



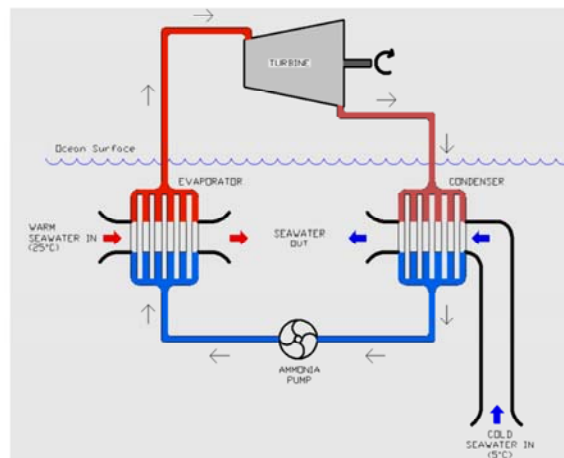
OTEC Ongoing Engineering Effort in Hawaii

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Good afternoon. My name is Joe Van Ryzin and I am from Makai Ocean Engineering, an ocean engineering firm located here on Oahu. I have been involved with Ocean Thermal Energy Conversion Research and Development over the past 30 years, off and on, and this afternoon I would like to share with you some of our past experiences and current ongoing OTEC efforts.

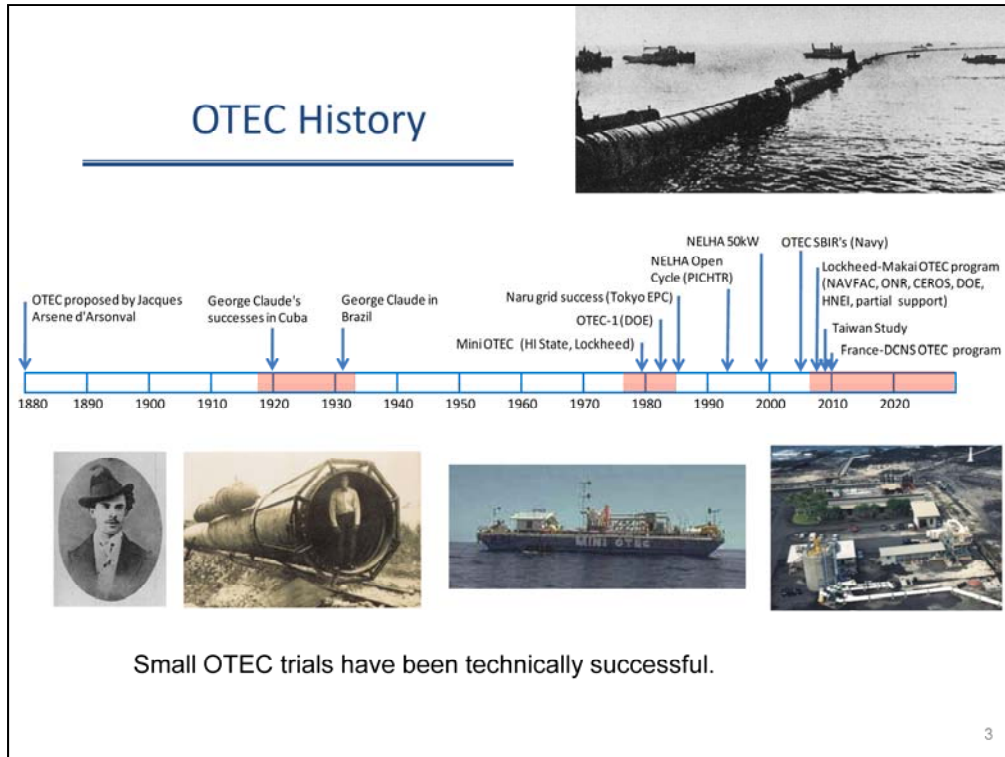
Ocean Thermal Energy Conversion



Several variations exist: Open Cycle with water vapor as the working fluid; closed working fluids of ammonia-water mixtures and propylene.

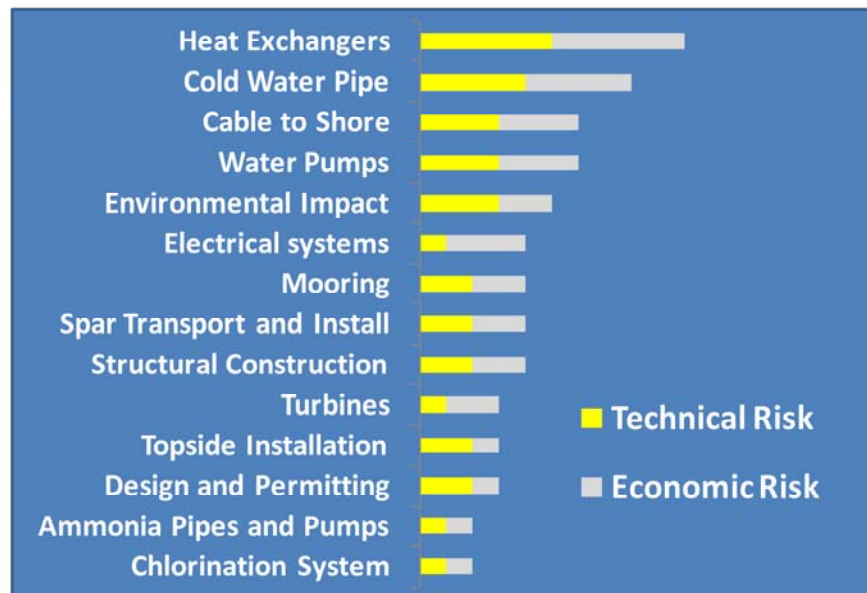
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Most of you I am sure are familiar with OTEC or Ocean Thermal Energy Conversion. For those who are not, I include a simple diagram of an OTEC system. OTEC uses the temperature differential that is found in tropical oceans and converts that stored energy to electricity. The warm seawater is used to evaporate a working fluid which passes through a turbine which turns an electrical generator. The exiting working fluid is condensed through a heat exchanger operating with the deep cold seawater and is then circulated back to the evaporator. There are many variations of this conversion process where different working fluids are used and even an open cycle systems has been built and tested by Luis Vega. All OTEC systems use both deep cold seawater and warm surface water as the driving energy.



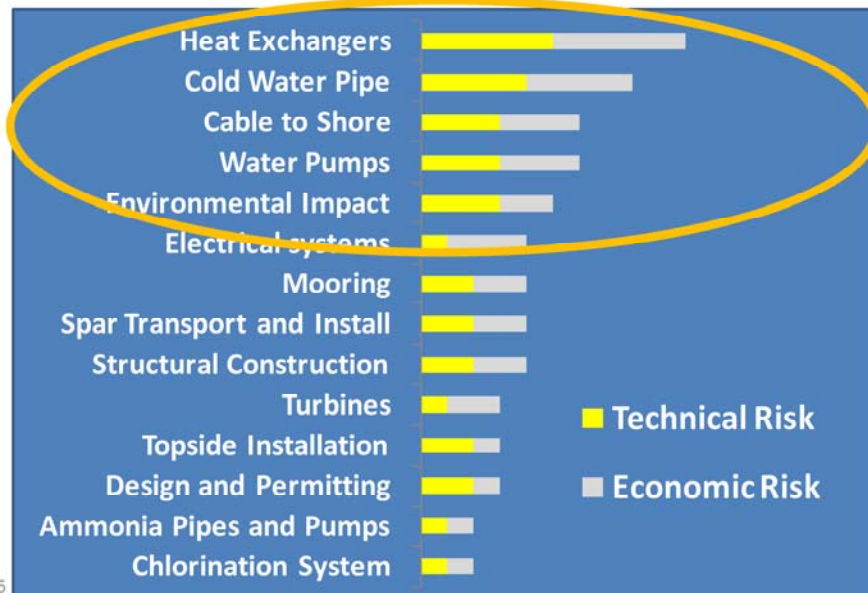
OTEC is not a new concept. It was first proposed by Jacque D'Arsonval in 1880 and a Frenchmen named George Claude tried building OTEC plants in the 1920s and 1930s off Cuba and Brazil. Claude's work was a magnificent attempt but he lacked the materials and engineering we know are necessary today. It was not until the energy crisis of the late 70s and early 80s that there was renewed interest in OTEC. That era made significant progress but the enthusiasm died with the price of oil. Most recently, the cost of energy and global warming has spurred renewed interest in OTEC. Within the United States the major effort is being led by Lockheed Martin, of which Makai is a partner. Dennis Cooper will discuss the Lockheed effort after this talk. There is also a new parallel effort in France and considerable interest in Taiwan. On the bar chart I have shown the concentrated periods of OTEC development as in red. Note that I have shown the next 20 years in red – a critical and challenging time in history.

OTEC Components and Risk



This next slide shows the various components of an OTEC system and ranks those components in terms of technical risk and economic risk for commercial development. Technical risks are whether the component can be built and can survive. The economic risk is a major factor for an OTEC system. OTEC plants are massive structures that operate at low efficiency and handle huge quantities of seawater. The structure is large and in order to be economically viable the system must be designed for a minimum capital cost.

Offshore Elec. Production



One can see that heat exchangers, cold water pipe, the cable to shore, water pumps and the environmental impact are some of the key issues associated with OTEC commercialization.

Large Diameter Pipelines – R&D in Hawaii



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One of the major and unique components of an OTEC plant is the cold water pipe. OTEC requires very large and very long deep water pipelines. Research on pipelines commenced in the 1980s in Hawaii. Shown in this picture is a Dept of Energy and NOAA research program for an 8 foot diameter cold water pipe study. A length of fiber glass cold water pipe was fabricated and suspended from a barge in order to study cold water pipe dynamics.

1.4m Hawaii NELHA Pipeline:

- 2.7 km long
- 1400mm diameter warm & cold water pipes
- 900m deep (4°C.) intake
- 27,000 GPM (1.7 m³/sec) cold water flow
- 40,500 GPM (2.5 m³/sec) warm water flow
- Deployed October, 2001



Makai Ocean Engineering, Inc.

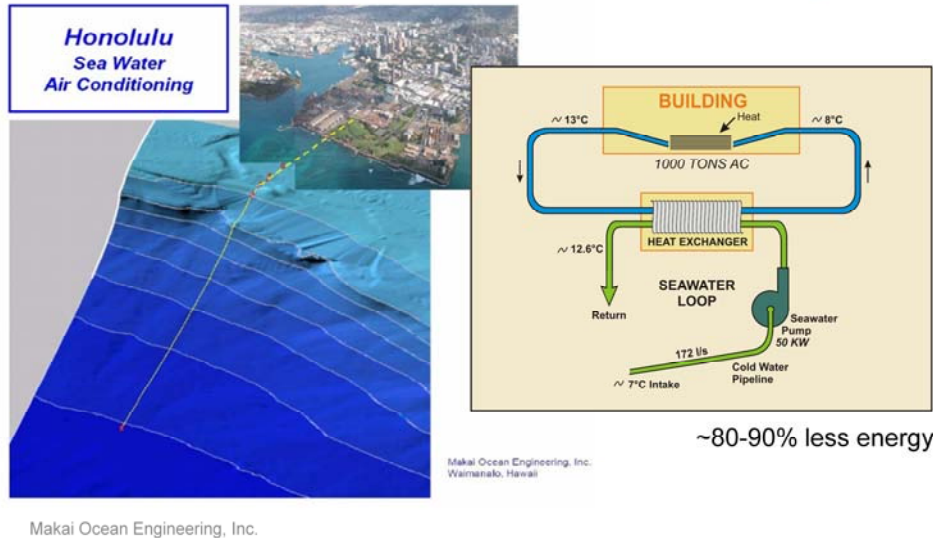
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The State of Hawaii has several deep water pipelines located at the Natural Energy Laboratory of Hawaii Authority on the Big Island of Hawaii. These pipelines were initially installed in order to support OTEC research and have also been used for aquaculture development. The largest of these pipelines is shown here and is 1.4m in diameter and goes to 900m depth. This is a down-the-slope pipeline and it can deliver 1.7 cubic meters per second of cold water to shore at NELHA.

Slide 8

OTEC Pipeline spinoff technology: Seawater Air Conditioning



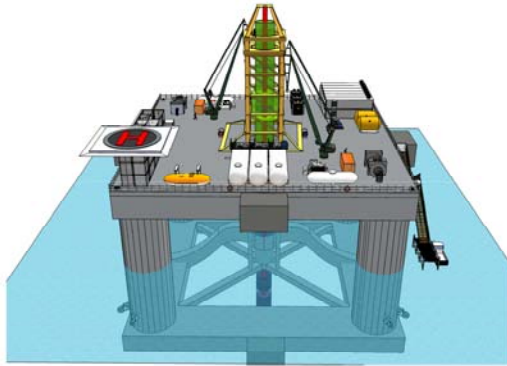
One interesting energy spin-off from the development of these deep down-the-slope pipelines has been the development of seawater air conditioning. The deep cold seawater can be used very economically to cool buildings and drive district cooling systems. Shown in this slide is a Honolulu seawater air conditioning project that is now under design and development. This system will air condition much of downtown Honolulu. The schematic diagram shows the simple flow diagram for a SWAC system. At some locations, direct cooling by seawater can save 80 to 90 percent air conditioning energy. While we are not producing power with SWAC, it is a major energy saver. The pipeline I showed you earlier could save 15 to 20MW of power used for AC.

100MW OTEC Cold Water Pipe Challenge

- Cold Water Pipes 10m diameter
- 1000m long, >2000 tonnes
- Very complex dynamic interaction with platforms
- Build vertically at sea: a handling challenge



George Claude vertically fabricating and installing iron OTEC pipe off Brazil in 1930's.



Pipe fabrication and handling today – more advanced materials and technology

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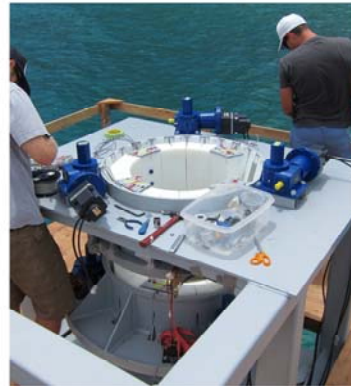
An OTEC pipeline for a large OTEC plant is a significant engineering challenge. For example, a 100 MW OTEC plant would have a cold water intake approximately 10m in diameter and at least 1000m long. This pipeline would weigh over 2000 tonnes and has a very complex dynamic interaction with the platform. In the picture on the right is shown a remarkable attempt by George Claude in the 1930s to build vertically an iron cold water pipe off the coast of Brazil. He fabricated the pipe at sea building it one section at a time and lowering it as it was built. Today, we are attempting to do the same thing. With different materials, more advanced technology and a much more sophisticated offshore industry, we will be fabricating a fiberglass pipe on the deck of a stable platform. As this pipe is being fabricated it will be lowered into the water. Dennis Cooper will later tell you more about this pipeline.

OTEC CWP ongoing testing



Makai Research Pier, Makapuu

Building &
Testing a
1/20th scale
CWP
Handling
System



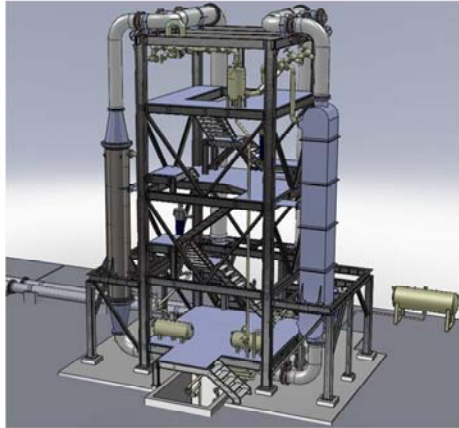
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If you have an opportunity while visiting Hawaii to drive around Oahu, you will see our research facility in Waimanalo on the east side of the island. Today, we are building a test device that will handle this cold water pipe during fabrication. Shown in these pictures is a 1/20th scale model of that device. This “Gripper” is being built to test the handling and control of the cold water pipe during fabrication.

HX Test Facility (NELHA – Hawaii)

HX performance testing

- 6000 gpm warm and cold water
- Testing variety of OTEC HX candidates
- Facility under construction today



Aluminum corrosion

- 700 samples in place
- Expanding to 2000
- Testing alloy, velocity, cold, warm, fabrication techniques, operational procedures

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Another major effort underway in Hawaii is the development of heat exchangers. OTEC involves massive heat exchangers on both the warm and cold water side. The heat exchangers are a major cost driver for OTEC and there is an effort underway to develop low-cost aluminum heat exchangers that will survive prolonged exposure to seawater. Today we are building a test facility on the Big Island of Hawaii at the Natural Energy Laboratory of Hawaii Authority. This will make use of the cold and warm water available to the pipelines that I have shown you earlier to test the performance of candidate evaporators and condensers and to also test a variety of aluminum samples for corrosion resistance. Those of you visiting NELHA will see this structure being erected. The corrosion lab has been in operation for quite some time.

Heat Exchanger Performance and Corrosion Testing Purpose

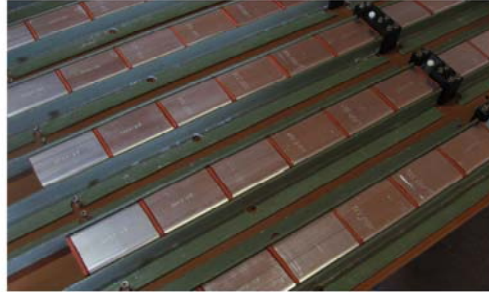
- Identify suitable **aluminum** alloys for heat exchangers based on corrosion performance
 - Titanium has excellent corrosion resistance in seawater but is very expensive
- **Optimize** heat exchanger by balancing heat transfer **performance, corrosion** and **biofouling resistance, and cost**

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The goal of this program is to identify suitable aluminum alloys that can be used in these heat exchangers based on corrosion performance. Furthermore, we wish to optimize a heat exchanger design by balancing its overall performance and lifetime with its initial cost.

Samples

- Testing individual alloys



- Testing manufacturing methods and surface finishes

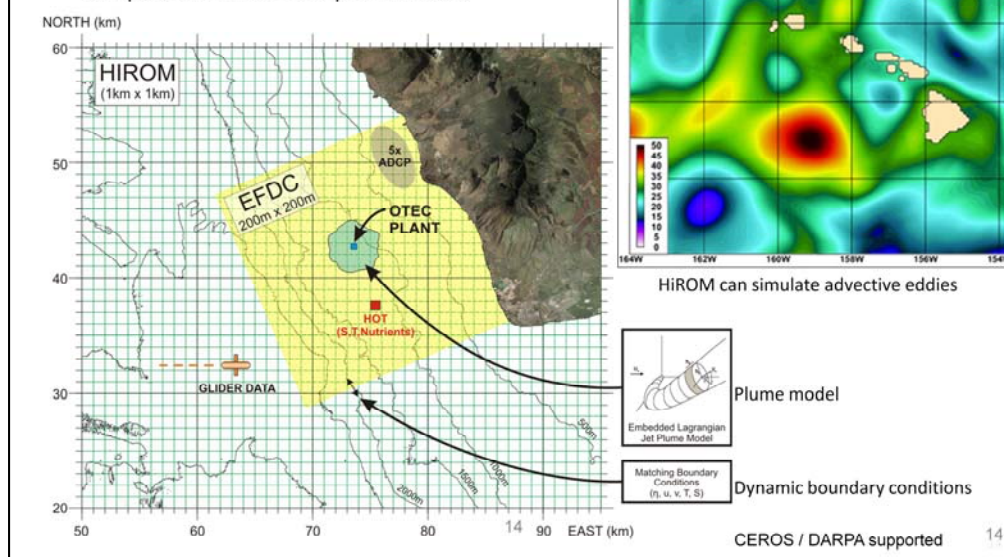


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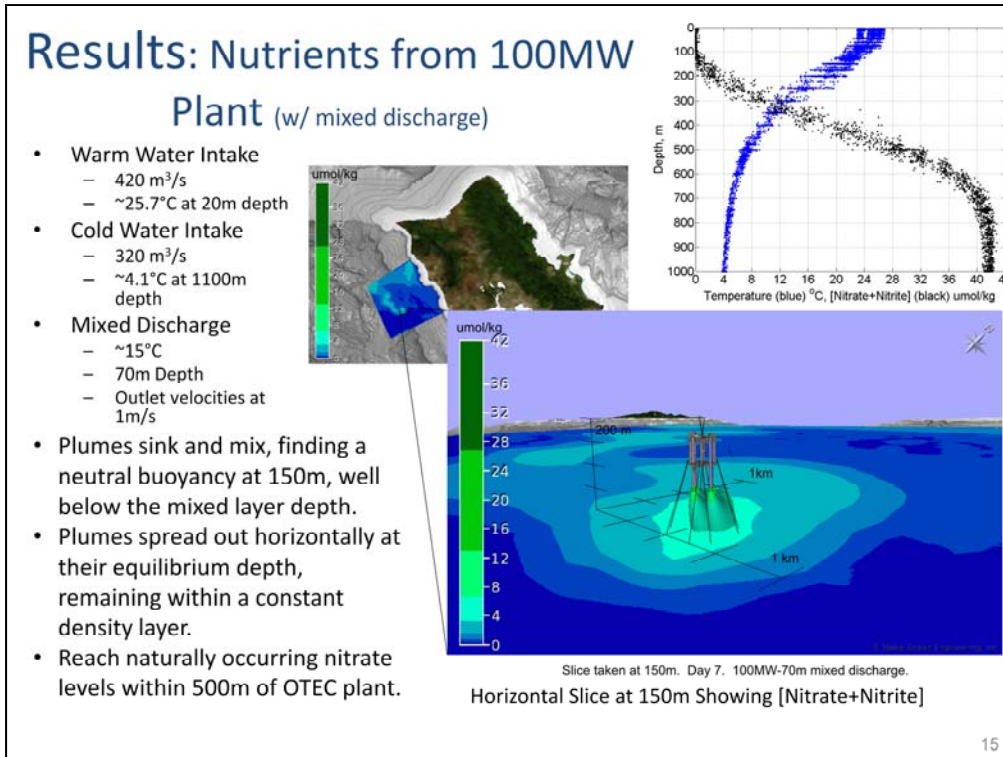
When fully loaded, there will be several thousand aluminum samples being tested in this facility over a prolonged period. We are testing individual alloys for their corrosion potential and, in addition, testing fabrication techniques for these alloys relative to their corrosion potential.

OTEC Plume Modeling

- Nested within University of Hawaii Regional Ocean Model (HiROM)
- Forced with Temperature, Salinity, U,V, and Z_{surface}
- Coupled with near-field plume model



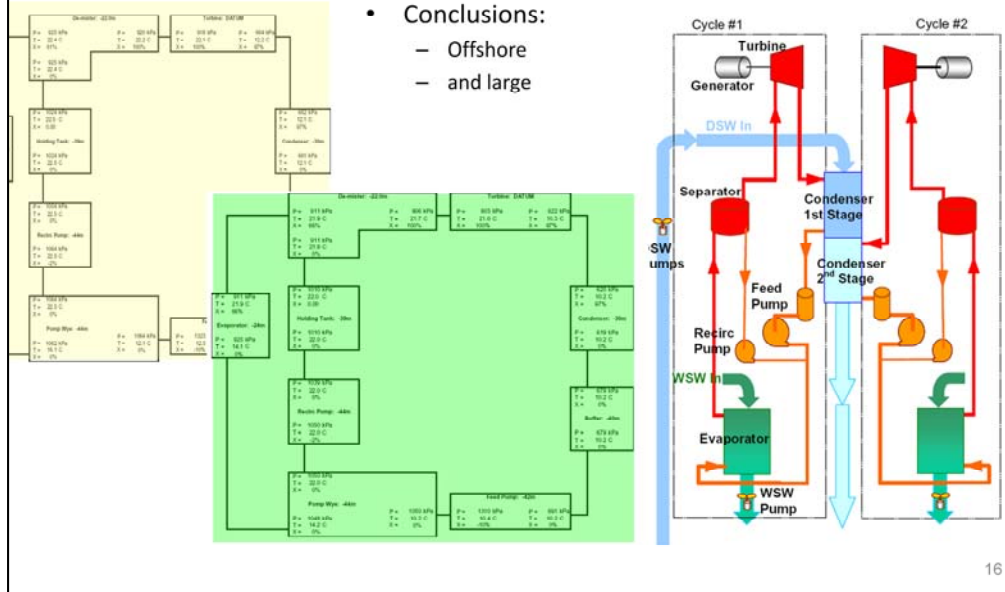
Another major program underway in Hawaii is the development of a hydrodynamic model for accurately studying the intake and effluent flows from one and multiple large OTEC plants. A 100 megawatt OTEC plant would pump as much as 350 cubic meters per second of deep cold seawater and an even greater quantity of warm surface water. This water is discharged into the environment and it is necessary that we do no harm and, in addition, that we do not damage the resource that is providing us OTEC power. The model that we have developed is a complex nested model. The outside model is operated by the US Navy and is a real-time model of oceanographic conditions in the entire Pacific. Within that model is a Hawaii Regional Oceanographic model operated by the University of Hawaii that has a finer grid and is focused about the Hawaiian Islands. Within that model is a model operated by Makai with an even finer grid that is focused about the OTEC plant. And finally, in that model is a plume model focusing specifically on the output jets from the OTEC plants. As a result, we can model the intake and discharge water from one and more OTEC plants under a wide variety of realistic oceanographic conditions.



The results of our plume models so far have been encouraging. We have been able to use the model to select design parameters for the OTEC plant that will minimize impact and not destroy our thermal resource. By mixing the discharge of warm and cold water and by discharging at depth, the discharge plume appears to have minimal environmental impact. This work is continuing to support the environmental studies.

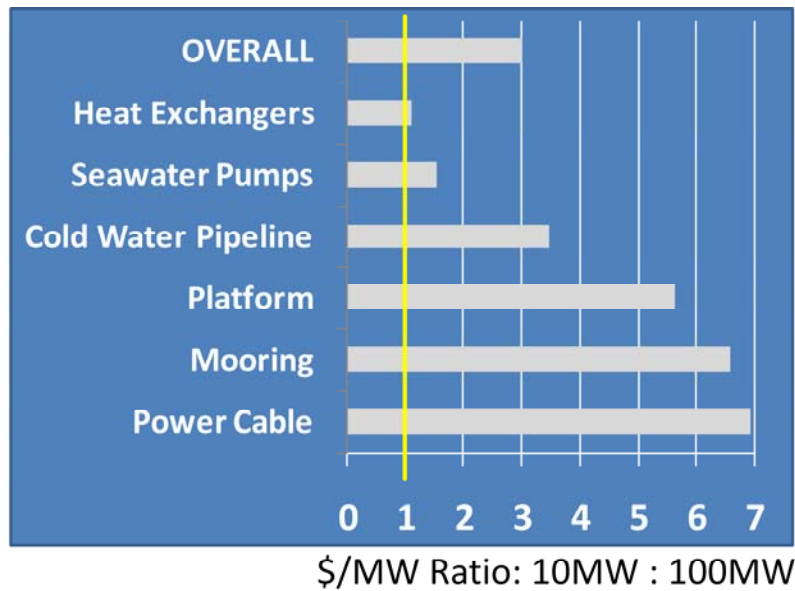
Cost Models

- Used to find lowest cost configurations
- Cost optimization – not efficiency – is critical for OTEC
- Conclusions:
 - Offshore
 - and large



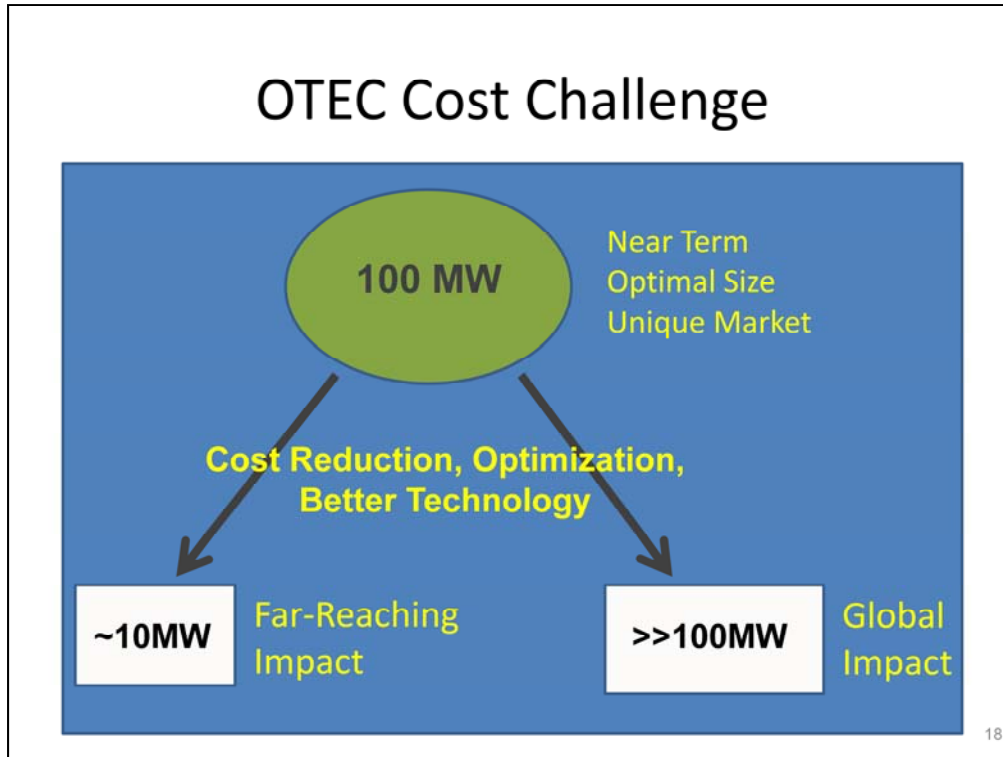
The success of OTEC is dependent upon cost. OTEC needs to produce power at a reasonable and attractive cost in order to be commercially viable. For OTEC, the major cost is the upfront capital cost of building the OTEC plant. A good design process therefore is always optimizing plant cost. Balancing the size of heat exchangers, the size of the cold water pipe, the complexity of the OTEC cycle, the depths of the cold water pipe, and the efficiencies of numerous components all involve the balancing of an entire OTEC system. We have developed models of the whole OTEC system which include not only the engineering relationships but also the system cost such that a design can be driven by capital costs.

OTEC Economy of Scale Challenge



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One economic concept that repeatedly comes out of OTEC studies is the strong economy of scales associated with OTEC. Basically, a smaller OTEC system is expensive per kilowatt but a large OTEC system can be very economical per kilowatt. This graph shows the ratio between the cost per megawatt for a 10 megawatt system compared to the cost per megawatt of a 100 megawatt OTEC system. The yellow line shows an economic scale of 1. The cost of heat exchangers, for example, are about the same per megawatt for a small system as a large system. However other components are not so linear. The cold water pipeline for a small system cost more than three times as much per megawatt as for a large system. Similarly the platform and mooring are very expensive per megawatt for very small systems. Nature does not scale down hurricanes and storms in order to accommodate a small OTEC plant. Overall, a 10 megawatt OTEC plant cost about three times as much per megawatt as does a large one. In order for OTEC to be economically viable, large OTEC plants must be the focus of attention. OTEC plants are large energy systems.



As a result, our team with Lockheed is focusing on a near term 100 megawatt plant for the State of Hawaii. In the long range, OTEC can move to plants that are considerably larger and toward plants that are considerably smaller. I predict that in the future the OTEC plant can be miniaturized through cost reduction and optimization and the economic disadvantage on the previous chart can be partly overcome for small OTEC plants. We see that technology trend over and over from airplanes to watches. For truly massive production of power, plants much larger than 100 megawatts can be used to produce massive quantities of energy that can be exported to other areas of the globe.

In conclusion, I have maintained a strong enthusiasm for OTEC and believe this energy source is unique among all alternatives: it can deliver the total energy levels needed by mankind. Developing OTEC is an economic challenge, however, for it is difficult to do on a small scale.

Thank you

