Ocean Thermal Energy Conversion in 2018: Operations, Simulations and Policy

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Abstract

Policymakers are trying to cut carbon-dioxide emissions and have promoted generating electricity using solar, wind, wave converters and tidal turbines. But a larger need is to supplement petroleum, the polluting but superb transportation fuel. Ocean Thermal Energy Conversion plants operated during the past 40 years show that OTEC plants have the (1) reliability and (2) massive scale to synthesize a sustainable new global fuel to replace dwindling petroleum supplies. For reliability, we will review the experience of the two OTEC plants currently operating in Japan and Hawai'i. Both plants have demonstrated robust performance for heat exchangers and power components. This record is possible because OTEC uses components similar to typical power plant or air-conditioning machinery. Mini-OTEC generated the first net power in 1978, and it was designed and built in only a year. Today's onshore plants easily synchronize with the grid frequency, and generate dispatchable electric power instead of the intermittent power from most renewable energy sources. Recent OTEC floating designs benefit from the offshore industry's hull and power cable research & development. For scale, large OTEC plants operating on the tropical high seas are a feasible supply chain to make transportation fuel in globally-significant volumes. Two recent computer studies suggest that industrial OTEC will have benign biological and climate impact. In comparison, it would require 100% of the US corn harvest to furnish only 30% of US gasoline needs – with no jet fuel or diesel. The expensive drama of obtaining permits for renewable energy projects show that the land and shoreline are already crowded, yet the solar energy equivalent to seven offshore Sahara Deserts is being ignored. Finally, policies and costs supporting or hindering OTEC will be compared for eight nations and the United States, including findings by the International Energy Agency's Ocean Energy Systems committee. These results explain the current state of this attractive ocean energy resource.

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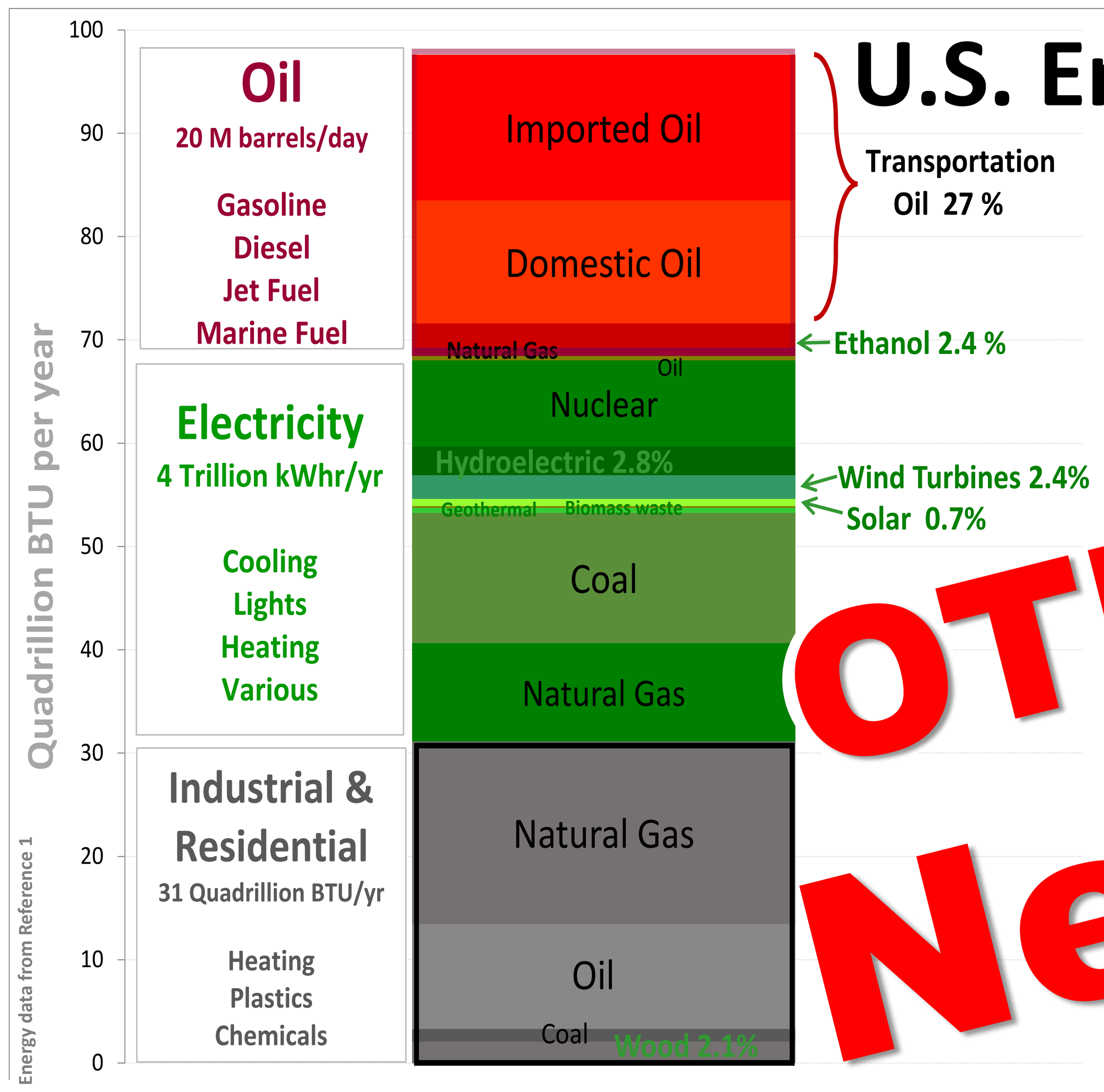
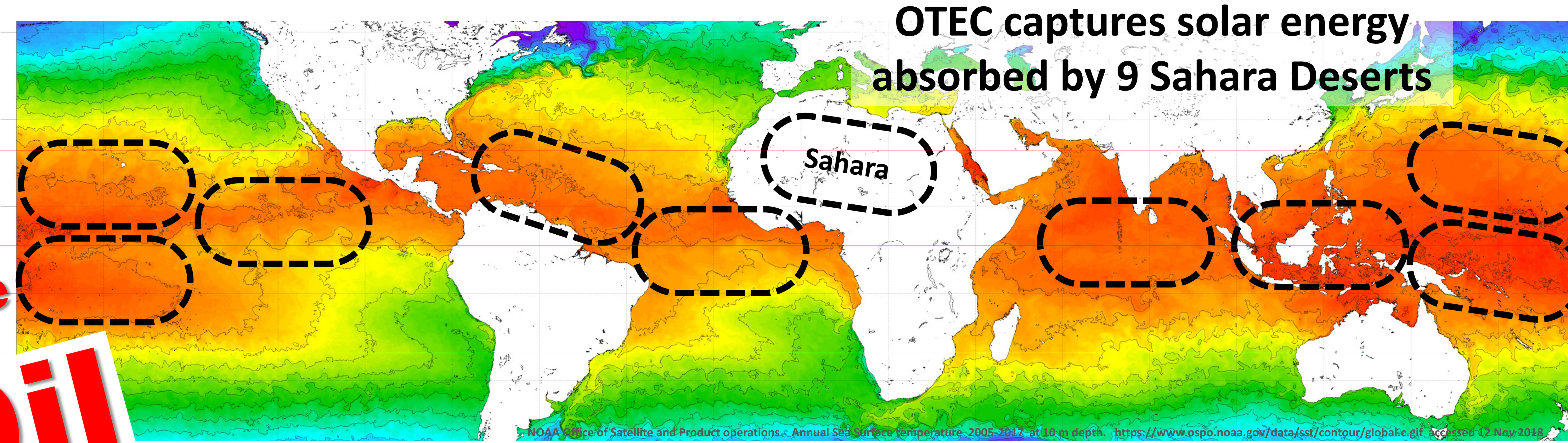
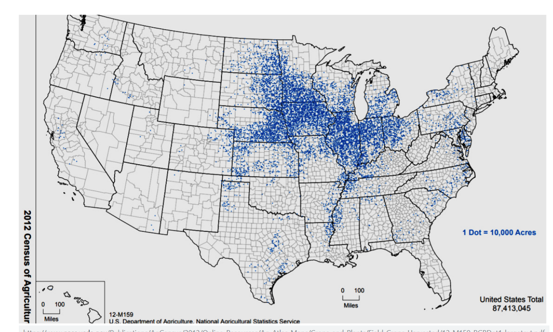


OTEC The New Oil



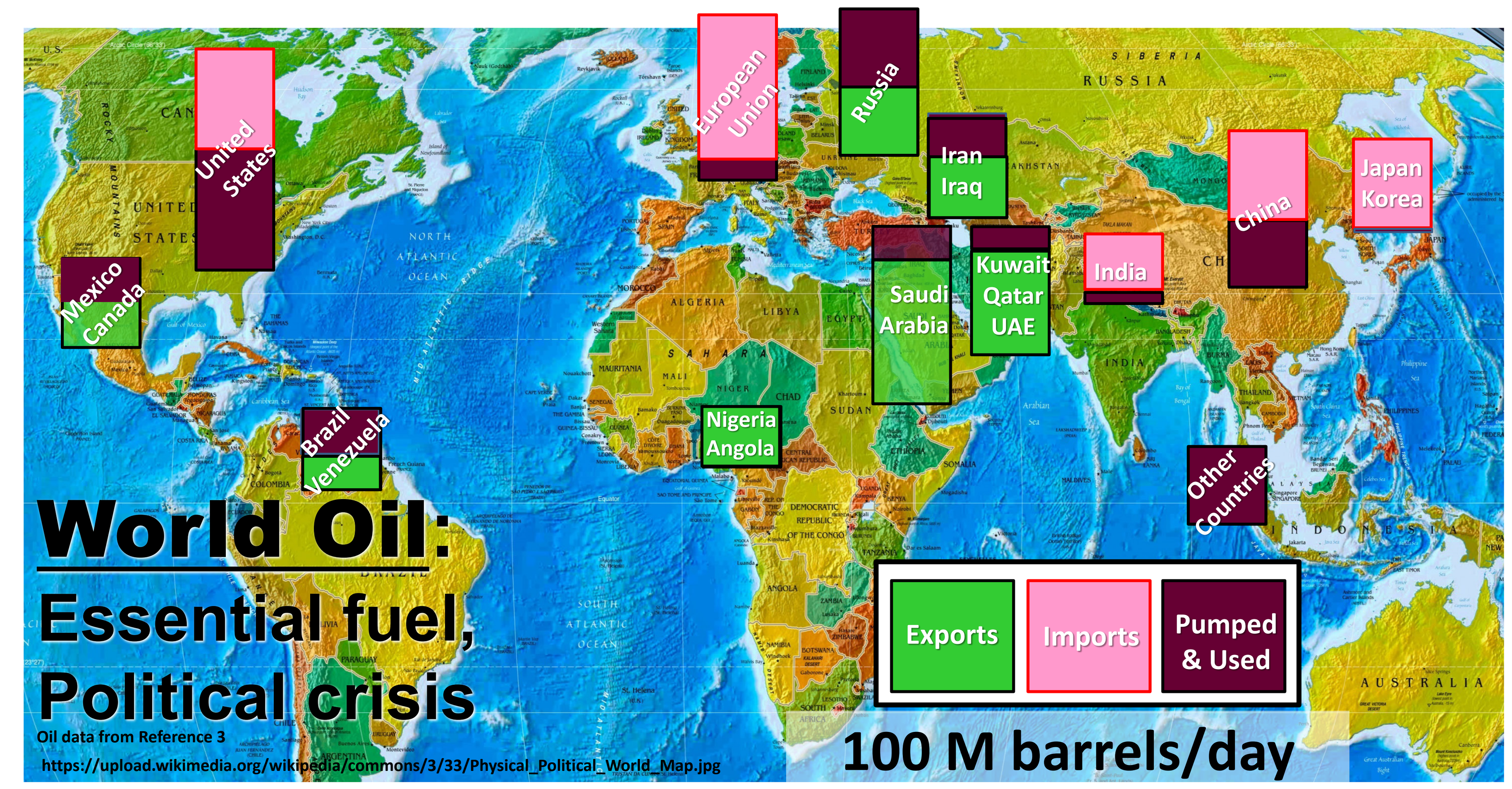
Ethanol: Only 2.4% Uses 38% corn harvest



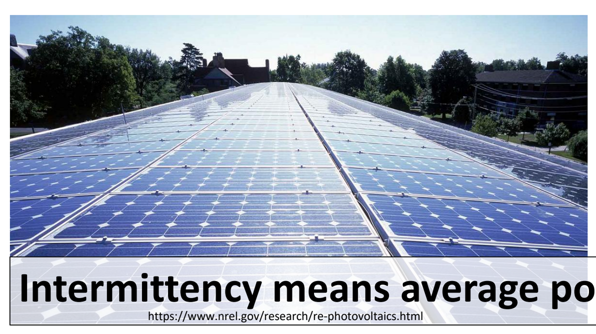
Ethanol fuel can't replace oil, it requires too much cropland. In 2017 ethanol fuel consumed 38% of the US corn harvest yet supplemented only 10% of gasoline consumption. Thus, the entire corn harvest can furnish only 26% of US needs. We still need the other 74% of oil, and prices for meat and eggs would soar.

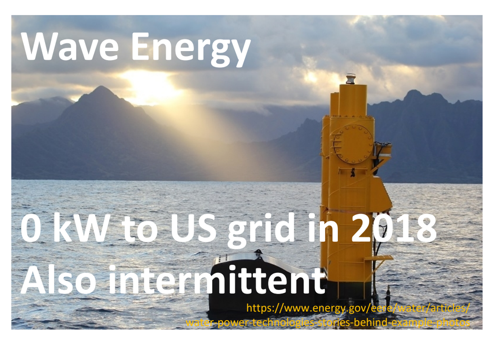
Both pillars of U.S. energy policy are impractical at truly large scale, while U.S. domestic oil supplies are finite and being consumed.

The awkward distribution of oil imports, exports and reserves strain world culture and geopolitics every day.



Solar & Wind: Only 3.1%





The United States needs a larger source of sustainable energy as petroleum becomes more scarce and politically insecure. That source will eventually be Ocean Thermal Energy Conversion (OTEC) because the ocean is massive and can furnish power continuously.

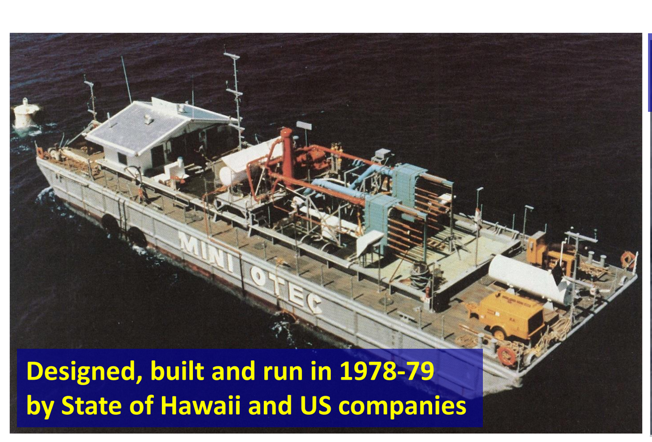
The intermittent nature of wind and solar electricity is a fundamental weakness, masked by the reliability of fossil fuel generating plants. The weak performance and high cost of batteries make grid storage and electric vehicles impractical. That is why solar and wind produce only 3.1% of U.S. energy despite tax incentives and government mandates. Projects are often delayed due to permitting conflicts – a symptom of overcrowding our land.

OTEC is Operating Now

A feasible solution is to use solar energy collected by the ocean. The map shows annual ocean temperatures at 10-meter depth, where the tropical ocean is heated to 27 to 25 C. Below 1000 meters depth, the entire ocean is colder than 5 C. This seawater can be pumped through dam-size pipes and heat exchangers to power a Rankine (steam turbine) power cycle that uses standard refrigerant to drive turbine generators. 1/3 of the power is used to pump seawater, 2/3 is available for use.

Three land-based demonstration OTEC plants are operating now in Hawaii, near Okinawa, and in South Korea. These plants generate power onto the grid day and night and are sited near steep seafloors with 3-km access to deep cold water.

But larger plants should be floating so the seawater pipes can be vertical. The U.S., Japan and India have operated small floating plants for science and demonstrations.



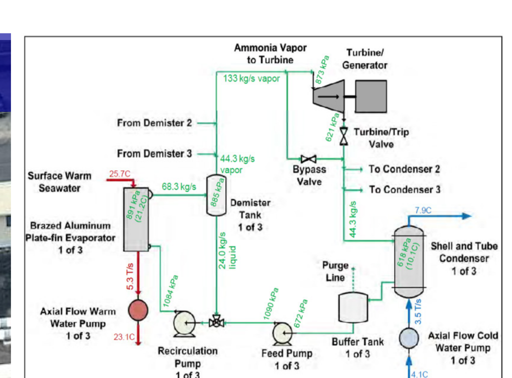


Image from Reference 4

OTEC can Replace Oil

Industrial-size floating OTEC plants will resemble proven offshore platforms such as oil and gas spars or FPSOs. Designs have been developed by US and French oil and defense companies, the US Navy and others. Dozens of 100 megawatt plants could be moored offshore Hawaii, Puerto Rico and other tropical cities. They could export electricity to shore via large power cables recently developed by the oil industry. These cities could become 100% electric renewable within the few years needed to build the plants.

Replacing oil requires an immense resource, too distant for city-size power cables. OTEC's real promise is far offshore, making a renewable fuel. Fleets of unmoored OTEC plants would patiently cruise earth's immense tropical ocean. They generate electricity and store it as hydrogen, charged batteries, or synthetic ammonia fuel.

Shuttle tankers bring this "fuel" product to shore and distribute it in a manner similar to current oil imports. We all know our planet is 70% ocean, this technique uses the non-land portion.

Global OTEC can make > 7 TW.

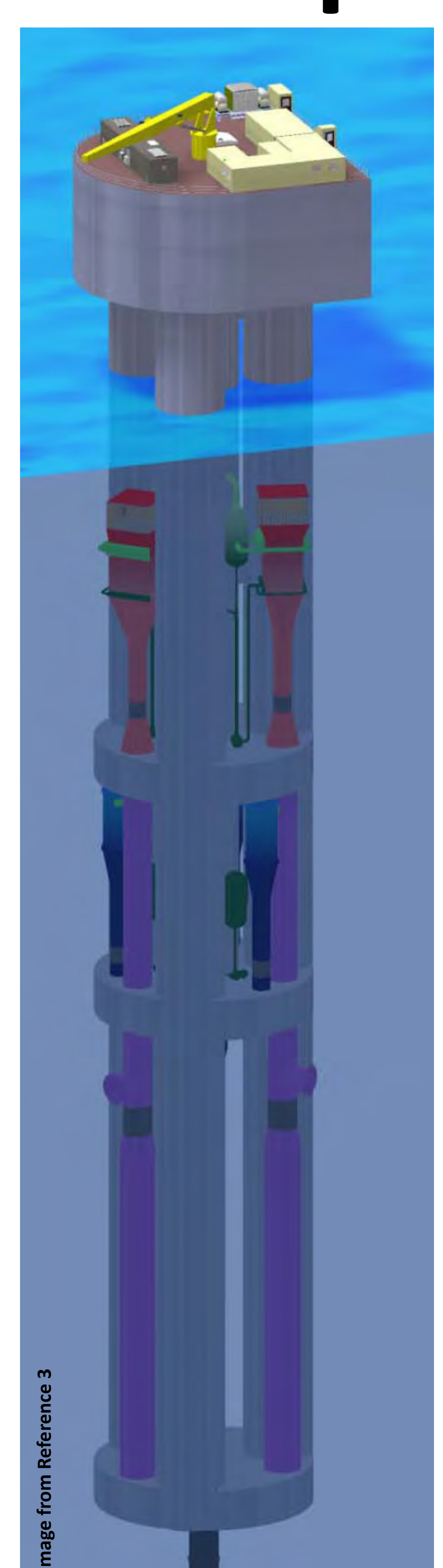


Image from Reference 3

Storing pure hydrogen requires extreme cold or extreme high pressure - both uneconomic for massive-scale use. Existing batteries are too heavy and expensive to be feasible. Until a "wonder-battery" is invented, liquid anhydrous ammonia (NH_3) is a more feasible fuel.

OTEC electricity would electrolyze distilled water into hydrogen and oxygen. The hydrogen is then reacted with catalyst and nitrogen to produce ammonia (NH3) as a synthetic fuel. Liquid ammonia can be stored under slight pressurization, just like propane. It burns well in high-compression engines, similar to diesel fuel. When burned with oxygen, energy is released from the three H-N bonds, resulting in H_2O and stable N_2. There is no carbon dioxide.

Ammonia is the world's most widely transported chemical. The midwest United States already has an ammonia transport pipeline network, with distribution systems to farms and factories.

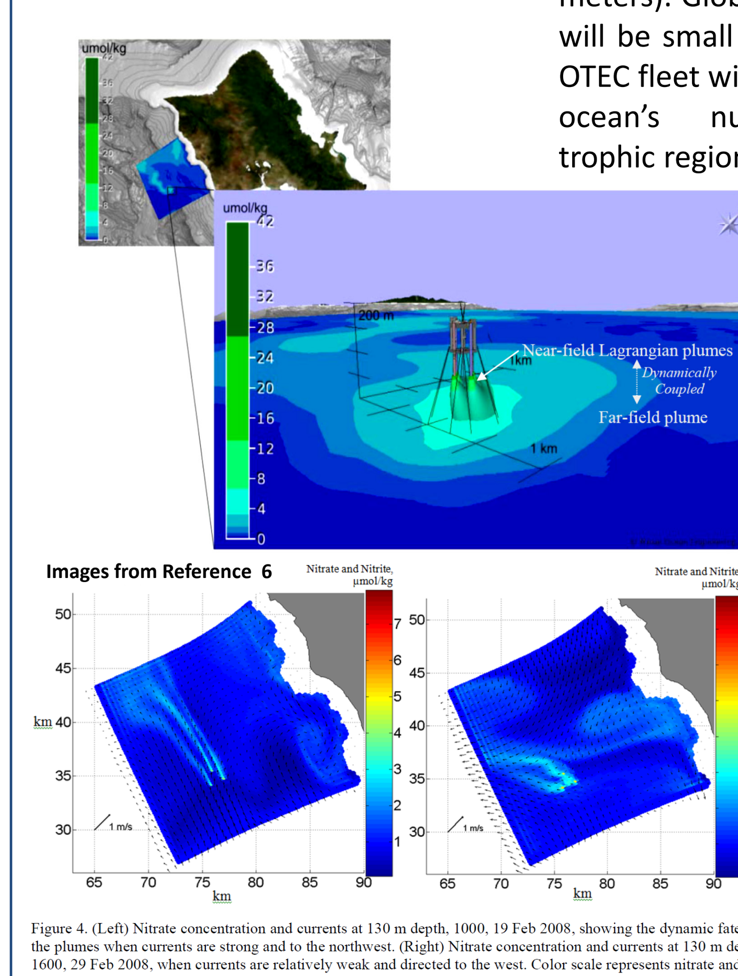
100 million barrels/day oil = 6.6 TW

OTEC will be Sustainable

OTEC is sustainable on a scale large enough for global energy production. The limiting planetary effect is alterations to the global thermohaline (deep cold seawater) circulation, which has been modeled by Nihous at the University of Hawaii. Continuous generation of 7 – 14 terrawatts, approximately the same as world oil production, would not affect ocean circulation.

Acceptable "crowding" of OTEC plants is governed by ocean nutrient enrichment from the deep water. Japan has studied this nutrient enrichment as a desired effect. Regional Ocean Modeling (Grandelli et al) simulated that phytoplankton growth effects from OTEC are smaller than natural variation if the seawater flows are returned below the photic zone (~90 meters). Global biological impacts will be small because the world's OTEC fleet will be operating in the ocean's nutrient-poor oligo-trophic regions.

Policy: In the United States, OTEC is governed by the OTEC Act of 1980 and is under the licensing authority of NOAA. It has no active tax incentives, although the Department of Energy has reported it is ready for commercialization. The European Union will provide an operating subsidy to the floating OTEC plant being designed for Martinique


Images from Reference 6

Costs & Policies

Identifier Nominal Size, MW	Capital Cost, $/kW	O&M, $M/year	R&R, $M/year	COEcc, c/kWh	COE OMR&R, c/kWh	COE, c/kWh
1.35	41,562	2.0	1.0	60	33.7	94.0
5	22,812	2.0	3.5	33	17	50.0
10	18,600	3.4	7.7	26.9	16.8	44.0
53.5	8,430	3.4	20.1	12.2	6.7	19.0
100	7,900	3.4	36.5	11.4	6	18.0
						8%/15 years

Price data from Reference 5

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Questions welcomed

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