Ocean Thermal Energy Conversion (OTEC)

P.O. Box 1206
Kailua, Hawaii 96734
Phone: +1 (808) 259-8871
makai@makai.com
www.makai.com

TABLE OF CONTENTS

MAKAI OCEAN ENGINEERING
ISO90011:2008 Certified
P.O. Box 1206
Kailua, Hawaii, USA 96734
PH (808) 259-8871
FX (808) 259-8238
info@makai.com
www.makai.com

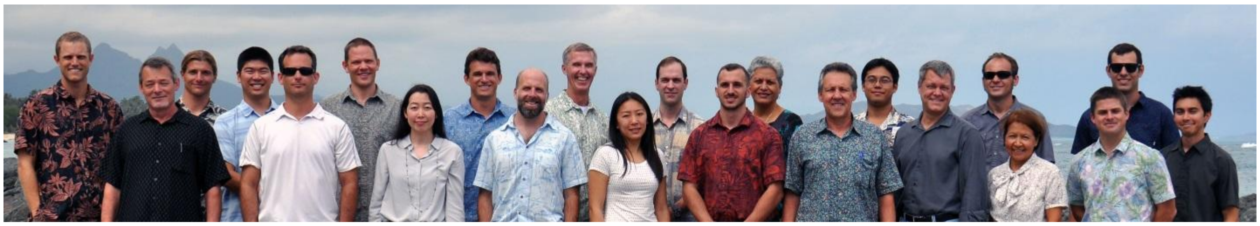
MAKAI OCEAN ENGINEERING
ISO90011:2008 Certified
P.O. Box 1206
Kailua, Hawaii, USA 96734
PH (808) 259-8871
FX (808) 259-8238
info@makai.com
www.makai.com

1. Introduction

Our Company.

Makai has been in business for over 50 years providing a wide array of professional ocean engineering services. We have become a world-recognized leader in several areas of ocean technology. Our clients have referred to us as a “think tank” for ocean-related problems, owing to our reputation for being innovative, fast, and thorough in our designs. We attribute our success to hiring the highest caliber of engineers and scientists who have the rare combination of rigorous training in math, science, and engineering with an entrepreneurial and curious nature.

Makai has been very successful in transitioning government-funded technology research and development into commercial products and services.



Our People.

Makai has developed a unique and powerful culture where creativity, intelligence, hard work, and independence are celebrated. These values are tempered with respect, humility, flexibility, and an open, cooperative demeanor. Our engineers truly love working here and they feel as though they are part of a carefully selected team of only the very best engineers.

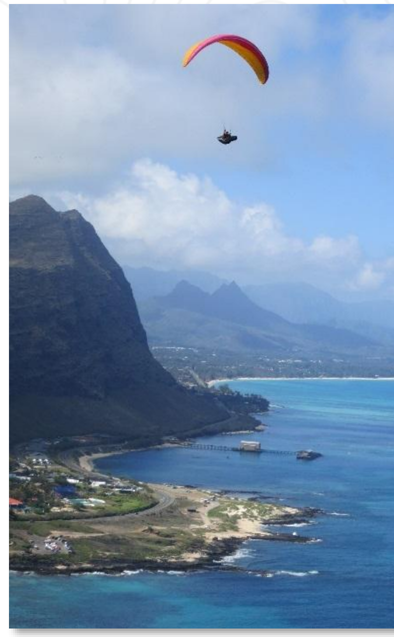
At time of writing, Makai has 48 employees, with 36 engineers who hold advanced degrees and experience in mechanical, civil, ocean engineering, computer science, physical oceanography, physics, and chemistry.

MAKAI OCEAN ENGINEERING
ISO90011:2008 Certified
P.O. Box 1206
Kailua, Hawaii, USA 96734
PH (808) 259-8871
FX (808) 259-8238
info@makai.com
www.makai.com

Our Place.

Two views of the Makai Research Pier on Oahu (above/right).

Makai's offices are located at the Makai Research Pier on the southeast coast of Oahu, Hawaii. The site is 30 minutes from Honolulu provides access to coastal testing areas for our ocean research and development projects.



Makai's corporate headquarters is located on a pier in eastern Oahu that has ideal conditions for testing surface and underwater vehicles. This location has ideal seabed soil conditions for at-sea testing of prototypes (Makai is currently performing tests for the US Navy here and near Pearl Harbor). Makai owns vessels to perform at-sea deployments, repairs, tests, and demonstrations in Hawaiian waters. Makai maintains an onsite workshop that houses welding and metal fabrication tools required for marine device fabrication and repair.

Makai has a satellite office in Kailua-Kona, on the Big Island of Hawaii. This is where Makai owns and operates the world's largest ocean thermal energy conversion (OTEC) demonstration plant in. Also part of this facility are seawater air conditioned (SWAC) facilities, a marine corrosion laboratory, and a marine heat exchanger test facility.

The Makai Ocean Energy Research Center is located in Kona on the "Big Island" of Hawaii.

MAKAI OCEAN ENGINEERING
ISO90011:2008 Certified
P.O. Box 1206
Kailua, Hawaii, USA 96734
PH (808) 259-8871
FX (808) 259-8238
info@makai.com
www.makai.com

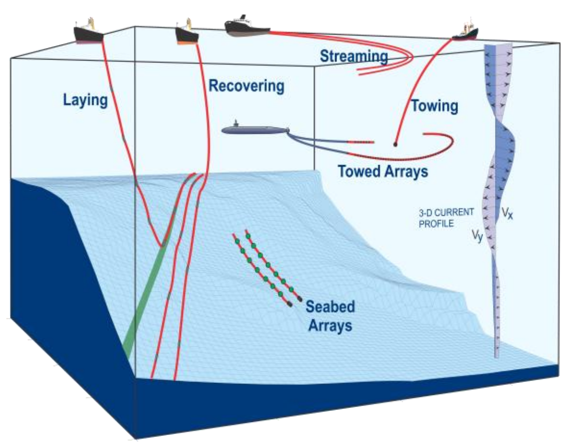
2. OVERVIEW OF TECHNICAL AREAS

Water and Energy Systems: Makai is active in the research, development and commercialization of emerging and innovative technologies at the water-energy nexus. Since 1978, Makai has been developing technology to harness natural resources in two main ways: for cooling and power. These systems include district cooling networks, thermal exchange and energy storage technologies, generating power from waste heat recovery (organic Rankine cycles), environmental modeling of industrial water flows, and more.

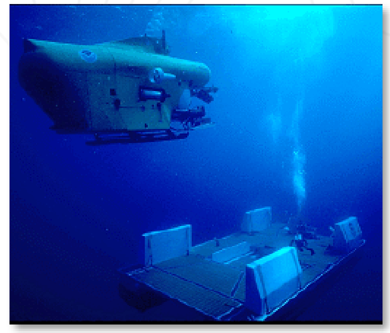
Seawater Air Conditioning (SWAC) and Deep Pipelines: Makai has been designing and working with deep water pipelines since 1979, and to date has designed more deep seawater intake systems than any other known engineering firm in the world. SWAC is a renewable energy technology that can save up to 90% of the electricity used for cooling in buildings. Makai's deep water pipeline designs have been proven to stand the test of time even in extreme ocean conditions.

Ocean Thermal Energy Conversion (OTEC): Makai has been heavily involved in OTEC research since the 1970s. We designed and oversaw construction of the cold water pipe for Mini-OTEC: the world's first ever net-power producing OTEC plant offshore Kona, Hawaii in 1978. Since that time, Makai has been involved in over 20 R&D contracts related to OTEC, including the design and construction of the world's largest grid-connected OTEC demonstration plant (pictured) from 2010 to present. A spinoff technology from this work is a heat exchanger that has non-OTEC applications. Makai is poised to take advantage of the growing interest in OTEC power.

Submarine Cables: Makai has been involved with ocean cable installation since 1983. Makai has grown into the world leader in submarine cable installation and planning software for over a decade, supplying software to over 80% of the world's deep water cable laying ships. Makai's software suite includes tools to plan, simulate and install cables and arrays on the seafloor, and has been used to successfully install over 400,000 kilometers of cable. We provide training classes to cable installers either abroad or at the pier and occasionally assist with cable lays at sea.



MAKAI OCEAN ENGINEERING
ISO90011:2008 Certified
P.O. Box 1206
Kailua, Hawaii, USA 96734
PH (808) 259-8871
FX (808) 259-8238
info@makai.com
www.makai.com



Ocean Engineering, R & D: Makai has performed custom research and development for a wide range of clients, including the largest defense contractors in the world and the US Navy. Makai's areas of expertise are: physical numerical modeling software, marine structures and vehicles, submarine cable planning services, marine heat exchangers, aquaculture, buoy and mooring designs, and corrosion research. Since 2010, the largest project that is rapidly becoming its own division is Makai's autonomous underwater vehicle project.

Makai is a leader in the research, development and commercialization of emerging and innovative technologies at the water-energy nexus. Since 1978, Makai has been developing technology to harness the energy of deep and shallow ocean and lake water in two main ways:

1) Cooling: Using a natural water reservoir of ocean, river or lake water for cooling.
2) Power: Using the ocean thermal gradient or waste heat sources to generate power using organic rankine cycles (ORCs).

In the process of developing systems that apply these two concepts, Makai has developed a variety of technologies and services, including:

- Seawater air conditioning (SWAC) system designs
- Ocean Thermal Energy Conversion (OTEC) system designs
- Organic rankine cycle (ORC) designs
- Hydraulic and thermal system modeling (engineering and economic)
- Marine heat exchangers design and testing
- Marine corrosion testing
- Hydrodynamic modeling of outfalls (physical/chemical/biological)

MAKAI OCEAN ENGINEERING
ISO90011:2008 Certified
P.O. Box 1206
Kailua, Hawaii, USA 96734
PH (808) 259-8871
FX (808) 259-8238
info@makai.com
www.makai.com

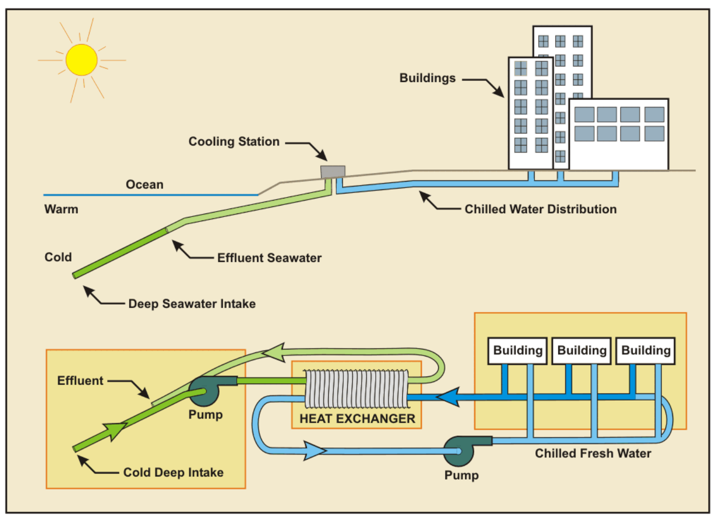
3. SEAWATER AIR CONDITIONING & DISTRICT COOLING

3.1. SEAWATER COOLING AND AIR CONDITIONING SERVICES

Seawater Air Conditioning (SWAC) is an alternate-energy system that uses the cold water from the deep ocean or a lake to cool commercial buildings, such as hotels, airports, or industrial facilities. It is an alternate energy for cooling and air conditioning. In some areas it is possible to reduce the power consumed by air conditioning (AC) systems up to 90%. SWAC systems are environmentally-friendly, predictable and sustainable, and can be a cost-effective and attractive investment.

Makai has participated in the design of more operational SWAC systems than any other firm. Many of the pipeline projects listed in this brochure were used to supply seawater for SWAC systems. Makai's SWAC services include: SWAC system modeling and feasibility studies, and conceptual to final design services for offshore pipes (intake and return water), pipeline shore crossings, water pumping/heat exchanger stations, and the onshore chilled water distribution system. More information on SWAC is available in a separate brochure.

3.2. METHOD™ MODEL FOR DISTRICT COOLING



For over 25 years, Makai has continuously developed custom software for modeling the hydraulic and thermal aspects of fluid networks. These software have been used to model, analyze, and design district cooling networks. The model is particularly useful for evaluating the economic viability of proposed district cooling projects.

The model, called the Makai Economic, Thermal, and Hydraulic Optimization and Design software, or METHOD™ software, takes into account the major capital and operational costs for both systems and the complex interplay between the sub-system designs and operational costs. This enables an "apples-to-apples" economic comparison of district cooling versus an equivalent conventional A/C system. Other financial metrics, such as payback period and rate of return of the district cooling system, are computed. The METHOD™ software consists of two components: an engineering and an economic model. It considers the primary engineering and economic parameters associated with a particular district

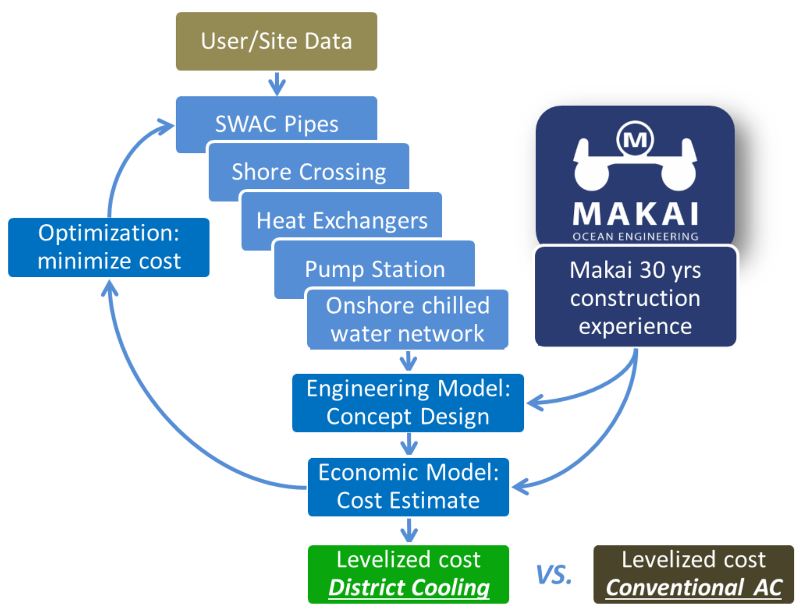
MAKAI OCEAN ENGINEERING
ISO90011:2008 Certified
P.O. Box 1206
Kailua, Hawaii, USA 96734
PH (808) 259-8871
FX (808) 259-8238
info@makai.com
www.makai.com

cooling site, produces a conceptual design, and provides a fair comparison of the cost of cooling provided by district cooling versus conventional air conditioning.

Engineering model. Starting from a few client-provided inputs, this software determines a very basic conceptual design for a district cooling system that may include discharge and intake pipelines (if using a SWAC system), a pump and heat exchanger station, and a cold-water distribution network. The software defines parameters (e.g. sizes, lengths, flow rates, temperatures, power requirements, etc.) for each point in the district cooling system, accounting for friction losses, heat gains, and equipment efficiencies.

The METHOD™ model was used to design a SWAC district cooling system in Mauritius. Once a layout is defined by the user, the major system components (deep seawater pipes, chilled freshwater network, etc.) and operations (pumping power, maintenance, etc.) are then optimized for a minimum cost of cooling.

Economic model. Once a conceptual engineering design is complete, Makai uses the software to compute a cost for the design, construction, operation and maintenance of the district cooling system. The cost estimate allows a fair economic comparison between district cooling and conventional air conditioning, using a levelized cost analysis. Usually a district cooling system must look significantly better than a conventional AC system solution before Makai will recommend it.



Makai's economic model is based on an analytical procedure developed by the Electric Power Research Institute (EPRI) in their Technical Assessment Guide

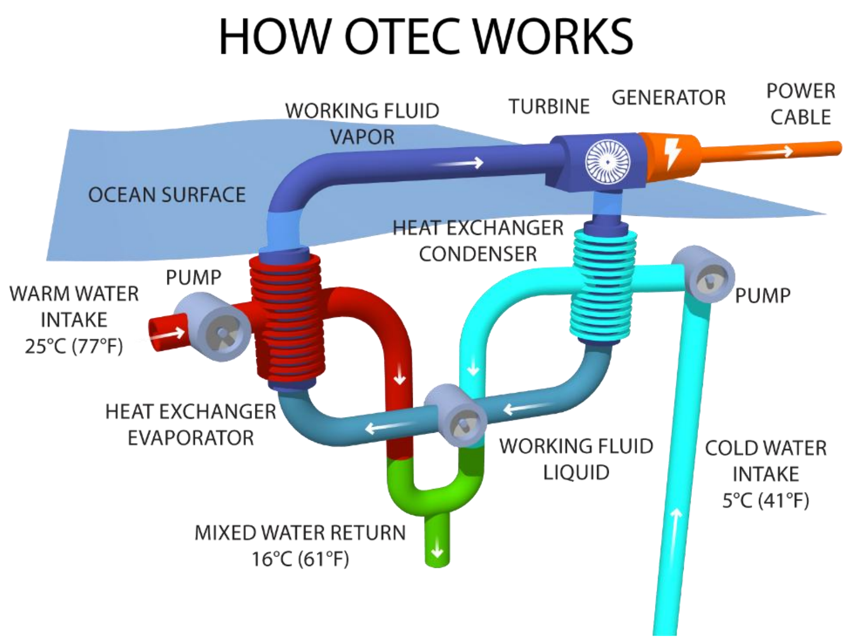
MAKAI OCEAN ENGINEERING
ISO90011:2008 Certified
P.O. Box 1206
Kailua, Hawaii, USA 96734
PH (808) 259-8871
FX (808) 259-8238
info@makai.com
www.makai.com

[TAG]. The TAG model is an economic analysis method of comparing two alternate energy systems with different capital and operating costs.

MAKAI OCEAN ENGINEERING
ISO90011:2008 Certified
P.O. Box 1206
Kailua, Hawaii, USA 96734
PH (808) 259-8871
FX (808) 259-8238
info@makai.com
www.makai.com

4. Ocean Thermal Energy Conversion

4.1. OTEC HISTORY AND EXPERIENCE



Ocean Thermal Energy Conversion (OTEC) is a process that can produce electricity by using the temperature difference between deep cold ocean water and warm tropical surface waters. OTEC plants pump large quantities of deep cold seawater and surface seawater to run a power cycle and produce electricity. OTEC is firm power (24/7), a clean energy source, environmentally sustainable and capable of providing massive levels of energy.

Recently, higher and more volatile energy costs, increased concerns for global warming, and a political commitment to energy security have made initial OTEC commercialization economically attractive in tropical island communities where a high percentage of electricity production is oil based. Even within the US, this island market is very large; globally it is many times larger.

Makai has been heavily and continuously involved in the study and design of Ocean Thermal Energy Conversion (OTEC) systems since 1978 when Makai was involved in the design of components for an offshore OTEC demonstration plant known as Mini-OTEC. Mini-OTEC successfully produced 'net power' using only warm and cold seawater as its input for the first time in history.

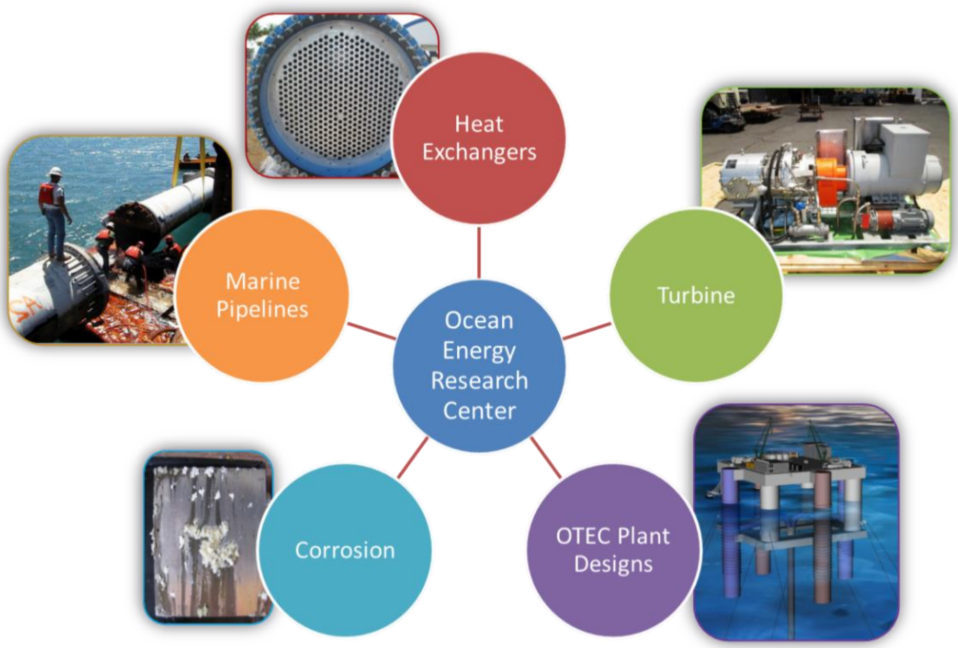
Since that time, Makai has worked on nearly two dozen unique studies and projects involving OTEC, including designs for systems sized at 50kW, 100kW, 1MW, 7MW, 10MW, and 100MW. A sampling of some of these projects are listed in the table below. In another section below, some of these earlier OTEC projects are described in more detail.

The most prominent, recent example of a Makai OTEC project is the land-based OTEC demonstration plant, called the Ocean Energy Research Center, described below. This is currently the world's largest operational OTEC power plant, and is the first and only closed-cycle OTEC system to be connected to a U.S. grid.

4.2. MAKAI'S OCEAN ENERGY RESEARCH CENTER

Ocean Thermal Energy Conversion (OTEC) can produce electricity using the temperature difference between the ocean's deep cold water and warm tropical surface waters. OTEC plants pump large quantities of deep cold seawater and surface seawater to run an Organic Rankine Cycle (ORC) to produce electricity. OTEC produces firm power (24/7), is clean, environmentally sustainable, and can provide enormous quantities of energy.

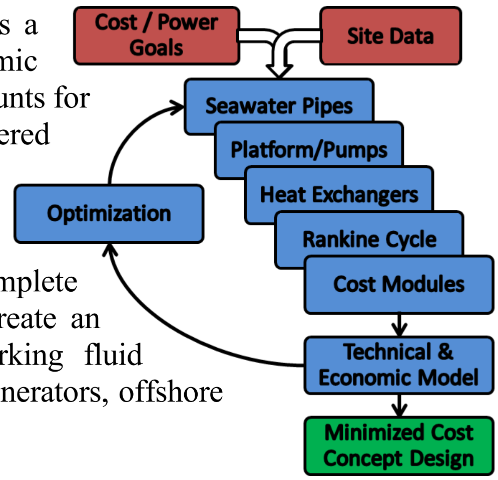
Makai has been heavily involved in OTEC research and development since the 1970s, and especially since 2006. The flagship project is the **Ocean Energy Research Center (OERC)** (pictured at right) that houses the world's largest operational OTEC plant. In 2015, Makai connected closed-cycle OTEC power to the U.S. grid for the first time. This facility is used for the research and development of **heat exchangers**, the **turbine-generator** and system controls, **corrosion** resistant materials and bonding methods, and **marine pipelines**. The developments resulting from each of these areas are ultimately fed into more cost-effective and technically advanced **OTEC power plant designs**. More details for each of these research and development areas are listed below. Makai works closely with most of the active international OTEC groups to provide third party technology R&D, testing and validation services.



MAKAI OCEAN ENGINEERING
ISO90011:2008 Certified
P.O. Box 1206
Kailua, Hawaii, USA 96734
PH (808) 259-8871
FX (808) 259-8238
info@makai.com
www.makai.com

4.3. MOTEM™: MAKAI'S OTEC THERMODYNAMIC & ECONOMIC MODEL

In 2007, Makai developed an OTEC optimization program called MOTEM™ (Makai OTEC Thermodynamic and Economic Model). The primary purpose of MOTEM™ is to assess the feasibility of both land-based and offshore OTEC systems on a levelized cost of energy (LCOE) basis. The difference between Makai's model and others is that it has been used to design an actual operational OTEC plant, with real cost, performance, and power output data to validate its results.



Engineering Modules. The core of MOTEM™ is a Rankine cycle simulator that calculates the thermodynamic state of each point in the OTEC system. The simulator accounts for heat transfer, hydraulics, and mechanical inefficiencies. Layered on top of this core simulator are modules for heat exchanger performance, seawater hydraulics and heat transfer, parasitic power loads, and offshore hull size or onshore plant footprint. These modules combine to create a complete OTEC system simulator. Engineers use MOTEM™ to create an OTEC plant design that includes: all seawater & working fluid properties, seawater pipe sizes, heat exchangers, turbine-generators, offshore hull/onshore plant size, and gross/net power.

Cost Module. MOTEM™'s cost module uses parameterized cost algorithms to estimate the cost of all major OTEC components. The parameterized costs are based on Makai's 35+ years' experience in design and construction of OTEC systems. The cost module determines the lowest cost OTEC configuration for any given site by optimizing all major engineering parameters (seawater pipe sizes/flows, platform & pump sizes evaporator/condenser pressures, etc.) to arrive at the configuration that minimizes total plant levelized cost of energy. This software allows for rapid evaluation of multiple configurations to find the optimum. MOTEM™ has been used for cost estimation and sensitivity studies requiring dozens of simulations.

MOTEM™ has been developed and used during several onshore and offshore OTEC plant designs since inception in 2007. During each project, Makai engineers enhance the model by improving optimization and heat exchanger modeling, and updating costs. Projects include:

- 100 MW and 10 MW conceptual OTEC designs (2008-2009),
- Evaluation of OTEC and SWAC at U.S. government facilities on Guam (2009),
- Evaluation of Taiwan onshore and offshore OTEC (2009-2010),
- U.S. Navy OTEC plant designs and evaluation of global opportunities (2010-2012),
- Makai's 105 kilowatt OTEC plant design, construction and operation (2009-present),
- 1 megawatt onshore OTEC plant conceptual design (2015).

MAKAI OCEAN ENGINEERING
ISO90011:2008 Certified
P.O. Box 1206
Kailua, Hawaii, USA 96734
PH (808) 259-8871
FX (808) 259-8238
info@makai.com
www.makai.com

4.4. OTEC TURBINE-GENERATOR

Makai has experience designing, installing, and operating OTEC turbine-generators. Makai's system consists of a 105 kilowatt generator coupled to a custom turbine that was recently installed on Makai's Ocean Energy Research Tower in Kona, Hawaii. Makai's vision is that this enhanced system will serve as the world's premier OTEC testing and training center.

The Governor of Hawaii, David Ige, and his wife Dawn, discuss OTEC with Makai engineer Mike Eldred on the top level of the Makai OTEC plant. The turbine-generator is visible in the foreground.

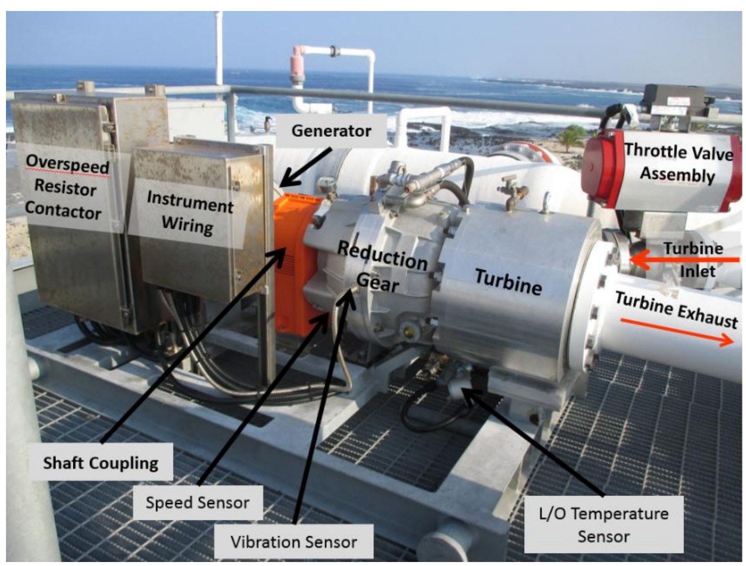
The OTEC system uses the heat of warm seawater to boil pressurized anhydrous ammonia. The pressurized ammonia spins a 12,500-rpm turbine to generate standard 60 Hz, 480 volt power. After driving the turbine, the low pressure ammonia vapor is condensed by deep cold seawater and then continuously re-used in a closed-cycle process.

In the summer of 2015, Makai commissioned the turbine-generator in electrical stand-alone mode, and adapted the control system so the generator can safely export power onto Hawaii's electrical power grid.

After commissioning and grid-connection, Makai is creating variable seawater flows to simulate variations of a floating OTEC plant to quantify how well the turbine-control system can maintain steady electrical power despite the unsteady flows. The system has been designed for longevity so it can serve as a long-term testbed for OTEC implementation and training.

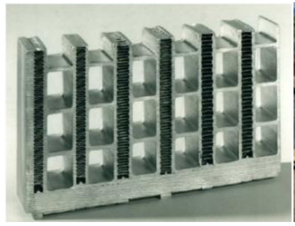
Makai's services for turbine-generators that serve OTEC and organic rankine cycle (ORC) systems include the following:

- Turbine-generator specifications & design,
- Connecting/synchronizing with the electrical grid,
- Development of autonomous controls,
- Performance testing, and
- Operation and maintenance.



MAKAI OCEAN ENGINEERING
ISO90011:2008 Certified
P.O. Box 1206
Kailua, Hawaii, USA 96734
PH (808) 259-8871
FX (808) 259-8238
info@makai.com
www.makai.com

4.5. HEAT EXCHANGER SERVICES



Makai has heavily invested in the research, design, testing, and manufacture of marine-grade heat exchangers (HXs). Makai provides HX design and testing services for government and commercial clients.

These marine-grade HXs have applications in the power generation, petrochemical, industrial cooling, heating/ventilating/air-conditioning/refrigeration (HVAC-R), desalination, and waste water treatment industries.

Makai's services include the design of marine-grade HXs. These HX designs are engineered to be high-performance, low-cost, compact, and corrosion-resistant, and serve a wide variety of marine applications.

Makai provides services to test the performance and lifetime of HXs using seawater and various other working fluids. During a typical test, Makai collects data on temperatures, working fluid flow rates and quality, and pressure drops in order to calculate a HX's performance. The primary output from Performance Testing is the HX's heat transfer coefficient (U) and the pressure drop (dP) for a range of working fluid flow rates. This information can be used to calculate the heat exchanger area required for a commercial application.

4.5.1. THIN FOIL HEAT EXCHANGER

Makai Ocean Engineering provides custom, high-performance heat exchanger designs and fabrication. Makai has developed a fundamentally new heat exchanger design that we call the Thin Foil Heat Exchanger (TFHX); it is constructed using novel advanced manufacturing methods.

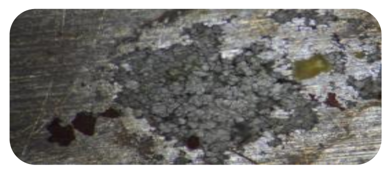
The TFHX can be designed for liquid, air-cooled, vapor-cycle, phase change, or Supercritical CO2 applications. The technology is the result of over 10 years and over $20 million of R&D. Contact us with your need– and let us provide you with a better thermal management solution.

4.5.2. Heat Exchanger Projects

Makai is heavily involved in the design of large marine-grade HXs for ocean thermal energy conversion (OTEC) plants. Since HXs will be the single most expensive component in a commercial OTEC plant, the HXs' **cost**, **lifetime**, and **performance** heavily influence a plant's economic success. The ultimate goal of Makai's ocean thermal HX project is to reduce the cost, extend the lifetime, and improve the performance of HXs for our clients.

Makai has designed two separate systems for heat exchanger testing: one for full-scale testing (up to 4 MW in thermal duty), and one for smaller scale prototypes (up to 100 kW thermal duty). The full-scale system (pictured at right) is the primary testing apparatus, but the small-scale system enables rapid prototyping and design.

4.6. MARINE CORROSION LAB AND SERVICES



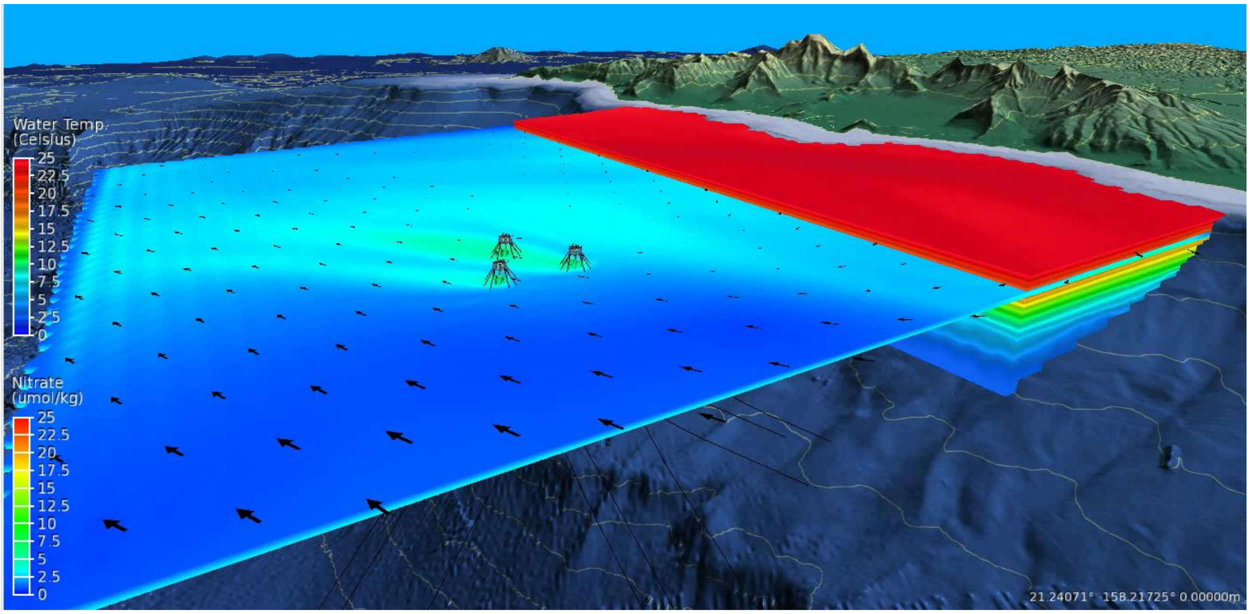
Makai owns and operates a marine corrosion facility for the research and development of corrosion resistant alloys, coatings, and manufacturing techniques. Since 2009, Makai has performed corrosion-related engineering services at this multi-million dollar state-of-the-art facility for a range of commercial and government clients.

The Facilities. Located in Kona, on the Island of Hawaii, this unique facility is ideally suited for marine-related materials evaluation due to its pollution-free, non-estuarine environment, stable tropical climate throughout the year. Deep and surface seawater is pumped to the facility from some of the world's largest and deepest seawater intake pipelines, providing direct access to the corrosive environment experienced by equipment exposed to essentially any type of seawater.

The Research. We provide unique laboratory services in materials testing for the U.S. Navy and industrial clients. Makai provides two types of support: providing research services as the principal investigator; or supporting client-led experiments at our lab. Our RDT&E support includes: material exposure testing, biofouling mitigation, antifouling coatings, marine coating development, marine alloy evaluation and certification, heat exchanger design and performance testing, and materials characterization (cost-savings and life-cycle management).

MAKAI OCEAN ENGINEERING
ISO90011:2008 Certified
P.O. Box 1206
Kailua, Hawaii, USA 96734
PH (808) 259-8871
FX (808) 259-8238
info@makai.com
www.makai.com

4.7. ENVIRONMENTAL MODELING SOFTWARE



Makai has developed custom software to simulate and analyze the physical, chemical, and biological impacts of outfalls or other discharges into marine environments. This model can simulate an outfall plume that is released into a lake, estuary, or ocean environment, and predict changes to water chemistry or nutrient content, temperature, and even potential biological effects.

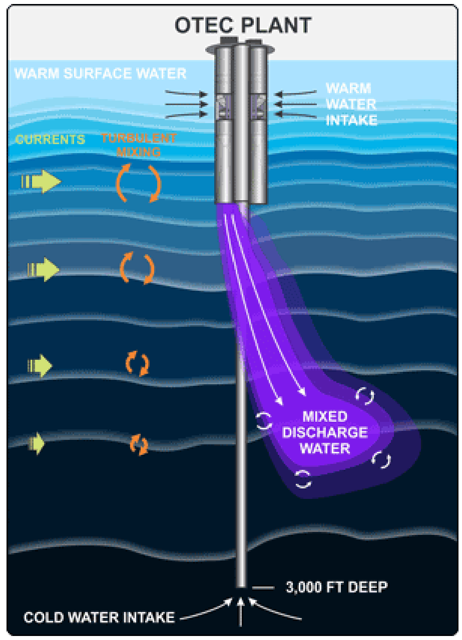
The 3D-hydrodynamic numerical model is based on the EPA-approved Environmental Fluid Dynamics Code (EFDC). Makai customized the software to include flow and density fields provided by the University of Hawaii's Regional Ocean Modeling System (ROMS). The outfall "sources" are inserted into the domain using a jet-plume model, which simulates the entrainment and turbulent mixing of plumes. The successful development of the model provides the tools needed to predict the impact of an outfall in the presence of realistic and time-varying ocean conditions.

This tool is particularly useful for developers seeking to understand the impacts of discharging wastewater, brine, or any other fluid that is of a different temperature, chemistry, or density into the environment. Makai's services include performing the hydro-dynamic modeling, assisting with environmental assessments or impact statements, providing analysis reports, demonstration videos, and presentations.

Visual media are powerful tools for informing regulators and the general public on any potential impacts of a project, such as the video shown here: **http://youtu.be/1hmAOVCvgc0**

MAKAI OCEAN ENGINEERING
ISO90011:2008 Certified
P.O. Box 1206
Kailua, Hawaii, USA 96734
PH (808) 259-8871
FX (808) 259-8238
info@makai.com
www.makai.com

4.7.1. Project #1: OTEC Hydrodynamic Plume Model



Makai has developed a numerical hydrodynamic model to assess the physical impacts of OTEC discharges in the ocean environment with funding from the National Defense Center of Excellence for Research in Ocean Sciences. Considering that no OTEC plants have been constructed, it is uncertain how the nearby ocean environment will be affected by the discharge of the nutrient rich deep ocean water. The project's goal was to create a toolset to use for sustainable design of OTEC plants, which for a 100MW plant would require about 720 m3/s of cold nutrient rich seawater and 420 m3/s of warm surface waters.

The 3D-hydrodynamic model is based on the EPA-approved Environmental Fluid Dynamics Code (EFDC), and is customized to accurately generate the regional flow fields and density fields supplied by University of Hawaii's data assimilative Regional Ocean Modeling System (ROMS). OTEC plants were "inserted" into the domain using a dynamically coupled finite-element jet-plume model, which simulates the entrainment and turbulent mixing of large scale plumes. The successful development of the model provides the tools needed to predict the impact of OTEC plants in the presence of realistic and time-varying ocean conditions.

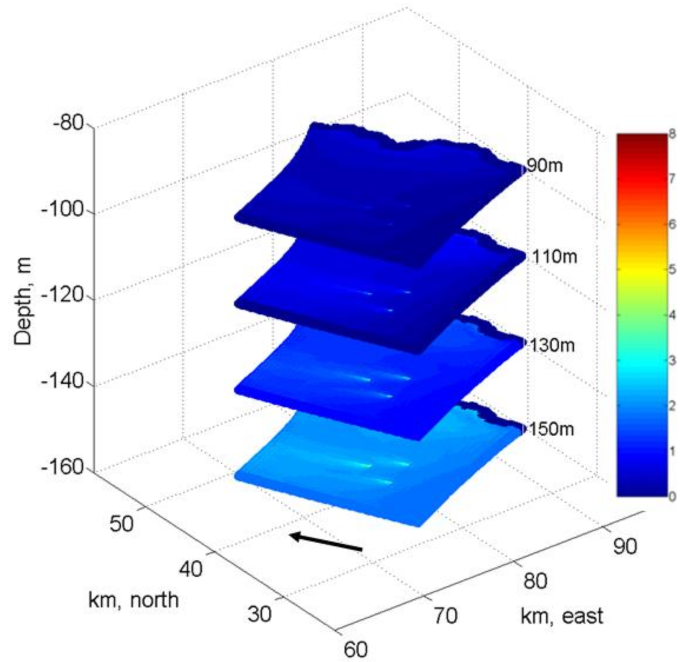
Results of the effort were presented at NOAA's OTEC Environmental workshop in June, 2010, and the Department of Energy has funded an extension of the project (under the Marine Hydrokinetics Initiative) to develop a biological component of the model in order to assess any bio-stimulation that may occur due to the nutrient rich discharges.

This model can be adapted to any other potential OTEC site in the world, in order to model and predict the potential impact of the OTEC discharge water on the surrounding environment.

Download the 2011 Water Power Technologies Peer Review Report

MAKAI OCEAN ENGINEERING
ISO90011:2008 Certified
P.O. Box 1206
Kailua, Hawaii, USA 96734
PH (808) 259-8871
FX (808) 259-8238
info@makai.com
www.makai.com

4.7.2. Project #2: OTEC Biological Plume Model



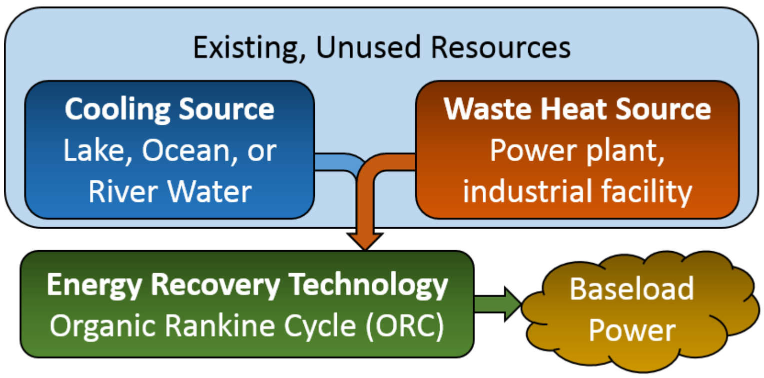
Ocean Thermal Energy Conversion (OTEC) uses large flows of warm surface seawater and cold deep seawater to generate clean electricity. The tropical ocean at a typical OTEC site has two distinct layers: a warm surface layer with low nutrient levels, and a cold deep layer that is nutrient-rich. Introducing deep nutrients into the ocean's sun-lit upper layers could potentially increase plankton growth or cause algal blooms. Thus, seawater discharged from an OTEC plant should be returned into the ocean deep enough so that these nutrients don't trigger biological growth.

The U.S. Department of Energy has released the final report from a study by Makai Ocean Engineering on the simulated biological impact from operating large OTEC plants that can be downloaded at http://www.osti.gov/scitech/biblio/1055480. This report has been peer reviewed by DoE Peer Review for Marine & Hydrokinetic Energy Devices on pages xii and 167 here. A video of the modeling can be viewed here: http://youtu.be/1hmAOVCvgc0

This new software is the most sophisticated tool available for modeling OTEC's environmental effects. When run with an OTEC plant, the model can determine the size, depth, and flows of the OTEC plant's seawater discharges that would minimize plankton increases. In all cases modeled in Hawaiian waters, no increase in plankton levels occurred in the upper 40 meters (130 ft) of the ocean. From 40 to 120 meters (130 – 400 ft) OTEC-induced plankton growth is low and well within the naturally occurring variability. These results suggest that suitably designed large OTEC plants will cause no significant increase in biological growth. This model will be an important tool for developers and regulators for defining rules and educating the public as commercial OTEC develops.

4.8. ORGANIC RANKINE CYCLES USING WASTE HEAT

Organic Rankine cycles are a technology that is closely related to OTEC. Instead of seawater, ORC systems typically use waste heat (from the exhaust of a power plant or other industrial process) and a cooling source (typically the air, but liquids can be used as well) to generate electricity. Makai has developed systems that could dramatically increase the performance of even commercial-off-the-shelf ORC systems, by using cold water from lakes or oceans as the cooling source / heat sink. Makai is currently engaged in a study for the U.S. Navy to evaluate the cost-effectiveness of ORCs as a source of baseload alternative energy at a variety of Navy facilities.



Organic Rankine cycles can produce stable, alternative energy using resources that already exist, or would be wasted byproducts of proposed other systems.

4.9. OTHER OTEC PROJECTS

In addition to the above, Makai has worked on a number of other OTEC projects over the years. These are listed below in chronological order from the first Mini-OTEC project in 1978. Some projects have been left out due to maintain confidentiality.

- Mini-OTEC. Makai engineered several portions of the Mini OTEC project under contract to Dillingham Corp. This project was a full demonstration of Ocean Thermal Energy Conversion (OTEC) and jointly funded by the State of Hawaii, Lockheed, Dillingham and Alfa Laval. Makai designed a 2' (610mm) diameter polyethylene pipe that served not only as an intake pipe from a 2000' (610m) depth, but also as the "mooring line" for the 120' x 35' (37m x 11m) barge. The initial design for the barge layout, seawater intakes (cold and warm), effluent lines, and pumps was also done by Makai. Makai developed and planned the deployment scheme and participated in the at sea deployment. On August 2, l979, Mini OTEC developed 50 kW of power and consumed 40 kW, for a net positive output of l0 kW. This was the first time that a positive output had been achieved from any OTEC facility.
- 12” Deep/Shallow Seawater Pipes. In conjunction with the design and construction of the 12-inch deep seawater and surface seawater intake pipelines in the early 1980’s, Makai was responsible for the design of the lab’s seawater distribution system which was fed by two head tanks originally located in the southwest corner of the fenced lab compound.

- 40″ Intake Pipeline Design and Installation. In 1987, under a contract with R.M. Towill Corporation, funded by the State of Hawaii and the U.S. Department of Energy, Makai designed a 40″ polyethylene cold water pipe to be used jointly by NELH and the Hawaii Ocean Science and Technology (HOST) Park sites on the Big Island. At the time of construction, it was the largest deep-waterintake pipeline in the world. This pipe is a larger and more rugged version of the previous MOE 12″ pipe design at NELHA and includes a 3000′ long buoyant section. Makai assisted in the deployment of this pipe to a depth of 2200′ in August 1987. It is currently a main source of water at NELHA and supplies all of the water for Makai’s currently operating 105 kW closed-cycle OTEC power plant.

MAKAI OCEAN ENGINEERING
ISO90011:2008 Certified
P.O. Box 1206
Kailua, Hawaii, USA 96734
PH (808) 259-8871
FX (808) 259-8238
info@makai.com
www.makai.com

- Onshore Seawater Supply System Modeling. In the early 90's as the NELHA tenant base expanded, Makai was responsible for the original hydraulic modeling of the entire onshore seawater network; this work led to the abandonment of the head tank system, and the establishment of the pressurized seawater distribution network in use today.

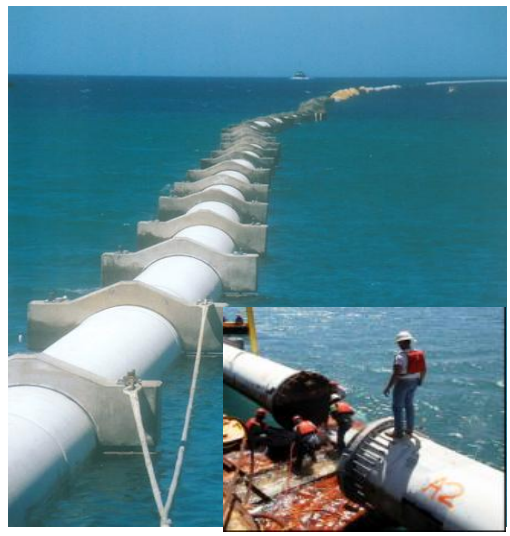
- 55" Deep/Shallow Seawater Pump Station. In 1994, in conjunction with the design of the 55-inch surface seawater and deep seawater intake pipelines, Makai designed the unique 55-inch vertical pump station on the south edge of the HOST park property. This pump station was originally designed to serve an OTEC power plant, but was later modified to serve the needs of upslope tenant seawater demands.

- 50 kW ALCAN Heat Exchanger system tests and 1 MW OTEC plant design. During 1994-1999, Makai designed, constructed and operated an OTEC closed-cycle ammonia heat exchanger test facility at NELHA. The system was developed to test potentially low-cost aluminum heat exchangers manufactured by AlGoods, at the time a subsidiary to AlCan, a large aluminum supplier. The test system used approximately 3000 gpm of warm and cold deep seawater, and was fully instrumented. Makai designed the system to meet standard refrigeration piping requirements as per ASTM B31.5 and supervised construction of the system. We specified all components, instruments and designed and installed the data collection and control system. We modeled the system performance with a computer model and operated the system during 1996. During 1998, AlGoods delivered improved heat exchangers, and Makai expanded and improved the ammonia system. Excellent high quality, repeatable data was collected and analyzed to fully characterize the heat exchanger performance. This data was then used to design a 1 MW OTEC plant at NELHA, and to develop a cost estimate.

- Interim surface seawater pump station. While waiting for construction of the 55-inch pump station, in 1998, Makai designed the interim surface seawater pump station to provide surface seawater to upslope NELHA clients. This design included the installation of the 12-inch surface pipelines that run exposed upslope along the south side of the access road.

MAKAI OCEAN ENGINEERING
ISO90011:2008 Certified
P.O. Box 1206
Kailua, Hawaii, USA 96734
PH (808) 259-8871
FX (808) 259-8238
info@makai.com
www.makai.com

- Seawater Supply System Design Tasks. In 1999, Makai was hired to design the refurbishment of the 18-inch offshore deep seawater pump station, the expansion of the 24-inch surface seawater pump station, pump selection and staging for the expansion of the Kau deep seawater booster pump station and to conduct a study of the installation of dry motor pumps in the 40/28-inch HOST Park pump station.



- 55-Inch Deep Seawater Intake Pipes. Makai engineered and oversaw the installation of the main seawater supply source for the Hawaii Ocean Science Technology Park (HOST Park) at Keahole Point, Hawaii. This supply system consists of a cold-water pipeline that is 55” (1.4m) diameter, 3000’ (915m) deep, and 2 miles (3 km) long, a 55” (1.4m) diameter warm water intake pipe, a tunneled shoreline crossing and a shore-based pumping station. The system provides a max of 27,000 gpm (1.7 m3/s) of 4-degree Celsius water and over 40,000 gpm (2.5m3/s) of warm water to the technology park. Two micro-tunnels extend from shore to a breakout point offshore at approximately 85’ (26m) depth. To our knowledge, this remains the largest and deepest seawater intake in the world, and it earned a major national award from the American Society of Civil Engineers.

- Seawater Distribution System Design. Following the installation of the 55-inch intake pipelines, Makai completed the design of the seawater distribution system up from the 55-inch pump station, the pump selection and installation design and through our subcontractors, the design of the pump station electrical building and the electrical service and controls.

- Navy Deep Ocean Water Applications Computer Modeling. In addition to OTEC, Makai has designed numerous deep sea pipelines that have been installed to provide highly efficient air conditioning for buildings and utilities. As part of these services, we have developed an engineering and cost computer model of cold water pipe costs and air conditioning savings. In 2003, NavFAC contracted Makai to expand our feasibility model to also include the costs and revenue for OTEC, potable water, and other deep ocean water co-products. The model was completed and used for an illustrative purpose for Diego Garcia. Our computer modeling showed that a small OTEC plant, with potable water production and seawater air conditioning was an economic improvement over conventional technologies. This computer model was eventually developed into what we now call MOTEM: Makai’s OTEC Thermodynamic and Economic Model.

MAKAI OCEAN ENGINEERING
ISO90011:2008 Certified
P.O. Box 1206
Kailua, Hawaii, USA 96734
PH (808) 259-8871
FX (808) 259-8238
info@makai.com
www.makai.com

- Lockheed Martin Internal R&D for OTEC. From 2008 through 2015, Makai has worked with Lockheed Martin for U.S. Navy and private clients, who was conducting a multi-million dollar and multi-disciplinary risk-reduction study for key OTEC components. Efforts were focused on design for cold water pipes, heat exchangers, the hull components and mooring. Heat exchanger performance and corrosion testing work was carried out at Makai's Ocean Energy Research Center at NELHA.
- Guam OTEC feasibility Study. In 2009, Makai Ocean Engineering was contracted by the U.S. Naval Facilities Engineering Services Command to evaluate the technical feasibility of both onshore and offshore OTEC plants to meet the growing needs of the Department of Defense (DOD) on Guam. Makai considered an integrated deep ocean water solution to provide three products: electricity from OTEC, fresh water from reverse osmosis or multi-stage flash evaporation, and cooling from seawater air conditioning. Makai used the Makai OTEC Thermodynamic and Economic Optimization Model (MOTEM) to carry out the OTEC analysis. MOTEM rapidly creates a conceptual power plant design and calculates the most cost-effective OTEC configuration for any given site conditions, which allowed Makai engineers to consider two different onshore power plant locations in addition to a floating offshore plant. The most technically feasible option was the offshore floating OTEC plant with an onshore reverse osmosis facility to provide fresh water. Makai completed a conceptual design of an OTEC plant that produced 100 MW net power for DOD facilities.
- Taiwan OTEC feasibility study. In 2010, Makai Ocean Engineering served as a sub-contractor to Lockheed Martin to evaluate the technical and economic feasibility of an OTEC plant to supply power to Taiwan. Makai used the Makai OTEC Thermodynamic and Economic Optimization Model (MOTEM) to carry out the OTEC analysis. Lockheed and Makai selected 2 potential OTEC sites from a total of 9 original options. Makai used MOTEM to create a conceptual design for a 100 MW offshore plant and a 10 MW onshore OTEC plant. The offshore plant produced 133 MW of gross power and delivered 100 MW of power to the grid. The onshore plant produced 14.2 MW of gross power and supplied 10 MW to the grid. MOTEM was used to evaluate the impact of seasonal variation in surface water temperatures on the amount of power that an OTEC plant can produce. MOTEM optimizes the plant operating parameters to maximize power output during any time of year.
- Shell Technology – Marine Renewable Program OTEC Development. In 2023, Makai signed an agreement with Shell Technology - Marine Renewable Program to further develop and test proprietary technologies that advance the engineering and economic viability of an offshore Ocean Thermal Energy Conversion (OTEC) system. In this contract, Makai will advance its unique concepts for OTEC systems and cutting-edge heat exchanger, the Thin Foil Heat Exchanger (TFHX). These hold the potential to reduce the capital costs and operating costs of an offshore OTEC system. A key part of this study is to work with Shell to accelerate the timeframe for reaching true economic viability of OTEC systems.

4.10. OTHER ANALYTICAL TOOLS

Makai uses a wide variety of analytical tools in the course of our ocean engineering design projects. Makai engineers understand the engineering and physical principles involved in designing lasting structures in the ocean, and are proficient users of several commercial and proprietary design, analysis, and data collection software. Below is a partial list of the software used at Makai on a regular basis:

- **3D Design software**: Solidworks, AutoCad.
- **Finite Element Analysis (FEA) software**: Orcaflex, ANSYS, MakaiPlan Pro, MakaiLay, Makai Pipe Deployment Software.
- **Computational Fluid Dynamics (CFD) and related software**: Environmental Fluid Dynamics Code (EFDC), CORMIX, Fluent, Simulating WAves Nearshore (SWAN), WAVEWATCH III, Cosmos.
- **Systems Engineering and Economic Modeling Software**: Makai OTEC Thermodynamic and Economic Model (MOTEM™), Makai Seawater Air Conditioning Model.
- **Geospatial Information Systems (GIS) software**: MakaiPlan cable route planning software, GeoMedia, ArcGIS, Global Mapper.
- **Data Collection and Analysis software**: LabView software, OTEC Power Plant Data Collection & Control software, Makai Real-Time Corrosion Measurement System (RCMS) software.

MAKAI OCEAN ENGINEERING
ISO90011:2008 Certified
P.O. Box 1206
Kailua, Hawaii, USA 96734
PH (808) 259-8871
FX (808) 259-8238
info@makai.com
www.makai.com

5. Deep Water Pipelines

Since its inception, Makai has been heavily involved in the research, development, and commercial application of deep seawater, with an emphasis on two technologies: Seawater Air Conditioning (SWAC), and Ocean Thermal Energy Conversion (OTEC) that provide cooling and power, respectively. Because these technologies require large quantities of deep cold seawater, Makai has developed an expertise in working with large diameter submarine pipelines.

Makai has been designing and working with deep water pipelines since 1979, starting with the design and installation of the 2,000' deep seawater intake pipeline. Since that time, Makai has designed numerous deep water down-the-slope pipelines, outfalls, and vertically suspended pipelines (described below). Makai has performed extensive research on pipeline material properties, especially for high density polyethylene (HDPE) pipes. Makai's designs have pushed the boundaries of what is possible with this material, and the 55" (1.4m) seawater intake pipeline installed in Kona to a depth of 3,000 ft. (915 m) is the largest and deepest seawater intake pipeline of its type in the world. Makai has also developed practical fabrication and deployment methods to allow long and large diameter deep seawater pipelines to be installed very cost-effectively.

More detailed information about Makai's pipeline projects can be provided in a separate brochure and can be found on Makai's webpage at www.makai.com/pipelines.

MAKAI OCEAN ENGINEERING
ISO90011:2008 Certified
P.O. Box 1206
Kailua, Hawaii, USA 96734
PH (808) 259-8871
FX (808) 259-8238
info@makai.com
www.makai.com

6. AWARDS

6.1. 2023, PACIFIC BUSINESS NEWS HAWAII'S BEST WORKPLACES

In 2023, Makai was again selected as one of Hawaii's best places to work by Pacific Business News. Makai was awarded the No. 2 medium sized business to work for in 2023, with a score of 94.56. Awards are based on employee satisfaction from anonymous surveys.

6.2. 2022, PACIFIC BUSINESS NEWS HAWAII'S BEST WORKPLACES

In 2022, Makai was selected as one of Hawaii's best places to work by Pacific Business News. Makai was awarded the No. 1 medium sized business to work for in 2022, with a score of 94.42. Awards are based on employee satisfaction from anonymous surveys.

6.3. 2021, 7TH GLOBAL DISTRICT ENERGY CLIMATE AWARDS, CERTIFICATE OF MERIT

In 2021, The Zakito District Cooling project in Curacao, mentioned above, received a Certificate of Merit at the 7th Global District Energy Climate Awards for its achievement in demonstrating local District Energy leadership in providing clean, sustainable energy solutions to protect against the risk of climate change.

6.4. 2016, SMALL BUSINESS INNOVATION RESEARCH "TIBBETTS" AWARD

Makai has been awarded the prestigious *Tibbetts Awards*, which recognizes the very best in class of the Small Business Innovation Research (SBIR) Phase I and II programs. Awardees are evaluated on technological innovations that create jobs and have a visible economic impact, serve federal R&D needs, encourage diverse participation, and increase commercialization of federal R&D.

MAKAI OCEAN ENGINEERING
ISO90011:2008 Certified
P.O. Box 1206
Kailua, Hawaii, USA 96734
PH (808) 259-8871
FX (808) 259-8238
info@makai.com
www.makai.com

6.5. 2014, LEADERS IN SUSTAINABILITY FINALIST

Makai was nominated for Pacific Business News' 2014 Business Leadership Hawaii Awards – Hawaii's premier business recognition event of the year. Based on our outstanding work during the year, PBN selected Makai as a finalist in the *Leaders in Sustainability* award, recognizing a company that has made significant strides in reducing energy use or conserving natural resources for itself or other businesses.

6.6. 2013, ISO 9001:2008 CERTIFICATION

Makai Ocean Engineering, Inc. has achieved ISO 9001:2008 certification, an internationally recognized standard for quality management systems. The Certificate is only awarded to companies that can demonstrate their ability to consistently provide products and services that meet customer requirements, placing customer satisfaction as a key component of those requirements.

6.7. 2011 APEC HAWAII BUSINESS INNOVATION FINALIST

Makai was chosen as one of the 30 finalist among 2000 local companies that competed to represent Hawaii at the 2011 Asia Pacific Economic Cooperative Summit, hosted by President Obama. The criteria for the award included business services or products that are attractive to markets outside Hawaii, having developed unique, leading and cutting-edge innovations in product development, technology, marketing or delivery; having positively impacted Hawaii's business environment, having growth and investment potential; and having adopted environmentally sound programs and practices.

MAKAI OCEAN ENGINEERING
ISO90011:2008 Certified
P.O. Box 1206
Kailua, Hawaii, USA 96734
PH (808) 259-8871
FX (808) 259-8238
info@makai.com
www.makai.com

6.8. 2011 AON GRAND BUILD AMERICA AWARD

Advanced American Construction, Inc. received the 2011 Aon Build America Award for their work constructing an innovative positively buoyant HDPE open channel flow sewage interceptor submerged in Lake Oswego, Oregon. Makai assisted in the design and engineering analysis of the pipeline. http://www.lakeinterceptor.com/

6.1. 2010 SBA PRIME CONTRACTOR OF THE YEAR FOR HAWAII AND REGION IX

The Small Business Administration honored Makai Ocean Engineering for their work in the Federal government contracting arena. Makai was nominated for their "outstanding performance, innovative solutions, professionalism, cost effectiveness and on-time delivery by the federal agencies that contracted their services.

6.1. 2005 COMPASS INDUSTRIAL AWARD

The Marine Technology Society awarded Makai with the Compass Industrial Award for outstanding contributions to advancement of the science and engineering of oceanography and marine technology.

MAKAI OCEAN ENGINEERING
ISO90011:2008 Certified
P.O. Box 1206
Kailua, Hawaii, USA 96734
PH (808) 259-8871
FX (808) 259-8238
info@makai.com
www.makai.com

6.2. 2003 EXPORTER OF THE YEAR AWARD

State of Hawaii Governor Linda Lingle awarded the Exporter of Professional Services award for 2003 to Makai Ocean Engineering. The award was earned based on the high quality and volume of service & sales of Makai's sophisticated submarine cable-lay software and advanced pipeline design services.

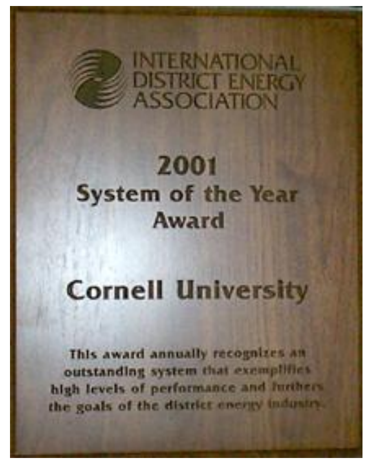
6.3. 2003 AMERICAN SOCIETY OF CIVIL ENGINEERS

The HOST Park Seawater Supply Pipeline, the world's deepest large diameter seawater intake pipeline, was selected as one of six finalists for the 2003 Outstanding Civil Engineering Achievement (OCEA) Award by the American Society of Civil Engineers. The survey, conceptual and final design, and construction observation for this project was performed by Makai Ocean Engineering.

MAKAI OCEAN ENGINEERING
ISO90011:2008 Certified
P.O. Box 1206
Kailua, Hawaii, USA 96734
PH (808) 259-8871
FX (808) 259-8238
info@makai.com
www.makai.com

6.4. 1999 CORNELL'S LAKE SOURCE COOLING

The success of Cornell's Lake Source Cooling Project in 1999 has won three awards: the New York State Society of Engineers, the International District Energy Association, and the Associated General Contractors of America. Makai was responsible for the design engineering of the two mile long 63 inch cold water intake pipe and the 48 inch discharge pipe.



6.5. 1980 OUTSTANDING ENGINEERING ACHIEVEMENT AWARD

In 1980, the National Society of Professional Engineers recognized the Mini-OTEC Project at Ke-ahole Point, Hawaii and one of the ten outstanding engineering achievements in the United States. Makai was involved in the design and construction management of the cold water pipe, mooring and platform.

MAKAI OCEAN ENGINEERING
ISO90011:2008 Certified
P.O. Box 1206
Kailua, Hawaii, USA 96734
PH (808) 259-8871
FX (808) 259-8238
info@makai.com
www.makai.com

7. Contact Makai to Discuss Your Project

Makai has been working on water and energy systems projects consistently for over 50 years. Our specialized engineering and economic analysis tools, coupled with our experience designing successful water and energy projects enables us to assess a site rapidly for its viability.

Makai provides a preliminary opinion of viability for a new project, free of charge. If the economics looks promising, Makai will propose one or more options for a feasibility study or preliminary design for your project that fit within your budget.

Please contact us at the phone, email, or mailing address listed below.

MAKAI
OCEAN ENGINEERING

Makai Ocean Engineering, Inc.

Website: www.makai.com
Email: makai@makai.com

Phone: +1 (808) 259-8871
Fax: +1 (808) 259-8238

Physical address:
Makai Research Pier
41-305 Kalanianaole Hwy
Waimanalo, Hawaii, 96795 USA

Mailing Address:
PO Box 1206
Kailua, Hawaii, 96734 USA