# Seawater Air Conditioning:  A Basic Understanding

## Introduction

Seawater Air Conditioning (SWAC) is an alternate-energy system that uses the cold water from the deep ocean (and in some cases a deep lake) to cool buildings. In some areas it is possible to reduce dramatically the power consumed by air conditioning (AC) systems; SWAC can be a cost-effective and attractive investment. It is an alternate energy for air conditioning.

This paper is an introduction to Seawater Air Conditioning; it describes the benefits, the technology, the areas best suited for this form of energy, some example projects, the economics and the key components of the systems.

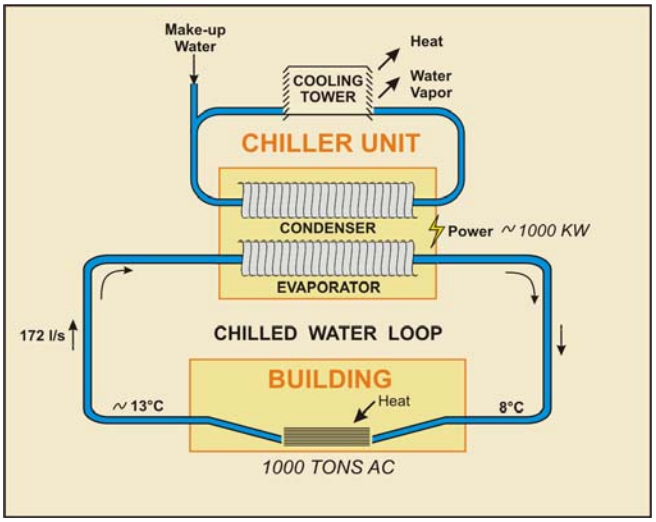
## Benefits of a SWAC System

The Seawater Air Condition Systems taps into a significant and highly valuable natural energy resource that is available at some coastal locations. The benefits of a seawater air conditioning system include:

- Large energy savings approaching 90%
- Proven technology
- Short economic payback period
- Environmentally friendly
- Costs are nearly independent of future energy price increases.
- No evaporative water consumption.
- Cold seawater availability for secondary applications.

## Conventional Air Conditioning Basics

The schematic to the right illustrates a conventional air conditioning system for a large building. A constant flow of cold fresh water is circulated throughout the building (sometimes multiple buildings) for heat removal. As this chilled water moves throughout the building and absorbs heat, its temperature rises from an incoming value of approximately 7-8ºC to an outflow value approximately 5ºC higher. This warmer water then enters the chiller.

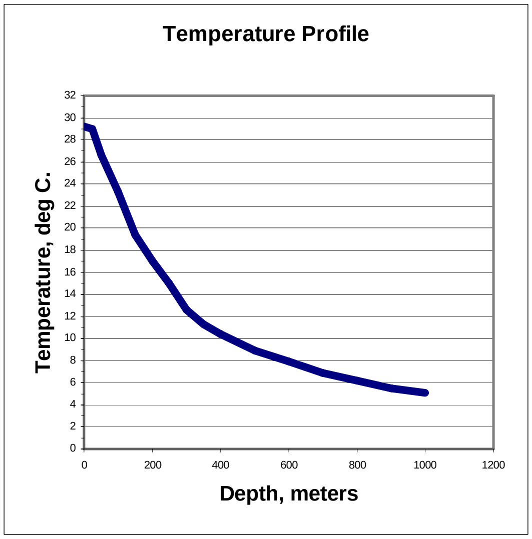


The chiller is a refrigeration system that cools the recirculation water. Water enters the chiller at a nominal 12-13°C and exits at 7-8°C. The chiller consumes electricity as it "pumps" heat from a cold source to a warmer source. The total heat removed from the building and the electrical power consumed by the chiller passes through the chiller's condenser to a heat sink. The most conventional means of eliminating this excess heat is to use a cooling tower that dumps the heat into the atmosphere primarily through evaporative cooling. Cooling towers consume fresh water; some chillers are air cooled if fresh water is not economically available.

The energy requirements for a large building's air conditioning system are significant and, depending upon the location, may be the dominant electrical load of the building. The electrical requirement for conventional chiller operation and cooling is 0.9 to 1.3 kW/ton depending upon the location, cooling system, and age of the system.

## Seawater Air Conditioning Concepts

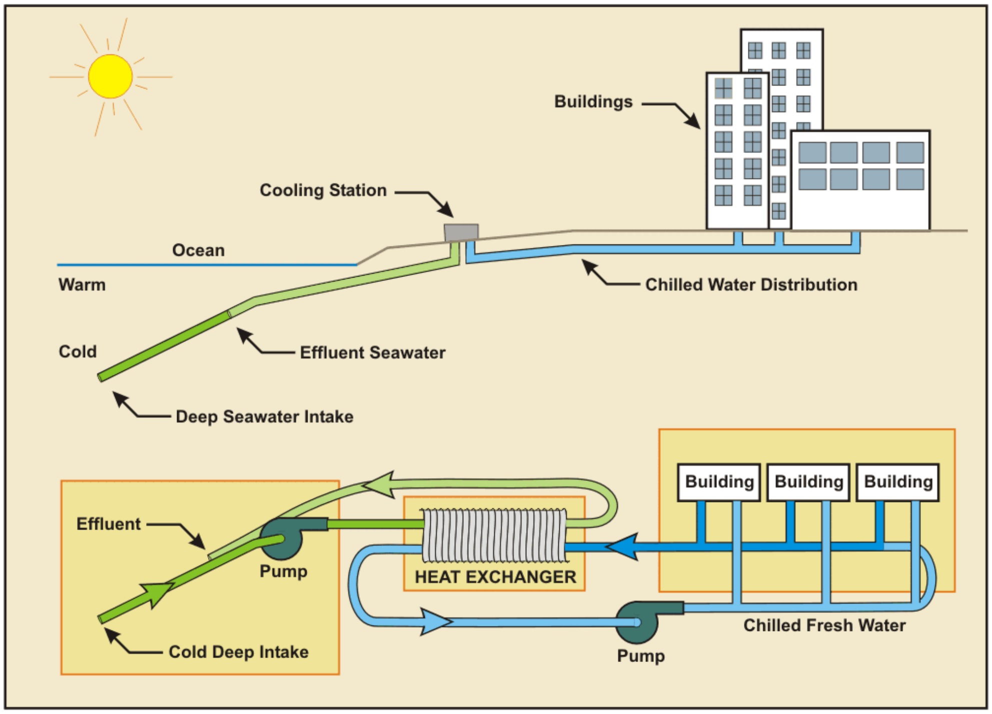
Along many ocean coastlines and lake shorelines, there is reasonable access to naturally cold water that is as cold or colder than the water used in conventional air conditioning systems. If this water can be tapped, then the significnat power for operating mechanical chillers to keep the chilled water cold can be eliminated.




The adjacent temperature profile illustrates the temperature vs depth that is typical for the world's tropical deep oceans in the summertime: 7°C or below can be reached at 700m depth, 5°C. or below at 1000m. The deep-water portion of this profile changes little seasonally and therefore cold water is available on a year round basis. In more northern climates, very cold water can be reached at shallower depths during the summer – in both oceans and in deep water lakes.

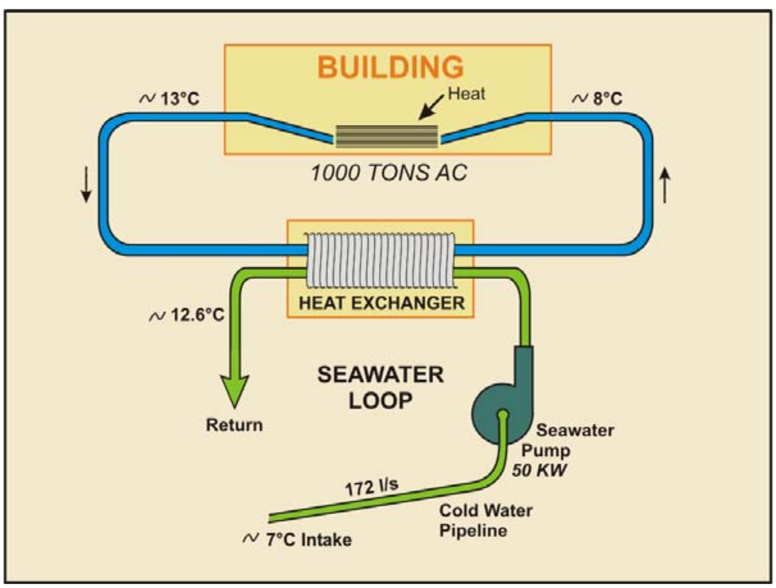
The basic concept of seawater air conditioning is to take advantage of available deep cold seawater to cool the chilled water in one or more buildings as opposed to using more energy intensive refrigeration systems.

A seawater air conditioning system is illustrated below. The buildings to the far right are identical internally to buildings cooled with conventional A/C. Chilled fresh water moves through these buildings with the same temperatures and flows of conventional systems. The seawater and chilled water pumps and heat exchangers would typically be located at the shoreline in a cooling station.

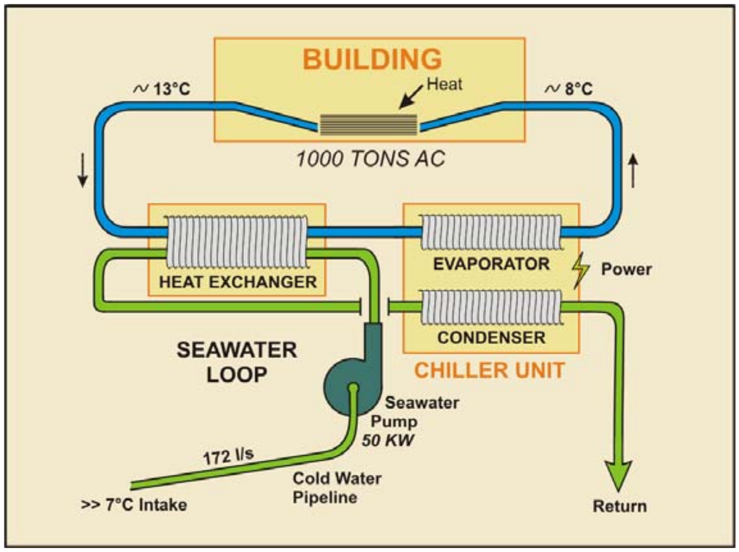



The main components of a seawater air conditioning system are the seawater supply system, the heat exchanger or cooling station and the fresh water distribution system. These basic components can be optimized for each specific location, climate and building.

This schematic is an alternate view of a basic centralized seawater air conditioning system. The chilled water loop is fresh water and operating at the same temperatures as with conventional AC. The interior of the building is unchanged with SWAC systems. The chilled water is kept cool through a heat exchanger with a counter flow of deep cold seawater. The heat exchanger is titanium to eliminate corrosion and fouling does not occur because of the purity of the deep seawater. Seawater is brought to the site through a deep-water polyethylene pipeline. These pipelines reach out several kilometers offshore and have a nominal intake depth of 700 m. The effluent seawater is discharged though a second pipe at a depth of approximately 40 m.



Seawater air conditioning is not technically complex nor is it a high technical risk. It is established technology being applied in an innovative way. All the components necessary exist and have been operated under the conditions required.




*Use of an Auxiliary Chiller:* In some cases, it is either too costly or impractical to supply seawater at the necessary low temperatures to maintain minimum temperatures in the chilled water loop. The distance offshore to reach sufficiently cold water might be prohibitive or the ocean depth may simply not be available. It is sometimes economically possible to use auxiliary chillers to supplement the cooling provided by the seawater exposure. This is illustrated below. The fresh chill water is first cooled by seawater through a heat exchanger and then secondarily cooled with an auxiliary chiller. The auxiliary chiller is basically a refrigeration system with its condenser cooled by the returning flow of cool seawater. With the condenser kept cool, the auxiliary chiller can operate at an extremely high efficiency – as high as double that of a conventional chiller.

*Cold Storage:* A SWAC system has a high capital cost and a low operating cost. The peak capacity of the system must match the peak demand of the buildings that it serves. These demands are not constant throughout the day or throughout the year, and the total system is frequently not being used to its maximum capacity. Therefore, capital dollars are spent on a system that may not always be used to its maximum potential. A means of minimizing the capital cost is to use cold-water storage. The seawater air conditioning system would be operated 100 percent of the time and when the building demands are low, the excess capacity is directed into a storage system of cold fresh water. When A/C demand is at its peak, the cold water is drained from its storage to meet the demand.

Cold water storage tanks are commercially available that are constant volume; the warm water remains at the top and the coldest water remains at the bottom. These tanks are now used in conjunction with conventional A/C systems to take advantage of low, off-peak electrical rates.

## Environmental Aspects

A SWAC system has significant environmental benefits: These include drastic reductions in electricity consumption which reduces air pollution and greenhouse gas production, and substitution of simple heat exchangers for chiller machinery which often use ozone-depleting chlorofluorocarbons (CFCs).

The existence of the deep ocean heat sink results from natural climatic processes where water is cooled at the poles, becomes dense and sinks to deeper water and slowly moves toward the equator. The cold ocean is therefore both immense and renewable.

Return water from a SWAC system can be handled in a number of ways. Typically it is returned to the ocean at a location where the return water temperature nearly matches the ambient water.

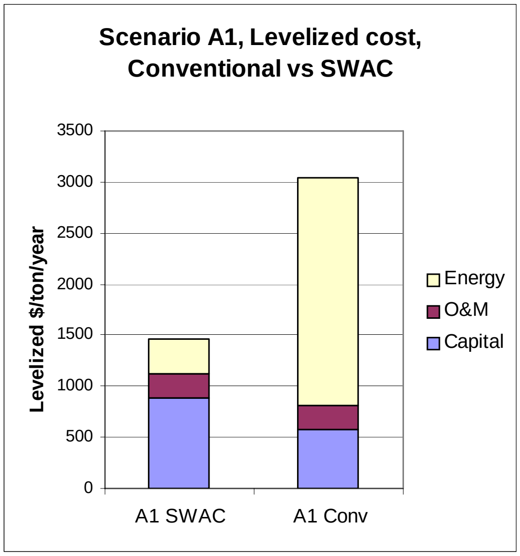
There are significant secondary applications for this seawater. Secondary cooling, aquaculture, desalination and even agriculture can benefit from the cold seawater. Aquaculturists value the water because it is clean and disease free. When used in conjunction with a warm source of water, they can have any temperature seawater their product needs. Secondary cooling can be used in greenhouses and other locations where humidity control is not a major factor. Finally, research in Hawaii has shown that even an arid land can be made highly productive with low fresh water consumption by cooling the soil and the roots of many tropical and non-tropical plants. Deep seawater is also desalinated and sold as a premium drinking water in the orient.

## Economic Viability

The economic viability of a SWAC system is site specific. Each location has unique opportunities as well as problems. The main factors influencing the economic viability of a specific location include:

- *The distance offshore to cold water*: shorter pipelines are more economical than long pipelines.
- *The size of the air conditioning load:* there is an economy of scale associated with SWAC – systems less than 1000 tons are more difficult to justify economically,
- *The percent utilization of the air conditioning system:* The higher the utilization throughout the year, the higher the direct benefits.
- *The local cost of electricity*: A high cost of electricity makes conventional AC more costly and SWAC, in comparison, more attractive. Any cost analysis should include current and future costs of electricity.
- *The complexity of the distribution system on shore:* SWAC works best with a district cooling arrangement, where many buildings are cooled taking

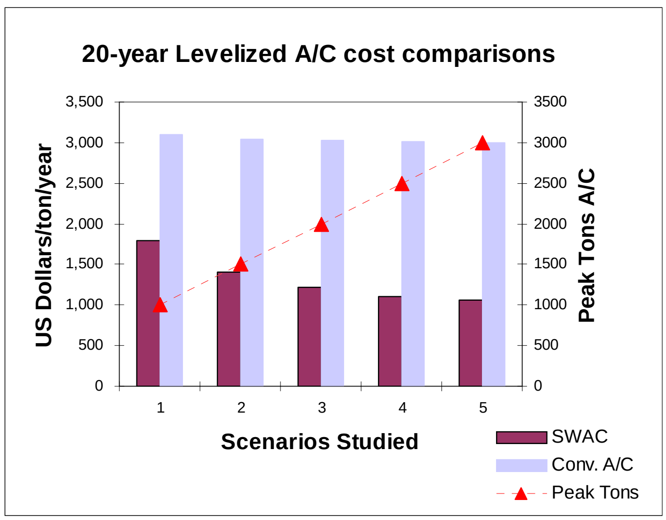
advantage of the economy of scale. SWAC is even more economical if this distribution system is compact.




The adjacent figure illustrates the difference in lifetime costs for a conventional AC system and a typical SWAC system. The costs are broken down into capital, operating (energy) and maintenance. The primary cost of a SWAC system is in the initial capital cost. The operating and maintenance costs are small. For a conventional AC system, the primary cost is in the power consumed over its lifetime. Hence, SWAC systems are ideal for base load AC that has high utilization and conventioal AC may be better for situations of infrequent use.

It's important to note that there is a dramatic economy of scale as the size of the pipeline increases. The reason is that the cold water pipe costs per liter of water delivered decreases as the pipeline size increases and temperature rise via large pipelines is practically negligible. The figure to the right illustrates five SWAC scenarios of varying overall size; the two bars compare the life time cost difference between conventional AC and SWAC.

Makai has performed SWAC feasibility studies of a variety of sites. Typical results are that electrical consumption is reduced by 80 to 90 percent. Simple payback can be from three to seven years, and long term costs can be half that of a conventional air conditioning system. Not all locations, however, are ideal. Some have poor access to deep cold-water sources or the overall size is too small to be economical. Each site is unique.



## SWAC History

The feasibility of using cold seawater to directly cool buildings has been studied and analyzed for many years. At certain locations, successful installation and operation has occurred. The following is a brief recent history of seawater air conditioning:

In **1975**, the US Department of Energy funded a program entitled "Feasibility of a District Cooling System Utilizing Cold Seawater." [Hirshman et al] Several locations were studied and the two most favorable sites were Miami/Ft. Lauderdale and Honolulu. The study, however, noted that one of the limiting technical factors was the inability to deploy large diameter pipelines to depths of 1500' and more. This technical challenge has since been addressed and demonstrated with Makai-designed deep-water pipelines at the Natural Energy Laboratory of Hawaii, Keahole Point, Hawaii.

In **1980**, the Naval Material Command at Port Hueneme, California, conducted a study entitled : "Sea/Lake Water Air Conditioning at Naval Facilities." [Ciani]. Computer models were developed which provided reasonable estimates of the capital cost and energy use of seawater air conditioning systems at Point Mugu, California and Pearl Harbor, Hawaii. The study concluded that: at a hypothetical typical Navy facility, a SWAC system will use 80% less energy than conventional A/C, but the capital costs of SWAC systems are 60% greater. The Life Cycle Cost of SWAC at a typical Naval facility would be 25% lower than the life cycle cost of conventional A/C.

In **1986**, a joint project between the Canadian government and Purdy's Wharf Development, Ltd. demonstrated the use of ocean water as a source for building cooling to a 350,000 square ft. office complex along the waterfront in Halifax, Nova Scotia. Due to the geographic conditions and annual low water temperatures, a small diameter pipeline was deployed to a depth of less than 100' ft. This was a major factor in limiting the overall expense of installing the cooling system. Total investment for this project was $200,000. The project was very successful and savings were identified in the following areas: a saving of $50-60,000 per year in avoided electrical cost, fewer maintenance staff, reduction in fresh water, savings in water treatment, and savings in cooling tower maintenance and replacement. The financial result in terms of a simple payback period was two years. [Building Cooling] Today, Purdy's Wharf continues to utilize successfully an expanded seawater air conditioning system for their waterfront properties.

In **1986**, the Natural Energy Laboratory of Hawaii Authority, Keahole Point, Hawaii began the successful utilization of SWAC in their main laboratory building. Deep-water pipelines were already installed to provide cold, nutrient rich, seawater for research purposes in alternate energy and aquaculture. Since a cold water supply was already incorporated into the infrastructure, it was decided to utilize the cold water for cooling. This proved to be a very sound economic decision that resulted in monthly electric savings of $400. Today, the use of SWAC has been expanded to a new administration building and a second laboratory. Estimated monthly saving in electricity is $2000.

In **1990**, the US Department of Energy funded a study entitled: "Waikiki District Cooling Utility." The purpose of this brief study was to evaluate whether it was economically and technically feasible to utilize seawater air conditioning as a means to provide cooling to the hotels in Waikiki and to create a Waikiki Cooling Utility. Waikiki was targeted because of the high density of hotels, high electrical consumption and a large demand for air conditioning. It was estimated by Hawaiian Electric Company that of the 107 Megawatts consumed in Waikiki, 51.4 Megawatts were used for air conditioning. This study concluded that economically and technically, Waikiki could be cooled by utilizing seawater air conditioning.

In **1995**, Stockholm Energy started supplying properties in central Stockholm with cooling from its new district cooling system. Most of the cooling is produced by using cold water from the Baltic Sea. The temperature of the cooling water leaving the plant is 6°C or lower and the return temperature from the distribution grid is 16°C at high load and a few degrees lower at low load. The district cooling system is designed for a maximum load of 60 MW.

In **1999**, the Cornell Lake Source Cooling Project installed a 63" diameter pipeline into nearby Lake Cayuga. This Makai-designed pipeline was 10,000' in length and installed to a depth of 250'. Cold water from this pipeline, at approximately 4°, provides air conditioning for the Cornell University Campus. This system is capable of providing in excess of 20,000 tons of cooling; the system started operation in mid-2000.

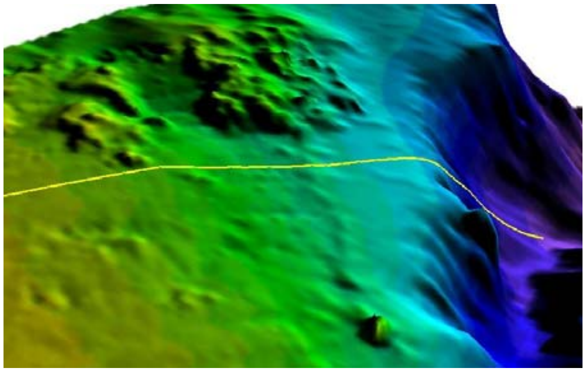
In **2004**, the Deep Water Cooling Project for Toronto, Canada, commenced cooling of downtown Toronto with a peak capacity of 58,000 tons. Three 63" pipelines reach far into lake Ontario for both potable and cooling water for the city. Makai assisted in the engineering of this project.

In **2004**, Makai completed the design for a 450 ton SWAC system in French Polynesia for a major hotel. Construction is commencing.

In **2004**, a SWAC system design and planning is underway in the Caribbean for 2500 tons AC for a complex of hotels, meeting centers and university.

In **2004**, a SWAC system design has commenced for very large SWAC systems to service Honolulu, Hawaii.

## Offshore Pipelines - Experience



The key cost and risk component of any SWAC system is the offshore pipeline. The lack of a low-cost methodology for the installation of these pipelines prevented SWAC development in the 1970's and 80's. Today, the technology for the successful installation of pipelines to depths of 3000' and greater is available. Numerous deep water intake pipelines have been installed – nearly all of the world's successful pipes have been Makai designs.

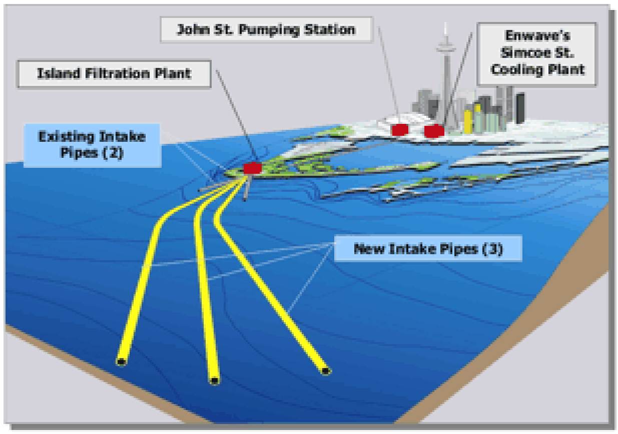
All of the deep seawater intake pipelines designed by Makai have used polyethylene as the pipeline material. Polyethylene has significant advantages for these pipelines in that it is inert and will neither corrode nor contaminate the water. Polyethylene lengths are heat fused together to form a long, continuous pipeline with joints that are as strong as the pipeline itself. Polyethylene has excellent strength and flexibility and is buoyant in water. These characteristics allow a great deal of design flexibility and deployment ease. The wall thickness can be varied depending on strength requirements for deployment and operating suction over the lifetime of the pipe.

Makai's approach for a deep water pipe deployment is to minimize the time at-sea. The pipeline is basically designed for the deployment process since this represents the major cost and risk of the installation. The pipeline is assembled complete on shore, launched floating using the pipeline to support all anchors and fastenings, towed to the site, and controllably submerged while carefully monitoring pipe tensions and pressures. The procedure is stable and reversible.

The major risk to the pipeline is during deployment. These are standard marine construction risks and would be covered by the installer's insurance. Once deployed, the likelihood of deep-water failure is very remote.

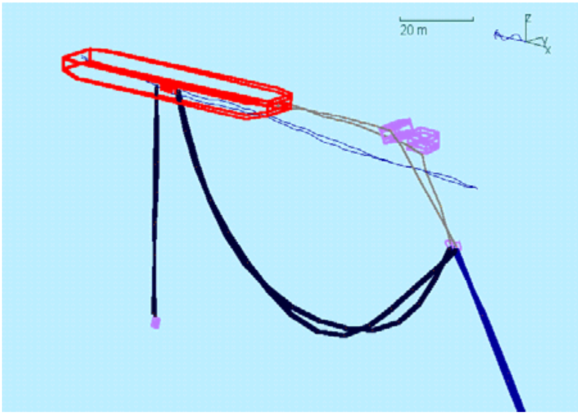
**Installed Pipelines**: Makai has been designing and working with deep water pipelines since 1979 and has designed a number of down-the-slope polyethylene intake pipelines and suspended pipelines. In addition, Makai has been involved with a variety of field research programs studying the installation and loading on large diameter pipelines - both deep and shallow. A brief summary of Makai's experience in HDPE (High Density Polyethylene) deep water pipeline design, analysis and deployment is summarized below:

Lake Source Cooling: Makai was selected by Gryphon International Engineering Services and Cornell University to design a 63" diameter HDPE intake and a 48" diameter outfall pipeline in Cayuga Lake, NY to provide 20,000 tons of centralized cooling for the university. The intake pipeline is two miles long with an intake at 250' depth. The pipeline provides 32,000 gpm of cold water and has a 75-year lifetime. Construction was completed in 1999.




Toronto Pipelines: The city of Toronto is now operating a district cooling system with a maximum capacity of 58,000 tons. The cooling is provided with deep lake water from Lake Ontario. Makai assisted in the design of three, nearly 4 miles long, 63" diameter intake pipelines for this project.

Indian OTEC Pipeline: Makai has provided conceptual designs and design guidance to the National Institute of Ocean Technology (NIOT) in Madras, India, for in OTEC intake pipeline and mooring system for a floating OTEC research barge in the Indian Ocean. This pipeline will be 1 meter in diameter and will provide water from a 1000 meter depth.



55", 3000' deep Pipeline: Makai has engineered 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 (55" diameter, 3000' deep, and two miles long), a 55" diameter warm water intake pipe, a tunneled shoreline crossing and a shore-based pumping station. The system has the capacity to deliver 27,000 gpm of 4 deg. C. water and over 40,000 gpm of warm water to the technology park. Makai received a national award from the American Society of Civil Engineers for this project as one of the six most outstanding CE projects in 2003.

40" Intake Pipeline Design and Installation: In a project with R.M. Towill Corporation, funded by the State of Hawaii and the U.S. Department of Energy, Makai was tasked with the design of a 40" polyethylene cold water pipe to be used jointly by the Natural Energy Laboratory and the Hawaii Ocean Science and Technology (HOST) Park sites on the Big Island. It is the largest deep-water intake pipeline in the world. This pipe is a larger and more rugged version of the previous MOE 12" pipe design at NELH 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 for the Natural Energy Laboratory.

18" Cold Water Pipeline: Makai designed and provided construction management for an 18" down-the-slope cold-water intake at the Natural Energy Laboratory of Hawaii. The goal to install a reliable, minimal cost, deep-water intake system to 2000'. This polyethylene design differs from previous NELH pipelines in that the deep water pipe is buoyed approximately 40' off the bottom on a series of pendants, the deployment was accomplished without major offshore equipment. This pipeline was successfully deployed in October, 1987, and is still operational.

Long Operating OTEC Cold Water Pipeline: Makai conceived, designed and managed the construction of an experimental, down-the-slope polyethylene OTEC pipeline, 12" in diameter, for the State of Hawaii. This one-mile long pipeline has an intake at 2000' and utilizes a unique 3000' long free-floating catenary section to avoid contact with the steep, rocky bottom. The pipeline was installed in 1981 off Keahole Point, Hawaii. In spite of its "temporary" design life of 2 years, it has survived many major storms including a hurricane and was operational for over twelve years.

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' diameter polyethylene pipe that served not only as an intake pipe from a 2000' depth, but also as the "mooring line" for the 120' x 35' 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.

French Polynesia: Makai has engineered a complete SWAC system for a hotel in French Polynesia for supplying 450 tons of AC. This demanding project involved a 2000m long pipeline going to 850m depth on a seabed with slopes up to 60 degrees. This project is underway in 2004.