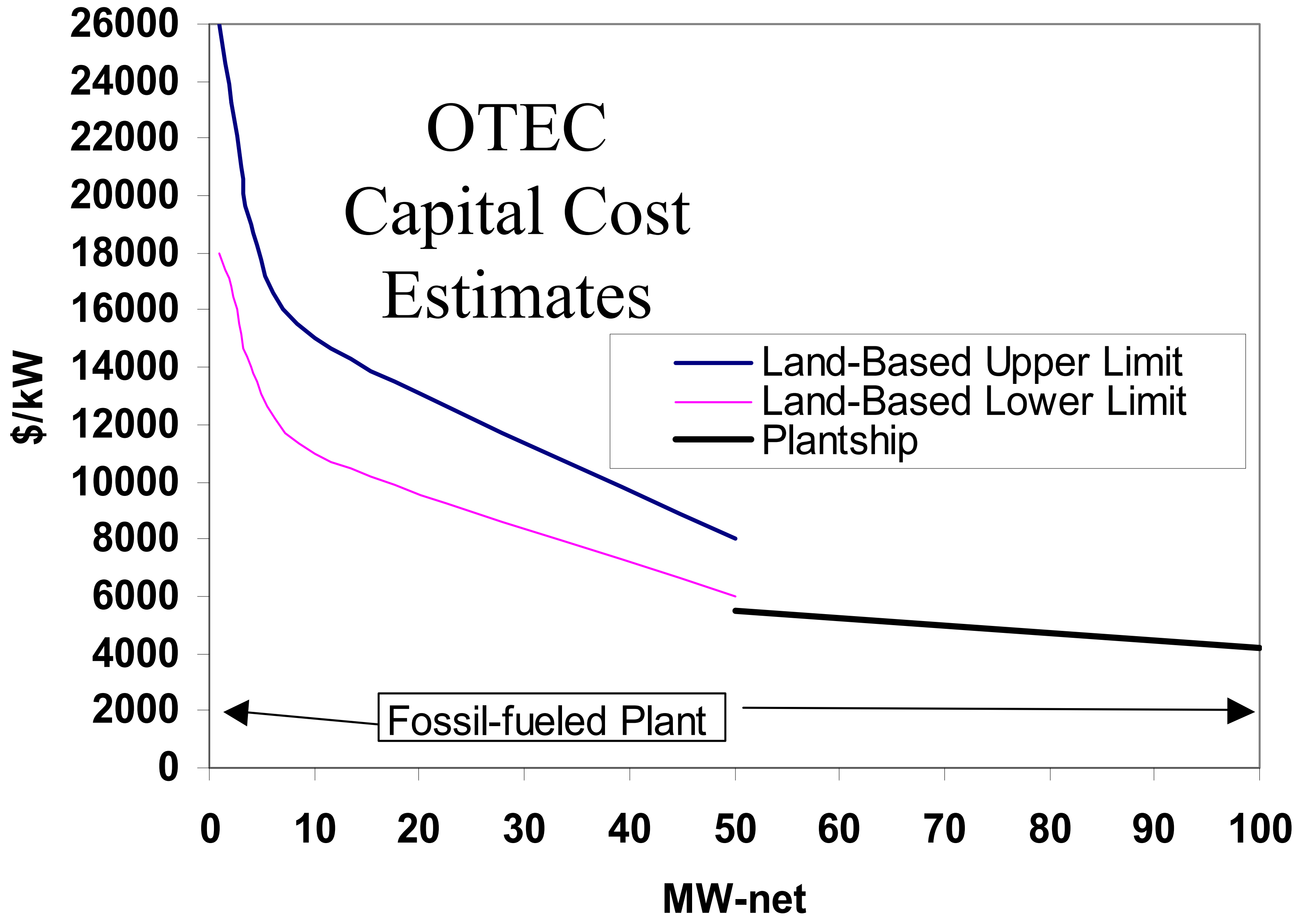
- Economic feasibility achievable under certain (fuel-and-water-costs) scenarios:

Cost of Electricity Production

COE ($/kWh) = CC + OMR&R + Profit
+ Fuel
- Environmental Credit

CC = Capital Cost Amortization
OMR&R = Operations + Maintenance
+ Repair + Replacement

Tariff = COE - Subsidy


OTEC
Capital Cost
Estimates
Land-Based Upper Limit
Land-Based Lower Limit
Plantship
Fossil-fueled Plant
$/kW
26000
24000
22000
20000
18000
16000
14000
12000
10000
8000
6000
4000
2000
0
0
10
20
30
40
50
60
70
80
90
100
MW-net

Nominal Size, MW	TYPE	Scenario	Potential Sites
1	Land-Based OC-OTEC with 2nd Stage for Additional Water Production.	**Diesel: $45/barrel Water: $1.6/m^3**	Present Situation in Some Small Island States.
10	Same as Above.	**Fuel Oil: $30/barrel Water: $0.9/ m^3**	U.S. Pacific Insular Areas and other Island Nations.
50	Land-Based Hybrid CC-OTEC with 2nd Stage.	**$50/barrel $0.4/ m^3 or $30/barrel $0.8/ m^3**	Hawaii, Puerto Rico If fuel or water cost doubles.
50	Land-Based CC-OTEC	**$40/barrel**	Same as Above.
100	CC-OTEC Plantship	**$20/barrel**	Numerous sites

Table 1. OTEC Potential Sites as a function of Fuel and Water Cost.

Cost of Electricity Production

Offshore Distance, km	Capital Cost, $/kW	COE, $/kWh
10	4200	0.07
50	5000	0.08
100	6000	0.10
200	8100	0.13
300	10 200	0.17
400	12 300	0.22

Table 2. Cost Estimates for 100 MW CC-OTEC Plantship (COE for 10 % Fixed Rate, 20 years, Annual O&M 1% of Capital Cost).

OTEC Commercialization?

Pro:

- Less environmental impact than conventional power plants;
- As long as the sun heats the oceans, the fuel for OTEC is unlimited and free.

Con:

- No operational record with <u>appropriate</u> size plant

What Next for OTEC?

- Not wise to scale from experimental-size to commercial-size;

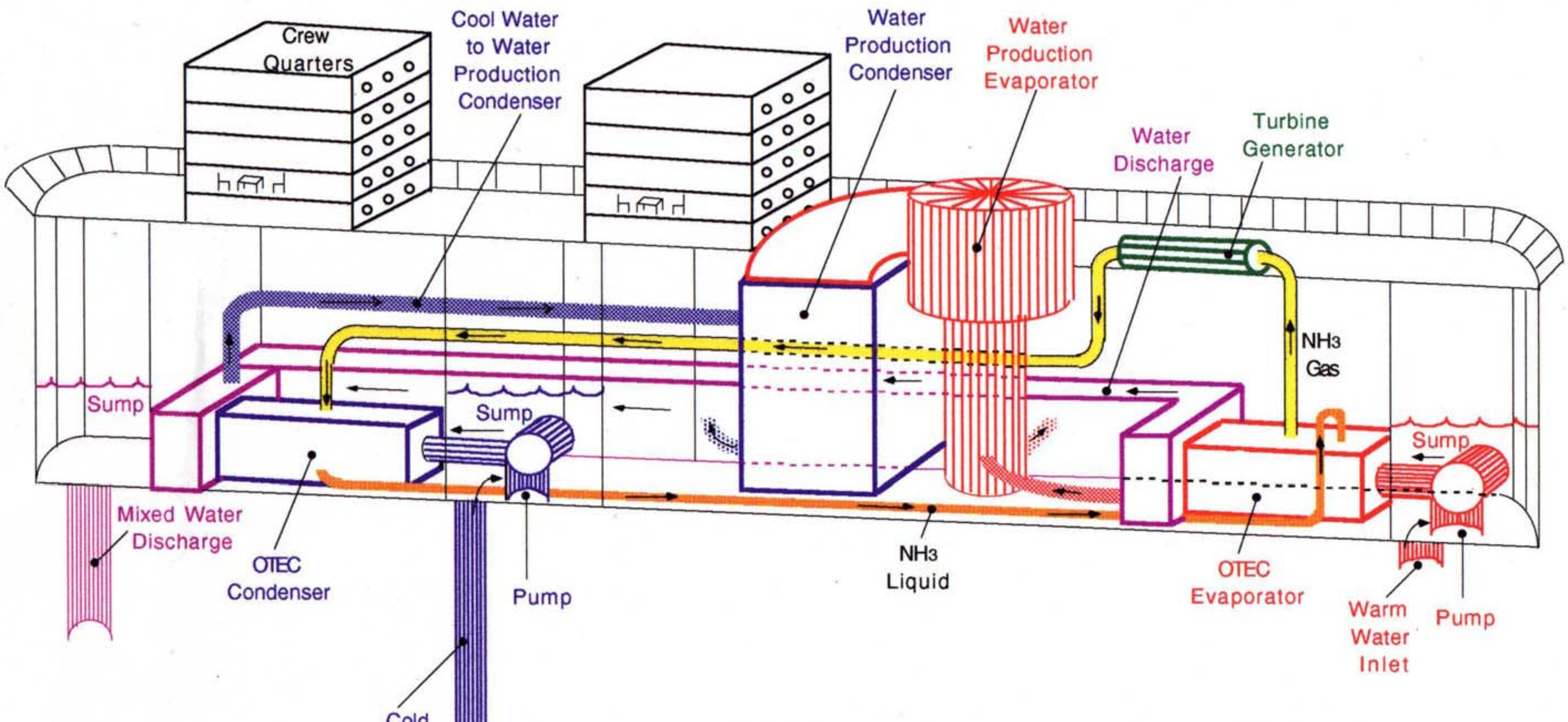
- Must build and test scaled version of commercial-size: $\approx$ 5 MW

  ($80 M to $100 M over 5-years).

Commercialization (Hawai'i)

- Hawai'i could use OTEC to Generate all Electricity Consumed (100%);
- Commercial-size ≈ 100 MW floater
  - $4500/kW ($450M)
  - C.O.E from 0.07 to 0.10 $/kWh

5 MWe OTEC Pre-Commercial Plant

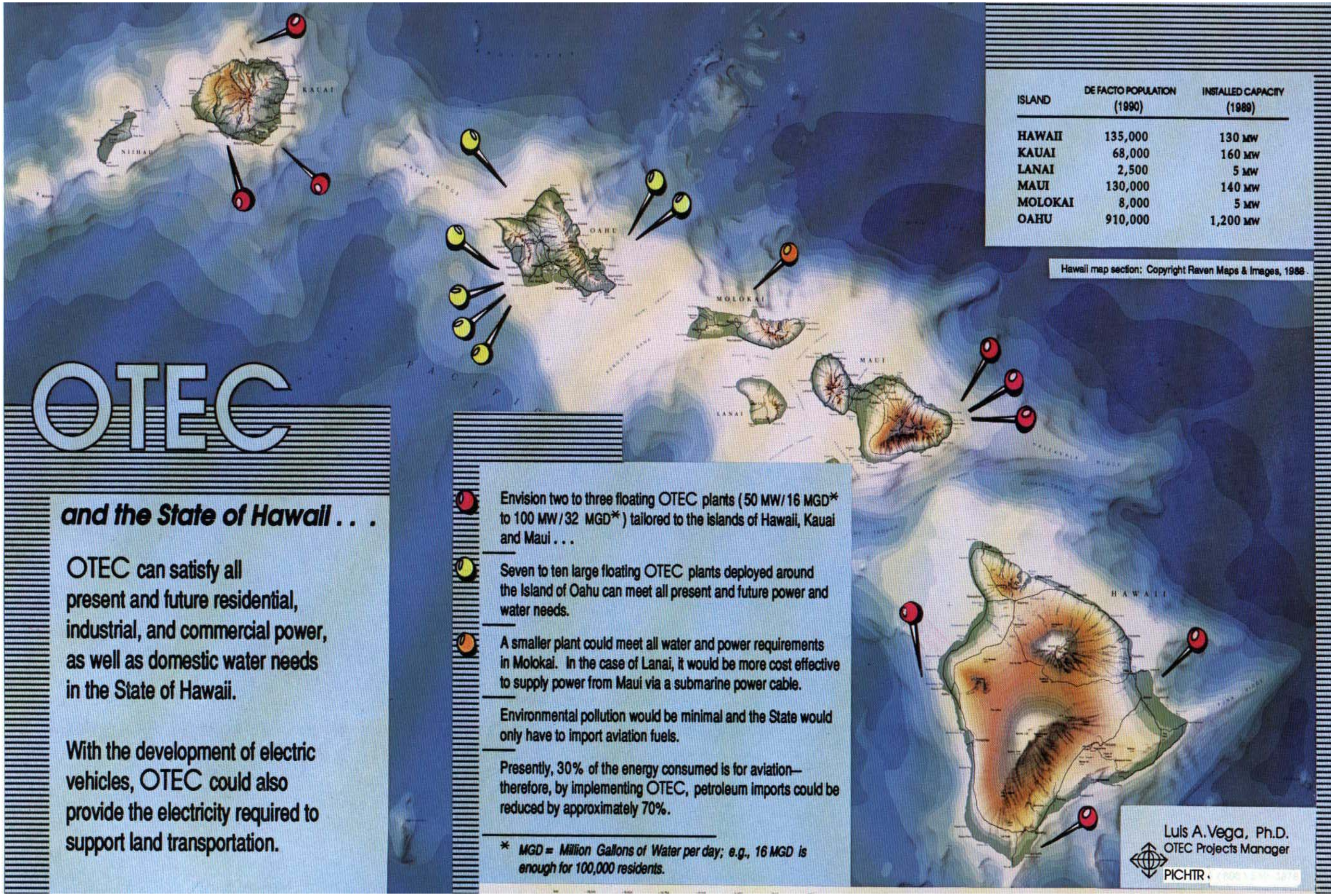


OTEC Components

(2) Condenser: 17.5m (L) x 5m ø
(2) Evaporator: 16m (L) x 7m ø
(2) Turbine/Gen.: 14.5m (L) x 3.5m ø
(1) WP Stg Evap.: 15m (H) x 9.5m ø
(1) WP Stg Cond.: 10m (W) x 10m (L) x 12m (H)
(1) Warm Water Inlet: 5m x 3m
(1) Cold Water Pipe: 2.8m ø x 1000m (L) m
(1) Mixed Water Discharge Pipe: 5.5m ø x 50m (L)

Platform

Length = 122m
Breadth = 30m
Depth = 16m
Draft = 9m
Displacement = 32,000 MT


OTEC
and the State of Hawaii . . .
OTEC can satisfy all present and future residential, industrial, and commercial power, as well as domestic water needs in the State of Hawaii.
With the development of electric vehicles, OTEC could also provide the electricity required to support land transportation.
Envision two to three floating OTEC plants (50 MW/16 MGD* to 100 MW/32 MGD*) tailored to the islands of Hawaii, Kauai and Maui . . .
Seven to ten large floating OTEC plants deployed around the Island of Oahu can meet all present and future power and water needs.
A smaller plant could meet all water and power requirements in Molokai. In the case of Lanai, it would be more cost effective to supply power from Maui via a submarine power cable.
Environmental pollution would be minimal and the State would only have to import aviation fuels.
Presently, 30% of the energy consumed is for aviation—therefore, by implementing OTEC, petroleum imports could be reduced by approximately 70%.
* MGD = Million Gallons of Water per day; e.g., 16 MGD is enough for 100,000 residents.
ISLAND
DE FACTO POPULATION (1990)
INSTALLED CAPACITY (1989)
HAWAII 135,000 130 MW
KAUAI 68,000 160 MW
LANAI 2,500 5 MW
MAUI 130,000 140 MW
MOLOKAI 8,000 5 MW
OAHU 910,000 1,200 MW
Hawaii map section: Copyright Raven Maps & Images, 1988.
KAUAI
OAHU
MOLOKAI
MAUI
LANAI
HAWAII
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Development Barriers (Hawai'i)

Tech. Issues: Need to Build & Operate Pre-Commercial Size Plant

Cost Issues: Cost Effective for Size ≈ 100 MW

Enviro. Issues: Relatively Minimal

Political Issues: Need Federal Help… only Hawai'i benefits (1/250 citizens)?

Other Applications: AC

Cold deep water as the chiller fluid in air conditioning (AC) systems: load can be met using 1/10 of the energy required for conventional systems and with an investment payback period estimated at 3 to 4 years.

Energy Carriers

OTEC energy could be transported via electrical, chemical, thermal and electrochemical carriers:

all yield costs higher than those estimated for the submarine power cable (< 400 km offshore).

EXTERNALITIES

- What are external costs of energy production and consumption?
- In USA ~ $78B to $259B annually (add $85 to $327 to oil barrel)
- USA to safeguard overseas oil supplies → add ~ $23 to barrel

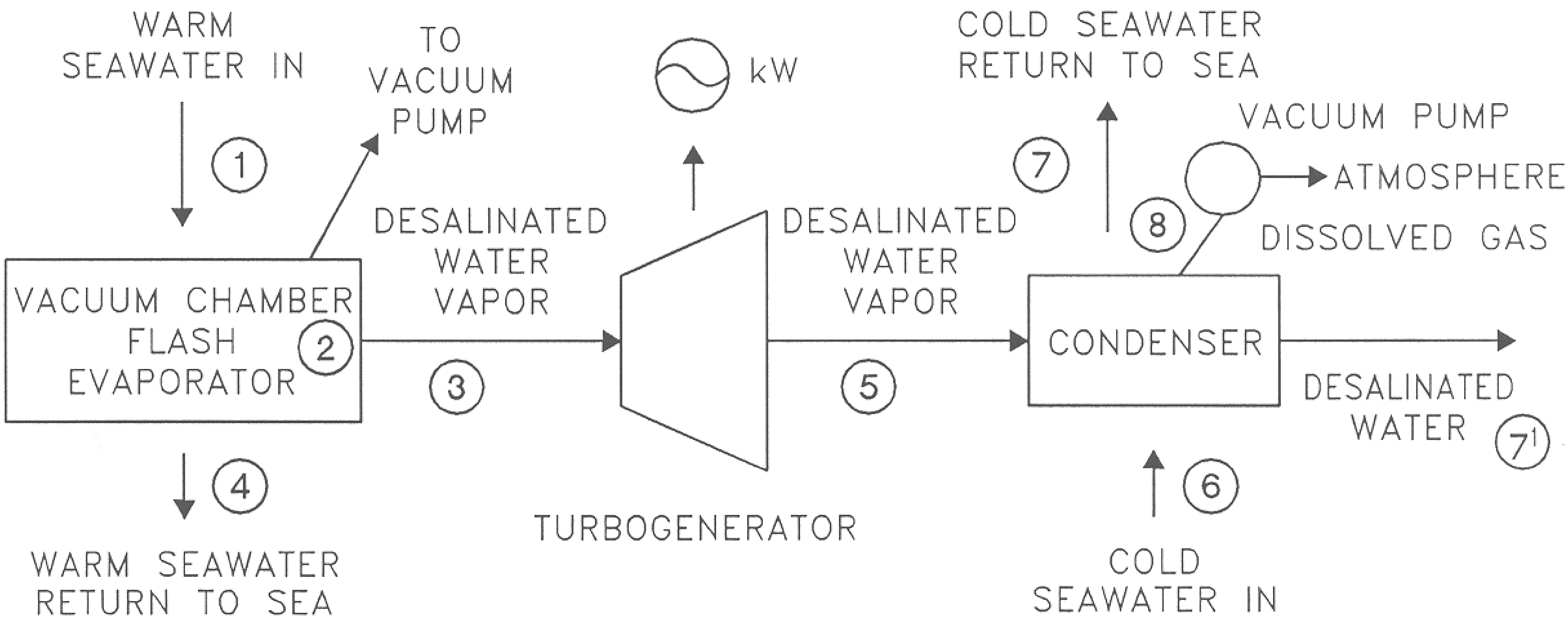
Final Thoughts:

Accounting for externalities will facilitate development and expand applicability of OTEC;

In the interim should use OTEC plantships to transmit the electricity (and water) to land via submarine power cables (and flexible pipelines).

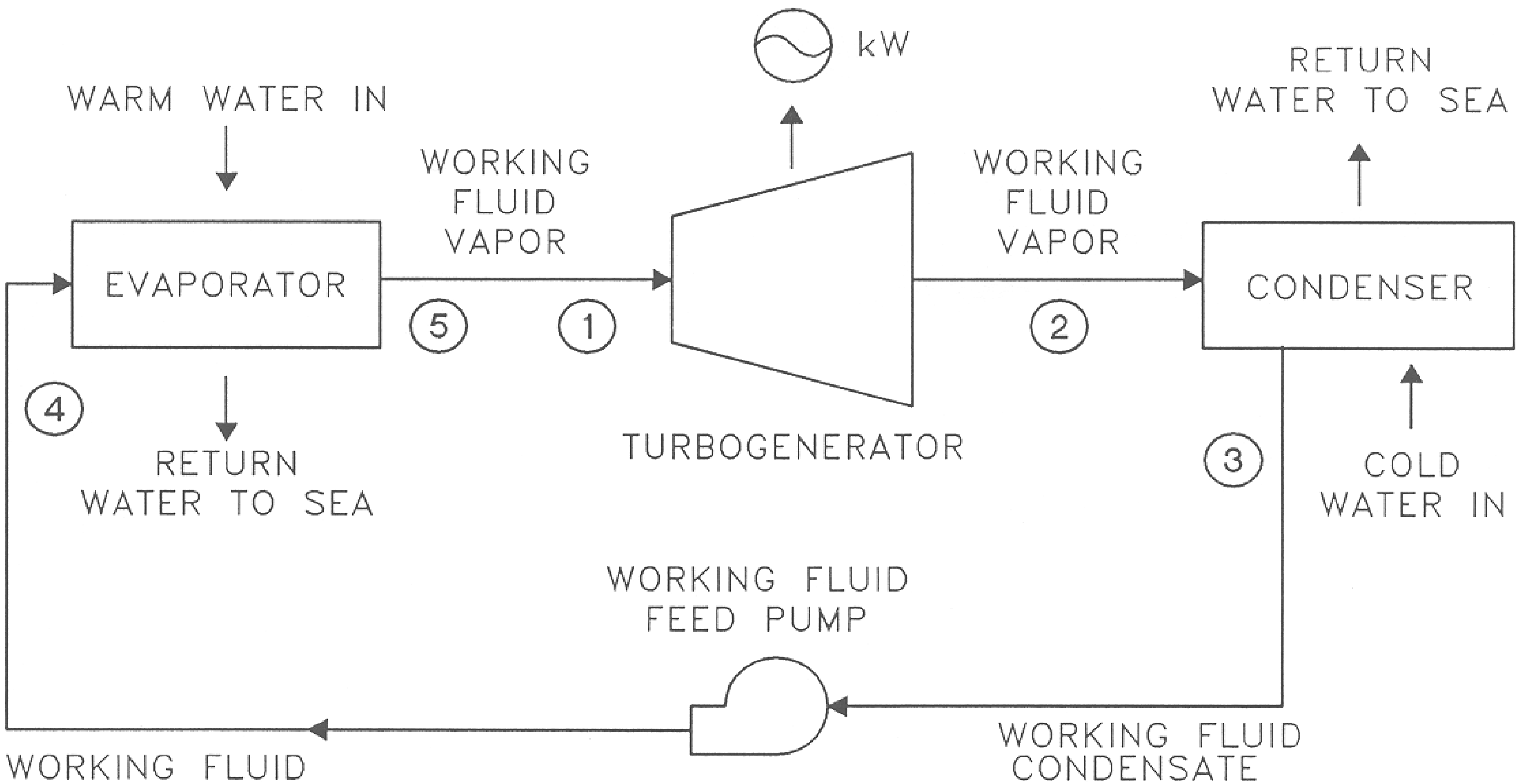
Open Cycle OTEC

Surface seawater is flash-evaporated in a vacuum chamber. The resulting low-pressure steam is used to drive a turbine-generator. Cold seawater is used to condense the steam after it has passed through the turbine. The open-cycle can, therefore, be configured to also produce fresh water:


WARM
SEAWATER IN
TO
VACUUM
PUMP
kW
COLD SEAWATER
RETURN TO SEA
VACUUM PUMP
ATMOSPHERE
DISSOLVED GAS
1
7
8
DESALINATED
WATER
VAPOR
DESALINATED
WATER
VAPOR
VACUUM CHAMBER
FLASH
EVAPORATOR
2
3
5
CONDENSER
DESALINATED
WATER
7[1]
4
6
TURBOGENERATOR
WARM SEAWATER
RETURN TO SEA
COLD
SEAWATER IN

Closed Cycle OTEC

Warm surface seawater and cold deep seawater are used to vaporize and condense a working fluid, such as ammonia, which drives a turbine-generator in a closed loop producing electricity:


kW
WARM WATER IN
WORKING FLUID VAPOR
WORKING FLUID VAPOR
RETURN WATER TO SEA
EVAPORATOR
CONDENSER
5
1
2
4
3
RETURN WATER TO SEA
TURBOGENERATOR
COLD WATER IN
WORKING FLUID FEED PUMP
WORKING FLUID
WORKING FLUID CONDENSATE