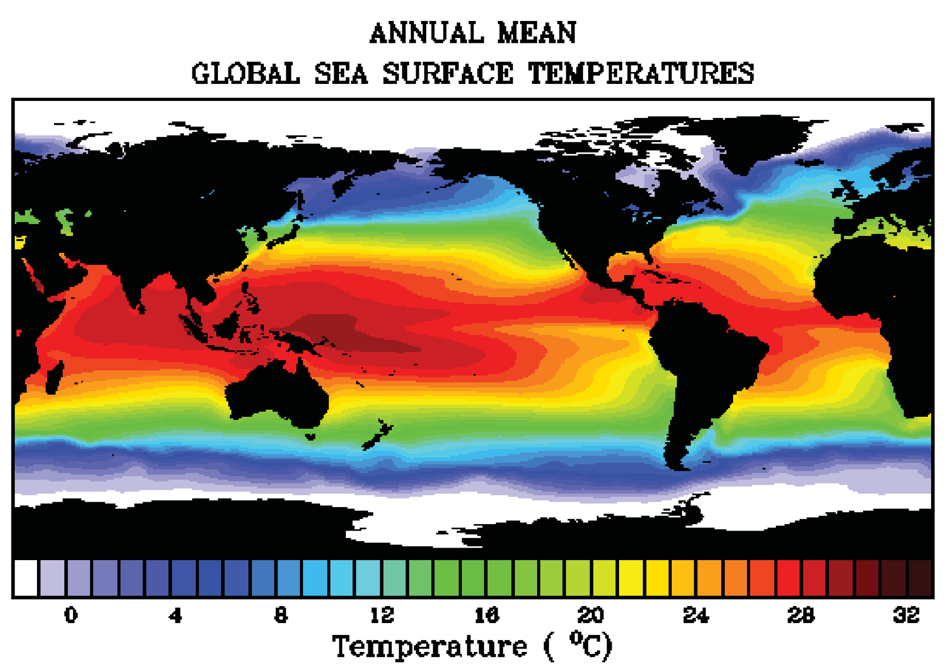
OTEC: Ocean Thermal Energy Conversion Will it Work?

Lindsey Andrade
Sean Karagianes
Meg Lidrbauch

Introduction

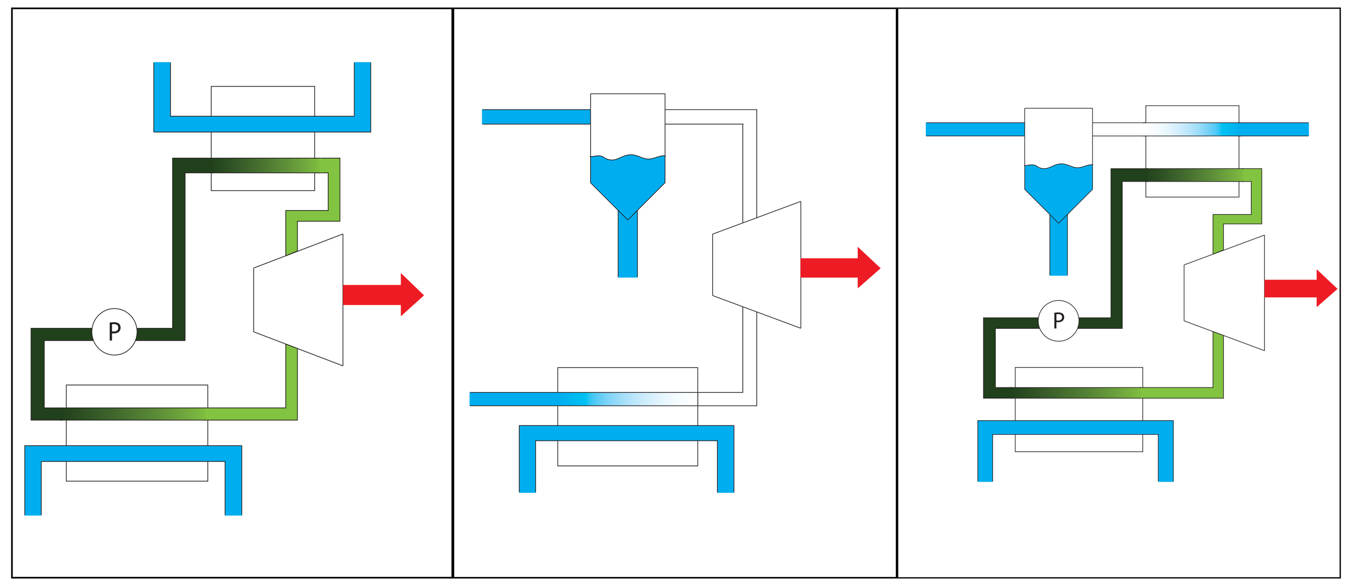
Ocean Thermal Energy Conversion power plants use the temperature differential between deep and shallow water to run a heat engine and produce useful work. OTEC works best with high ocean surface temperatures, mainly around the equator. Hawaii is a candidate for potential OTEC plants, but none are currently in commercial operation. Our project looks at the validity of an OTEC power plant in Hawaii.



Source: http://www.abc.net.au/science/slab/elnino/story.htm

System Overview

We worked with three iterations of the OTEC power cycle to compare different system configurations and add complexity to our model.



(a) Close System (b) Open System (c) Hybrid System

(a) The closed system uses warm ocean water to evaporate a refrigerant that then runs through a turbine. Cold ocean water is used to condense the refrigerant after exiting the turbine to complete the cycle.
(b) The open system uses ocean water as a working fluid. The water is flash evaporated and the steam is sent through a turbine then cold ocean water condenses the steam to expel fresh water from the system.
(c) The hybrid system uses evaporated ocean water to evaporate a refrigerant, which gets passed through a turbine and then gets condensed by cold ocean water.

Questions to Answer

Is OTEC technology a viable source for renewable, "green" energy?

What effect do different working fluids have on the closed and hybrid OTEC systems?

How do the three types of OTEC (closed, open, and hybrid) compare to one another?

Model

Assumptions

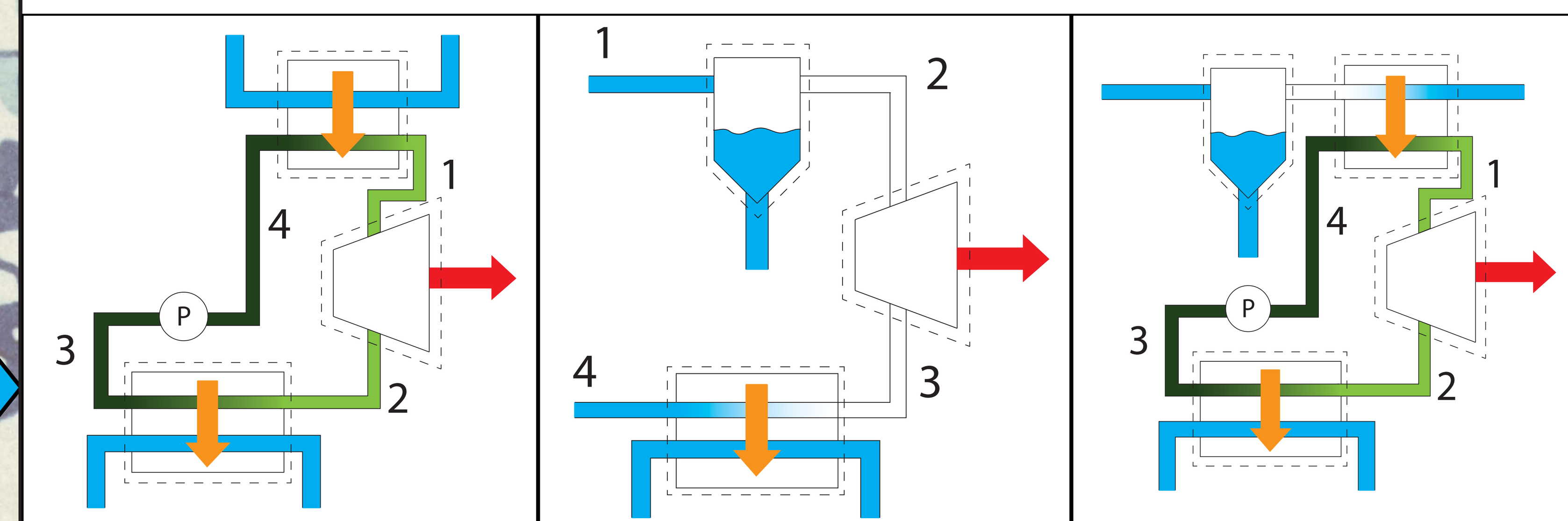
For all models:
- All components are modeled as control volumes at steady state.
- No internal irreversibilities anywhere in the cycle.
- No kinetic or potential energy effects.
- Pumps and turbines operate isentropically.
- The seawater is pumped at a rate of 1686 kg/s.

For closed model:
- Saturated vapor enters the turbine.
- Saturated liquid exits the condenser.
- The working fluid leaves both heat exchangers at the temperature of the other fluid in the exchanger.

For open model:
- Sea water is modeled as pure water.
- Flash evaporation process is isenthalpic.

For hybrid model:
- The working fluid leaves both heat exchangers at the temperature of the other fluid or vapor in the exchanger.

System Diagrams

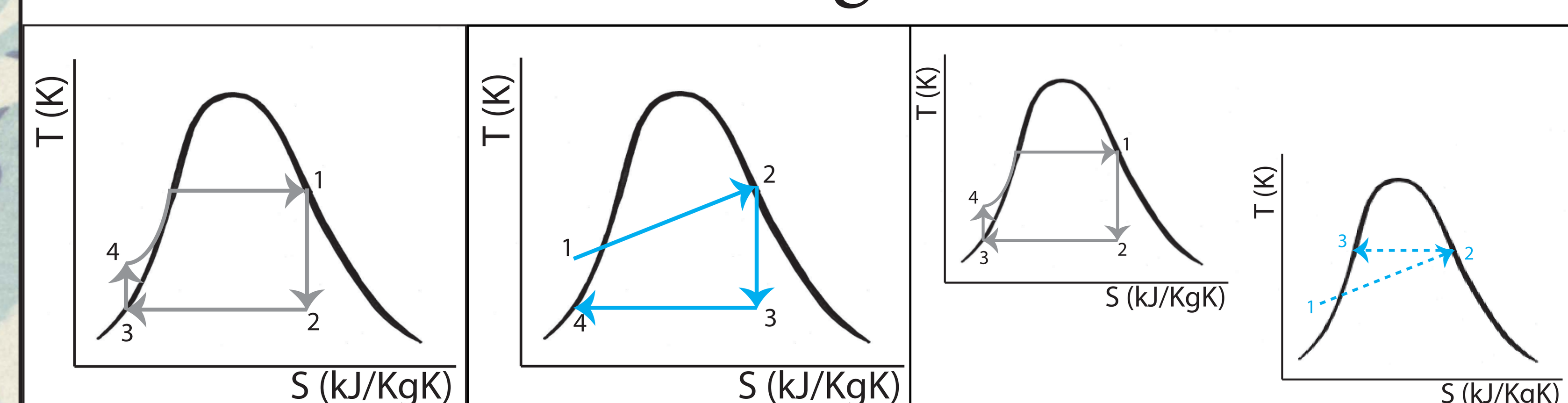


State 1-2: Isentropic work extraction.
State 2-3: Isobaric heat rejection.
State 3-4: Isentropic work addition.
State 4-1: Isobaric heat addition.

State 1-2: Isenthalpic flash evaporation.
State 2-3: Isentropic work extraction.
State 3-4: Isobaric heat rejection.

State 1-2: Isentropic work extraction.
State 2-3: Isobaric heat rejection.
State 3-4: Isentropic work addition.
State 4-1: Isobaric heat addition.

T-S Diagrams



(a) Closed System (b) Open System (c) Hybrid System

Note: The T-S diagram for a hybrid system include both the refrigerant cycle as well as the evaporated seawater processes. The refrigerant is shown above in grey and the seawater processes are shown in blue.

Results

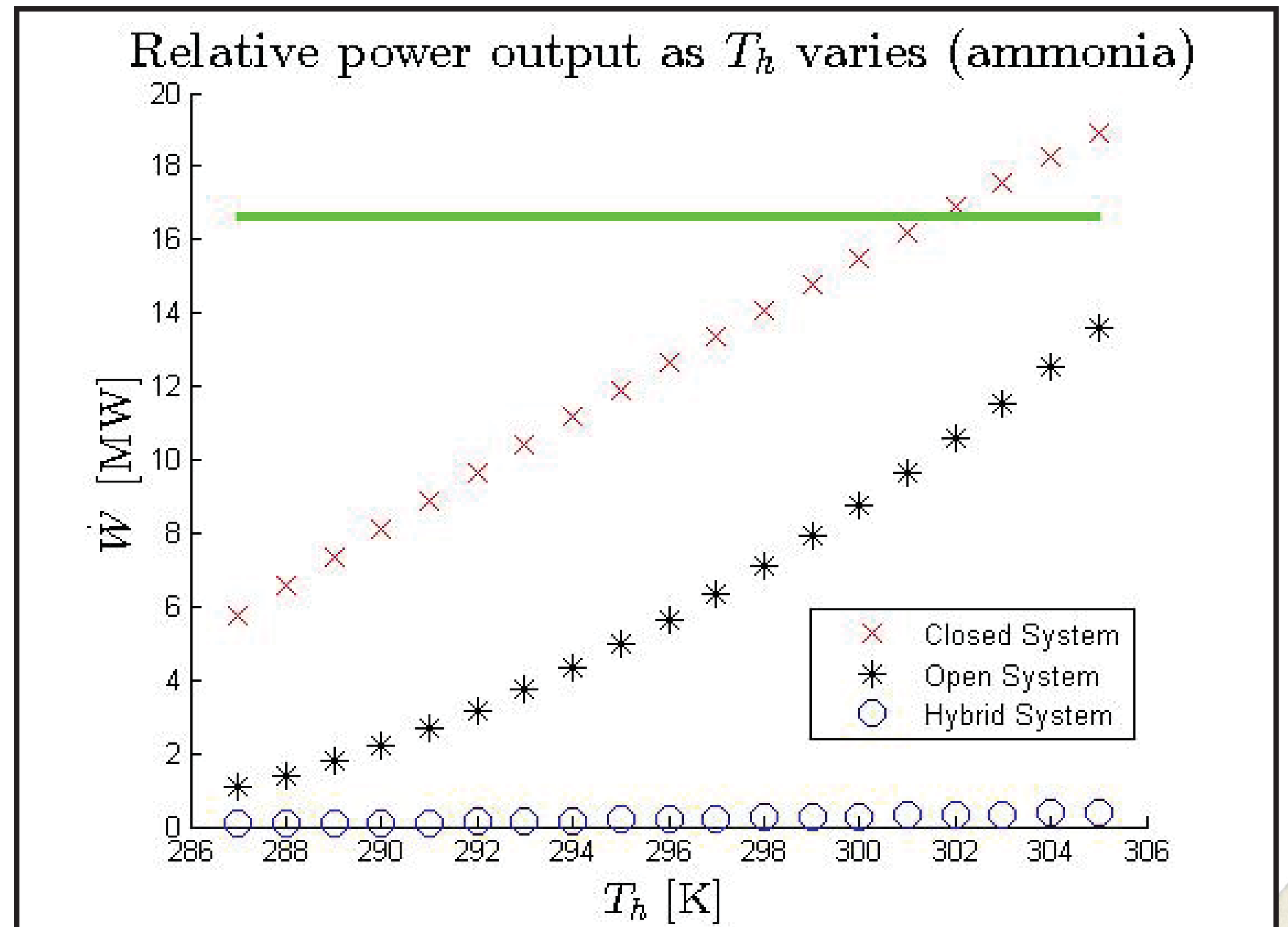


Figure 1: A plot of net power out of each of the three systems we tested. The green line is the power required to pump seawater in the surface and marks the break-even point of the power generation.

None of our models directly take into account the pump work required to bring the seawater into the system, but a simple calculation shows that the cold water pump alone draws about 16 MW of power when pulling from a depth of 1000 meters [3][6] so the system must produce a lot of power to have a net gain.

Our model shows that only the closed cycle OTEC system produces enough power to generate a net gain, and only with warm ocean temperatures above about 302 K (29 °C), when ammonia is the working fluid. A real-world application of this system would take into account irreversibilities and component efficiencies, contributing to less net work from the system.

The hybrid system seems as though it should produce more power than the open system because it hypothetically takes the best aspects of both cycles. Since only half a percent of seawater vaporizes in the open portion of the hybrid system, the heat transferred to the working fluid and the flow rate through the turbine is very small.

Working Fluid	Work Output per Mass Flow (kJ/kg)	System High Pressure (kPa)	System Low Pressure (kPa)	Price per kg	Environmental Effects
Ammonia	91.18	1162	550.9	$0.72	Toxic/harmful to humans. Hazardous to environment.
Butane	29.22	282.1	132.8	$0.54	Extremely flammable. No effect on aquatic environments.
Propane	27.23	1075	581.7	$1.23	Extremely flammable. No effect on aquatic envrionments.
R134a	14.42	766.9	372.7	$8.08	Not a hazardous waste material. Will evaporate at STP.
R245fa	15.40	176.8	71.8	$33.07	May explode if heated. Avoid discharges to the atmosphere.
Water	188.22	4.2	0.99	$0.0076	None

For non-seawater working fluids, ammonia and butane seem to be the leaders of the fluids we looked at, with preferences on priorities for the project (cost, pressures, etc.). Although water produces the most work as a working fluid, it operates between less than one percent and four percent of atmospheric pressure, requiring special pipes and vacuum pumps to maintain the lower pressure. However, water also is very cheap and has no negative environmental effects, which may make it more appealing. We did not examine the materials specifications required for each cycle under each working fluid. It is possible that the type of pipe necessary for certain conditions is not space- or cost-efficient, thus eliminating that working fluid as a viable option.

Sources

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