Technology Collaboration Programme
by iea

2022

USING SEA WATER FOR HEATING, COOLING AND POWER PRODUCTION

OES OCEAN ENERGY SYSTEMS

Published by:
The Executive Committee of the IEA Ocean Energy Systems (OES)

Edited by:
Ana Brito e Melo

Designed by:
Formas do Possível | www.formasdopossivel.com

Suggested Citation:
OES (2022), Using sea water for heating, cooling and power production, www.ocean-energy-systems.org

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INTRODUCTION

This brochure presents six interviews to give a flavour of projects in different parts of the world taking advantage of the temperature of the ocean for heating, cooling and power production. The interviews focus on Ocean Thermal Energy Conversion (OTEC) demonstration plants, Sea Water Air Conditioning (SWAC) and Sea Water Heat Pump (SWHP) systems, sharing experiences, challenges, and lessons learned.

Ocean Thermal Energy Conversion (OTEC) takes advantage of the temperature difference between warm seawater at the surface of the ocean, and cold seawater at between 700–1000 m depth to produce electricity; typically, the difference is ~20ºC. The warm seawater is used to produce a vapour that acts as a working fluid to drive turbines; the cold water is used to condense the vapour and ensure the vapour pressure difference drives the turbine.

Sea Water Air-Conditioning (SWAC) is a renewable substitute for cooling in which seawater from the ocean at depths of about 700–1000 m and temperatures of 3–5 °C is pumped to the coast into the cooling system. 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.

Sea Water Heat Pump (SWHP) transfers heat from seawater with electrical energy input for heating and cooling building district's spaces. While air temperature varies a great deal according to season, the sea enjoys relatively stable temperatures at depth all year round. Therefore, in winter, SWHP can pump heat from seawater to higher temperatures suitable for space heating; in summer, SWHP can use seawater as cold source for space cooling.

Ocean Thermal Energy Conversion (OTEC)

Okinawa OTEC Demonstration Facility

This facility was commissioned by the Okinawa Prefecture Government to demonstrate OTEC and to test equipment. The facility is located in Kumejima island, in the southernmost part of Japan, owned by Okinawa Prefecture and operated by Xenesys Inc. Operation began in 2013.

Makai Ocean Engineering's OTEC power plant in Hawaii

Makai Ocean Engineering's OTEC power plant in the US is located at the Natural Energy Laboratory of Hawaii Authority (NELHA) in Kailua-Kona. This facility was connected to the grid in August 2015.

1 MW OTEC power plant developed by KRISO

The 1MW OTEC plant developed by the Korea Research Institute of Ships and Ocean Engineering (KRISO) was designed and manufactured from 2016 to 2019. A trial operation was carried out successfully on the southern coast of the East Sea. This plant will be towed for installation on the coast of South Tarawa, Republic of Kiribati, in the South Pacific Ocean.

Sea Water Air Conditioning (SWAC)

SWAC project of the French Polynesian Hospital in Tahiti

A SWAC system has been designed and implemented at the French Polynesia Hospital Center, located in Tahiti. A 3.6 kilometer long underwater pipe draws water at 5°C, 900 m deep in the Pacific Ocean; in a heat exchanger, this salt water cools the fresh water in the air conditioning system. The project is funded by French Polynesia, the European Investment Bank (EIB), the *Agence Française de Développement* (AFD) and the French Agency for Ecological Transition (ADEME). It is planned to start operation very soon.

Sea Water Heat Pump (SWHP)

Seawater heat pump system in Monaco

Monaco was one of the first countries to develop the use of the seawater heat pump system along its coastline. The Principality installed its first seawater heat pump in 1963 at the Rainier III Outdoor Swimming Stadium to heat the water for the pool. The country now has more than 80 pumps. The use of this heat pump technology provides a particularly attractive alternative for buildings, with significant reductions in greenhouse gas emissions in the region, compared to traditional air conditioning systems.

Thassalia power station on France's southern coast

In 2016, the French utility Engie inaugurated the Thassalia power station on France's southern coast, in Marseille. This system pumps seawater from a depth of 6 m in the Mediterranean into heat exchangers and heat pumps to provide heat and refrigeration to a custom-built network integrated with the heart of Marseille's business center.

KEY MESSAGES

OTEC, SWAC and seawater heat pump technologies have been under development with several existing demonstration and pre-commercial projects. SWAC and seawater heat pump systems are proven and mature technologies, while OTEC still requires development and large-scale validation.

Over the past decades, a lot has been experienced on OTEC, but the most important challenges are still related to the economics of the projects. The "industry must do its best to reduce costs in any way". The financial risks are the most critical challenge that OTEC currently faces. In the past years, much work and learnings have been undertaken with pilot projects on reducing the cost and attracting private investment. The components used in these systems, such as heat exchangers, pumps, pipes to transport water, have been used in marine environments for decades, so the operation and maintenance of these sub-systems seem to be well known, however, while there are several lessons learned from pilot testing on the key components and successful validation of most critical elements, the next step in de-risking the technology for commercial adoption needs to focus on a long-term operation of a commercial OTEC plant.

SWAC and Sea Water Pump systems are demonstrating cost-effective and environmentally friendly ways of heating and cooling buildings or urban areas close to shore. These systems can be particularly appealing for Small Island Developing States (SIDS), reducing reliance on imported oil, and generating new skills and employment opportunities. The impact of air conditioning on the overall electrical power demand being very high in an island environment makes these solutions an extremely relevant response to energy issues to meet the challenges of climate change.

1

OTEC

Ocean Thermal Energy Conversion (OTEC) takes advantage of the temperature difference between warm seawater at the surface of the ocean, and cold seawater at between 700–1000 m depth to produce electricity; typically, the difference is ~20°C. The warm seawater is used to produce a vapour that acts as a working fluid to drive turbines; the cold water is used to condense the vapour and ensure the vapour pressure difference drives the turbine.

OKINAWA OTEC DEMONSTRATION FACILITY

Benjamin Martin
Project Manager
Xenesys Inc.

Which relevant milestones have been achieved during the operation of the 100 kW OTEC power plant in Kumejima, Okinawa, Japan?

The OTEC Demonstration Project in Okinawa was established by the Okinawa Prefectural Government with construction subcontracted to a joint venture. Xenesys has been commissioned to operate the Okinawa Prefecture OTEC Demonstration Facility on the government's behalf and so we will answer from that standpoint. Results of the demonstration are included in a Japanese-language public access report from FY2018, and we will include some excerpts here. The purpose of the OTEC Demonstration was defined in two parts:

In "the "Power Generation Utilization Demonstration Project", an Ocean Thermal Energy Conversion demonstration facility was installed at the Okinawa Prefectural Deep Ocean Water Research Center (ODRC), and operation performed using actual surface seawater and deep seawater to confirm technical reliability. In order to connect this to the "expansion of the introduction of renewable energy" in Okinawa Prefecture, this project was implemented including the utilization of obtained empirical data in a commercial-level power generation plant."

The second part included the "advanced combined use demonstration project," which conducted verification tests using post-power generation seawater to identify the feasibility, effectiveness, and issues of combined use.

Major results included "thermal cycle efficiency exceeding planned value (simulation predicted value) by about 5% on average annually," "heat exchanger performance, especially in the evaporator was about 5 to 7% higher than the planned value," and in terms of controllability, "it was possible to control the output within ± 5% of the simulated predicted values for 90% or more of the operating time."

To date, the facility has been visited by well over 10,000 people from 68 countries.

Courtesy Okinawa Prefecture Industrial Policy Division

To date, how much public funding and private investment has been granted for the construction and operation of this project?

The initial construction and operation were part of the Okinawa Prefecture "Demonstration Project of Power Generation Used for Advanced Deep Seawater Utilization" the budget was not disclosed in the above report, but was fully provided through the Okinawa Prefectural Government. The project connected to the existing deep seawater intake facility at the Okinawa Prefecture Deep Ocean Water Research Center. In 2016, a New Energy and Industrial Technology Development Organization (NEDO) project conducted by Saga University and Kobe Steel retrofitted a portion of the Okinawa Demonstration for use to test operation with a double Rankine cycle and high efficiency heat exchangers. Also in 2016, the Okinawa Prefecture "Demonstration Project for Advanced Combined Use of Post-OTEC Power Generation Seawater Use" established new pipelines to provide post-OTEC water to local industries. This was a combination of public and private funds. From April 2022, Mitsui OSK Lines (MOL), Saga University, and Kumejima Town are renting the demonstration equipment from Okinawa Prefecture towards expansion to 1MW-scale.

The development of an OTEC project involves a wide variety of risks, including technical, regulatory and financial, could you describe

which are the most critical ones you have encountered and how could they be overcome?

Technical Risks were mitigated through testing and validation on small-scale at the Institute of Ocean Energy, Saga University (IOES). The demonstration provided the further demonstration of technical readiness for larger-scale implementation. The regulatory environment in Okinawa was supported by existing infrastructure and early collaboration with necessary stakeholders such as the local fishery cooperative.

Financial risk remains the most critical since, as with other renewable energies, OTEC's cost is mostly from capital costs rather than future operational costs from fuel purchases. For the demonstration, this was mitigated as a government-led project. For larger-scale implementation as well, significant government support may be required to accelerate introduction of commercial plants. OTEC power generation itself, is now at a stage where it may be able to compete with other traditional power generation methods, however the required deep ocean water intake for onshore applications should likely be treated as a public infrastructure serving industrial and economic development through fishery, water production, and OTEC comprehensively.

Operation and maintenance of marine energy equipment have always been a challenge for the ocean energy industry. What difficulties have been faced on O&M and how have they been resolved?

In terms of onshore OTEC deployment, maintenance and operation is quite easy compared to other thermal power generation facilities due to lower heat stress and few moving parts. Provided sufficient corrosion mitigation is in place, such as through housing equipment in a building, the lack of fuel costs leads to very low O&M costs. In terms of offshore applications, similar considerations to ships or offshore platforms should be applicable.

The Okinawa Prefecture project report notes "Regarding the reduction of OTEC maintenance costs, the operation and maintenance costs of a 1 MWc-lass OTEC plant were estimated based on results of demonstration for five-years from 2013 to 2017. As a result, the operation management cost will be about 4.2 yen/kWh."

What are the important lessons learned in this project?

This project achieved 24/7 continuous automatic operation. Through actual operation, the facility has shown expected O&M costs for an 1MW OTEC facility can be reduced about 70% from initial estimates included in

OTEC power generation itself, is now at a stage where it may be able to compete with other traditional power generation methods, however the required deep ocean water intake for onshore applications should likely be treated as a public infrastructure serving industrial and economic development through fishery, water production, and OTEC comprehensively.

New Energy and Industrial Technology Development Organization of Japan (NEDO) funded research resulting in an overall power generation cost reduction of about 25%. In addition, the heat exchanger technology developed and demonstrated in this project operated better than initially expected. Post-OTEC water use had led to new applications in industrial use with increasing potential for aquacultural industry development on Kumejima. More details are provided in the previously mentioned report.

The large volumes of cold deep seawater required for OTEC energy production make possible many unique applications. What are your thoughts on the potential by-products from OTEC? Which applications the Okinawa Research Center has been investigating?

The ocean water resource on Kumejima has created an environment where DOW-related industries are the single largest sector in the local economy, outpacing agriculture and the fishery sectors. As a resource for local and sustainable food and water production, DOW is a critical resource on its own. As part of an OTEC facility, the post-OTEC water provides various benefits to industrial users such as clean energy, thermal management, and increased resource access. Recently, with increasing effects from warming ocean water, researchers at the ODRC, which is under the jurisdiction of the Okinawa Prefecture Department of Agriculture, Forestry, and Fisheries, have focused on aquaculture such as onshore sea plant aquaculture. In addition, other aquaculture products have been researched and demonstrated through joint research and private sector efforts. Kumejima Town and private sector businesses are continuing development activities towards expansion of intake capacity.

The potential environmental impacts of OTEC have been studied extensively over the last decades. Based on your practical experience is it possible to "retire" some of the environmental effects that have been potentially assigned to OTEC?

Xenesys is not specialized in environmental impact assessments and does not do such work directly, however, as far as we have heard, existing DOW discharge in Kumejima has not shown negative affects after 20 years of operation though we believe it is important for ample consideration of discharge methodology in each implementation case. The most common concerns expressed about larger-scale OTEC we have heard are the effects of DOW nutrients on near-shore environments (coral) and potential to affecting the current temperature in the ocean from over-use. For the latter concern, we believe comparison of intake scale (though large) with the surrounding environmental resource (vast) as well as the excellent modeling work done at the University of Hawai'i allays any fears provided ample consideration of OTEC placement is undertaken.

In the case of DOW nutrients, it is our opinion effluent from OTEC should be managed according to the regulations and best-practices established for aquaculture such as discharging past coral environments.

There is consensus that a major roadblock to the large-scale adoption of OTEC has been the relatively high estimated Capital Expenses (CAPEX) associated with such projects; there is a need for a serious and medium-long term commitment from the industry and governments. In your opinion, how could such commitment be triggered?

For onshore OTEC, ocean water intake can be treated as a public investment such as other infrastructure projects. This can de-risk uncertainty from long-term operation and the ocean environment. It is much easier for the private sector to invest in specific companies and projects with an existing resource, such as is seen at the Natural Energy Laboratory Authority of Hawaii (NELHA). OTEC provides an "anchor" tenant for such intake projects, providing reliable revenue, reduced pumping costs, and clean energy, while also allowing for community development through small to large scale aquaculture development. In some cases, SWAC and desalination may provide such benefits as well. For many island and near-shore communities around the world, access to financing of the scale needed for a public infrastructure intake project is not currently available. An international mechanism to support such communities would enable accelerated project implementation, a projects pipeline that would support related industries in reducing costs, and act as the developmental steppingstone to offshore OTEC commercialization.

The lack of reliable cost data is often mentioned as a barrier to understanding the economic feasibility of OTEC plants. In your view, what are the knowledge gaps surrounding the economic aspects of OTEC? To what extent do you agree that the development of this potentially promising technology would benefit from more data sharing?

Cost data is a challenge as private sector involvement is required to get accurate costs, though without an existing industry there is little incentive for suppliers to provide such work/data for free. Developers and researchers who do such work often have to invest resources, so data is often proprietary. The costs of economic analysis such as is regularly done at NELHA, are also significant making it a challenging prospect for smaller implementations and the private sector.

Sharing results where possible should significantly reduce duplication while also alleviating many concerns financiers have about OTEC, but it would require commitment from a variety of competitors and a trust in the organizer to protect any IP revealed in the process. The easiest method to provide such data more widely is for governments to fund projects and publish relevant cost data with the support of the developing industries. Standard use cases with a range of potential costs and benefits would significantly help stakeholders consider implementation of OTEC projects. In the onshore case, the variability of intake pipe infrastructure would likely require significant cooperation from companies capable of such projects. In the offshore case, compilation of research to data and updates based on recent offshore developments should be informative.

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For onshore OTEC, ocean water intake can be treated as a public investment such as other infrastructure projects.

MAKAI OCEAN ENGINEERING'S OTEC POWER PLANT IN HAWAII

Hermann Kugeler
Vice President of Business Development
Makai Ocean Engineering, Inc.
Hawaii, USA

Which relevant milestones have been achieved during the operation of the OTEC power plant in the Ocean Energy Research Center (OERC) in Kona, Hawaii?

The milestones achieved with the 105 kW facility include:

- Being the world's largest grid-connected OTEC system.
- First OTEC plant connected to a U.S. grid
- Development and operation of autonomous controls system
- Led to the development of a fundamentally new heat exchanger technology that should reduce the cost of OTEC and enable commercial adoption.

To date, how much public funding and private investment has been granted for the construction and operation of this project?

The primary purpose of the funding is for heat exchanger research and development for OTEC, and not necessarily for the OTEC demonstration plant development. The program has received over $20M in funding since 2009. The construction and operation of the OTEC pilot plant itself is a small fraction of this cost.

The development of an OTEC project involves a wide variety of risks, including technical, regulatory and financial, could you describe which are the most critical ones you have encountered and how could they be overcome?

The financial risks are the most critical challenge that OTEC currently faces. OTEC is up against the economies of scale, making it difficult to scale up from Makai's 100 kW plant to a commercial OTEC plant. In the past it was believed that 100 MW would be the smallest commercially viable OTEC plant, meaning the system would need to scale 1000x. Makai's efforts have been focused on reducing the cost of OTEC in order to overcome these challenges and attract commercial developers to invest in the technology. Makai's efforts in reducing

Makai has learned a lot over the decades, but the most important lessons learned are related to the economic challenges mentioned above, and that the industry must do its best to reduce OTEC costs in any way.

the cost of heat exchangers has developed the thin foil heat exchanger (TFHX), which is an ultra-compact heat exchanger that is 5-8x more compact than off the shelf heat exchangers. Makai believes this technology will enable commercial OTEC plants at a smaller scale, on the order of approximately 10 MW.

Operation and maintenance of marine energy equipment have always been a challenge for the ocean energy industry. What difficulties have been faced on O&M and how have they been resolved?

Makai has developed autonomous controls, that would eventually enable "lights out" operation of commercial OTEC plants. The components used in OTEC, such as plumbing, heat exchangers, and pumps, have been used commercially in marine environments for decades, so the operation and maintenance of these systems are well known.

Makai has been pioneering OTEC research since 1979. What are the important lessons learned?

Makai has learned a lot over the decades, but the most important lessons learned are related to the economic challenges mentioned above, and that the industry must do its best to reduce OTEC costs in any way.

The large volumes of cold deep seawater required for OTEC energy production make possible many unique applications. What are your thoughts on the potential by-products from OTEC? Which applications Makai have been exploring?

While there are other uses for deep seawater, such as aquaculture and seawater air conditioning, the primary interest is in having these systems on-shore, which would not be possible for a commercial offshore plant. It is infeasible to build a large-scale commercial OTEC plant on-shore due to the pipeline requirements. The only case where we would tie other by-products to OTEC, at least at this stage, is for a smaller-scale research facility like that at NELHA, where the purpose of OTEC is not for commercial electricity production. In the near term, Makai believes that a commercial OTEC plant should be economically stable on its own as an energy provider, and not rely on other by-products. That being said there may be a place for these by-products like aquaculture, on future OTEC plants, that leverage the nutrient rich deep seawater, once OTEC has proven its commercial viability on its own.

The potential environmental impacts of OTEC have been studied extensively over the last decades. Based on your practical experience is it possible to "retire" some of the environmental effects that have been potentially assigned to OTEC?

The primary environmental concern when developing an OTEC plant is the discharge of nutrient rich seawater, and the risk of causing an algal bloom. This concern has been well studied, and there are methods to avoid this, so yes, it is possible to retire these concerns. The primary method to avoid this is to make sure the discharge is below the photic zone (the upper surface layer that receives sunlight). An algal bloom would require the nutrient rich seawater to be exposed to sunlight. The other method used to avoid this is designing the discharge in order to promote proper mixing of the discharge water within the ocean. Makai developed an environmental model that can be used to model the dispersion of the discharge water, to ensure the nutrient levels remain within acceptable levels.

There is consensus that a major roadblock to the large-scale adoption of OTEC has been the relatively high estimated Capital Expenses (CAPEX) associated with such projects; there is a need for a serious and medium-long term commitment from the industry and governments. In your opinion, how could such commitment be triggered?

Makai believes the next step in de-risking OTEC for commercial adoption and investment will be a long term operation of an OTEC system. Ideally, it would be good if someone would invest in the development of the first commercial OTEC system, but that may not be possible until a smaller system is developed and in operation for an extended period of time. This would not only

Makai Ocean Energy Research Center © Makai Ocean Engineering, Inc.

prove the system can be operated for long durations, but also provide truth data that can be used to validate Makai's cost models.

The lack of reliable cost data is often mentioned as a barrier to understanding the economic feasibility of OTEC plants. In your view, what are the knowledge gaps surrounding the economic aspects of OTEC? To what extent do you agree that the development of this potentially promising technology would benefit from more data sharing?

Makai has a good grasp of the economic feasibility of OTEC, and have developed an extensive cost model based on Makai's OTEC and other marine project experience. Makai often contacts marine contractors to get actual cost data to back-up our estimates, so there is a decent amount of data sharing between engineers like Makai and marine contractors when evaluating sites for OTEC development.

Makai has a good grasp of the economic feasibility of OTEC, and have developed an extensive cost model based on Makai's OTEC and other marine project experience.

1 MW OTEC POWER PLANT DEVELOPED BY KRISO

Dr. Hyeon-Ju Kim
Principal Researcher
Seawater Energy Plant Research Center
Marine Renewable Energy Research Division
Korea Research Institute of Ships and Ocean Engineering (KRISO)
KOREA

Which relevant milestones have been achieved so far with the 1MW plant developed by the Korea Research Institute of Ships and Ocean Engineering (KRISO) for installation on the coast of South Tarawa, Republic of Kiribati, in the South Pacific Ocean?

OTEC system and core parts were designed and manufactured from 2016 to June 2019. The system was installed onto a rectangular barge to conduct riser deployment as well as assembly checkups (leakage, etc.). Afterward, a trial operation was carried out successfully on the southern coast of the East Sea (near Pohang), in late September 2019. The system is still stored in Korea so that the project can resume when the border is opened, and the budget is secured in the near future.

Kiribati was selected as the demonstration site for the Korean OTEC plant due to its thermal gradient stabilization, and installation and operation conditions.

Why KRISO choose a small Pacific island to be the target of a 1 MW OTEC plant? How did it start the OTEC partnership formed by KRISO and the Government of Kiribati?

KRISO considered various sites worldwide including domestic sites suitable for technological achievement and demonstration experiments of the OTEC plant. In 2014, the president of Kiribati made a visit to KRISO's OTEC pilot plant at Goseong while visiting Korea for attending the Yeosu EXPO Symposium. After the visit, the president of Kiribati hoped to utilize electricity as renewable energy for SDGs achievement and requested the Korean government to demonstrate the OTEC plant in Tarawa. As a result of a field survey, Kiribati was selected as the demonstration site for the Korean OTEC plant due to its thermal gradient stabilization, and installation and operation conditions.

To date, how much public funding and private investment has been granted for the development of this project?

Public funding (from the Government of Korea) of $14M and private investment of $0.8M have been granted.

The development of an OTEC project involves a wide variety of risks, including technical, regulatory and financial, could you describe which are the most critical ones you have encountered and how could they be overcome?

Because no former project on practical use of ocean thermal energy was conducted and it requires a high initial investment cost, it is hard to secure the project budget. To overcome these issues, KRISO has tried not only to minimize the financial burden of the investment cost but also maximize the additional benefit of using discharged deep seawater for downstream applications such as district cooling, desalination, aquaculture and hydroponics. We also emphasized the necessity of climate technology to reach the government's carbon-neutral goals, which leads to higher demands for such R&D projects.

KRISO has led research and development on OTEC since 2010 and built a 20 kW OTEC pilot plant. How important was the research with this plant for the design of the 1 MW OTEC Kiribati plant? Which important lessons learned you could mention?

1MW OTEC Riser Installation at Pohang (Courtesy: KRISO)

1MW OTEC operation at Pohang (Courtesy: KRISO)

Lessons learned from pilot experiment are specifications of the key components (heat exchanger, turbine, etc.) to fill the gap between the theoretical modelling and the actual system, stabilization of initial and emergency operation, potential methods to reduce parasitic losses and so on.

The usefulness of OTEC-generated electricity to Kiribati and other islands may depend upon social acceptability and economic feasibility. What is your view on the approach for these two aspects?

Social acceptability was supplemented by capacity-building ODA (*Official Development Assistance*) projects such as SSUA (*Sustainable Seawater Utilization Academy*). This includes achieving sustainability of regional demand for energy (electricity and air-conditioning), water (desalination) and food (aquaculture and hydroponics) as living lab programs. Due to COP26, developing countries also have the opportunity to mitigate greenhouse gas. Moreover, OTEC can hold economic benefits by replacing the base load of the grid system and supplying more green and economic-efficient energy than the diesel generator.

OTEC Kiribati plant is the largest in the world and it may lead to more ambitious, larger-scale OTEC developments. How do you see future prospects for realising the potential of OTEC technology?

The 1 MW OTEC demonstration was designed for 24ºC seawater temperature difference and has successfully carried out in a trial operation (output of 338 kW under operating condition of 18.7ºC temperature difference) in Korea. If the demonstration of the 1 MW OTEC plant near the equators is successfully carried out in the future, competent professionals can draw a positive outlook on the scale of 10, 100, and 400 MW OTEC plants gradually. This will improve the power generation cost (estimated LCOE at $0.05/kWh~$0.1/kWh), facilitating the development of practical OTEC plant. These larger OTEC plants are most likely to be offshore type with the possibility of combining the P2G method (hydrogen, ammonia, etc) depending on technological development.

2

SWAC

Seawater air-conditioning (SWAC) is a renewable substitute for cooling in which seawater from the ocean at depths of about 700–1000 m and temperatures of 3–5 °C is pumped to the coast, into the cooling system, and the warmer water is returned to the ocean.

SWAC PROJECT OF THE FRENCH POLYNESIAN HOSPITAL IN TAHITI

Cathy Tang
Project Manager
SDE- Energy Service of French Polynesia
Tahiti, French Polynesian

The SWAC of the French Polynesia Hospital Center is now fully operational? What are the main characteristics of this project (including depth of collected seawater, pipe length and diameter)? Which challenges were faced in the development of this system?

Yes, the SWAC system of the French Polynesia Hospital Center, located in the town of Pirae, is now fully operational. The official commissionning of the installation took place on July 8, 2022.

It is characterized by:

- Marine structures (primary network): made up of two DN 710 mm HDPE pipelines, approximately 3,600 m long and up to 900 m deep for the pumping line; 200 m long and up to -5 m deep for the discharge pipe. The pipelines are equipped with various anchoring and stabilization equipment.
- A technical room housing all the equipment necessary for the operation of the SWAC system: located on the grounds of Aorai Tini Hau, 50 m behind Taaone beach and less than one kilometer from the hospital, the technical room is made of reinforced concrete, buried in the basement and made up of two levels. The low level, located about 7 m below the natural level, accommodates the primary pumps allowing the pumping of sea water from the depths. The upper level accommodates the heat exchangers allowing the transfer of cold temperatures from the primary network to the secondary network, the pumps of the secondary network as well as the SWAC control and regulation system.
- A secondary network: made up of two HDPE chilled fresh water pipes DN 450 mm, with a large part buried in the ground (about 600 m) and an aerial part (about 40 m), connecting the technical room from the SWAC to the chilled water network of the CHPF.

© GEOCEAN

The SWAC provides a maximum cooling capacity of 6 MWf to the hospital.

The main technical challenge of this project was the construction of the maritime pipelines and their installation, carried out on two geographical sites of Tahiti presenting distinct meteorological conditions. Indeed, the transfer operations from the construction site to the pipe laying site, and the laying itself are only possible at certain times of the year during which the weather conditions are favorable (swell and very light winds).

What are the advantages when compared to traditional air conditioning methods?

Air conditioning by cold water from the depth sea has the advantage of having low electricity consumption compared to cold production by refrigeration units. It can reduce electricity consumption related to air conditioning by up to 90% compared to a conventional system. No refrigerant is used, only sea water and fresh water.

Air conditioning by cold water from the depth sea has the advantage of having low electricity consumption compared to cold production by refrigeration units. It can reduce electricity consumption related to air conditioning by up to 90% compared to a conventional system.

SWAC can play a vital role in enabling the development of SIDS. The island of Tahiti, with major French Polynesia's electricity needs, benefits from a context, due to the bathymetry of its seabed, and existing expertise, favourable to the use of cold water air conditioning.

The development of an OTEC project involves a wide variety of risks, including technical, regulatory and financial, could you describe which are the most critical ones you have encountered and how could they be overcome?

As a public project owner, the most critical risks that have been identified concern the tendering procedures. Even if the regulatory framework for public procurement is present and its application makes it possible to legally award a public contract to a private company, challenging this award through legal action remains possible. Also, if the appeal is successful, it is quite possible that the execution of the contract will be interrupted. As part of this project, the client paid particular attention to scrupulously following the rules of the Polynesian public procurement code in order to ensure that no recourse could jeopardize the execution of the works.

Regarding the technical aspects, the very strong Polynesian experience on SWAC positions Polynesian actors as "knowledgeable" on deep pumping issues, the main technical difficulty of the OTEC solution.

What are the total costs of this project and how financing was met?

This project required an investment of 3.7 billion Pacific Francs (XPF), i.e. approximately 31 million euros, financed at 45% by equity from French Polynesia, 24% by a loan granted by the Agence Française de Développement (AFD), 24% by a credit granted from the European Investment Bank (EIB) and finally 7% by a subsidy from the French Agency for Ecological Transition (ADEME).

Operation and maintenance of marine energy equipment have always been a challenge for the ocean energy industry. What difficulties have been faced on O&M and how have they been resolved?

The implementation of the equipment is very recent and we do not yet have feedback on the operation and maintenance for this particular project. Nevertheless, we know from feedback on the SWAC structures already installed, in particular the one in Bora-Bora Hotel, that it is essential to ensure a regular inspection of the maritime structures to verify their integrity and intervene in prevention. Here again, the experience acquired on SWAC operations, for more than 15 years, has made it possible to consolidate the monitoring obligations (underwater inspections) but also to provide the CHPF SWAC installation with more technical choices and presenting guarantees of durability.

Dependence on imported fossil fuels has been a major source of economic vulnerability and a key challenge for small island developing states (SIDS) for many decades. Do you think SWAC can play a critical role in enabling the sustainable development of SIDS? What constraints do you see?

Yes, SWAC can play a vital role in enabling the development of SIDS. The island of Tahiti, with major French Polynesia's electricity needs, benefits from a context, due to the bathymetry of its seabed, and existing expertise, favourable to the use of cold water air conditioning. Nevertheless, to have interesting economic profitability, it is necessary to have an end-user with constant cooling needs (24h/24h), a location close to the sea coast and an air conditioning network by chilled water (the only system compatible with SWAC).

The impact of air conditioning on the overall electrical power demand being very high in an island environment (40 to 50% for a building) makes the SWAC solution an extremely relevant response to energy issues and consequently to the issues that they are climatic and economical for tropical island environments. The OTEC, by exploiting the same resources and allowing the production of electricity is also a solution particularly adapted to the problems and contexts that we know in the islands.

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SEAWATER HEAT PUMP SYSTEM

Seawater heat pump (SWHP) transfers heat from seawater with electrical energy input for heating and cooling building district's spaces. While air temperature varies a great deal according to season, the sea enjoys relatively stable temperatures at depth all year round. Therefore, in winter, SWHP can pump heat from seawater to higher temperature suitable for space heating; in summer, SWHP can use seawater as cold source for space cooling.

SEAWATER HEAT PUMP SYSTEM IN MONACO

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Monaco's expertise in heat pumps dates back to the 1960s. The Principality was one of the first countries to develop this kind of renewable energy on its coastline. Could you tell us what was the motivation for the implementation of this system? And the challenges that have been faced?

It's actually true that Monaco's expertise in heat pumps dates back to the 1960s. The Principality was one of the first countries to develop this kind of renewable energy on its coastline, installing its first seawater heat pump at the Rainier III Outdoor Swimming Stadium in 1963 to heat the water for the pool.
While air temperature varies a great deal according to season, the sea enjoys relatively stable temperatures at depth all year round.
Using heat pump technology, it is possible to draw heat or cold from seawater to warm or cool buildings, or to heat swimming pools. Buildings which take advantage of this form of energy need to consume electricity to operate the heat pumps, which then produce between three and four times more energy than they use.
The Principality has set itself the goal of reducing its GHG emissions by 55% by 2030 and achieving carbon neutrality by 2050.

Building energy being responsible for 33% of national GHG emissions in 2020 the Prince's Government is organizing the exit from fossil fuels to heat our buildings by articulating its approach through 3 axes :

- Regulations (new energy regulations and ban on fuel oil as of January 1, 2022);
- Incentives (subsidies to carry out energy audits and renovate buildings: replacement of windows, insulation of roofs, exemplary renovations);
- The deployment of renewable alternatives (thalassothermal loops, solar energy, geothermal energy, wastewater, etc.).

The deployment of two new thalassothermal networks, at La Condamine and at Le Larvotto, is at the heart of this strategy.

Which entities have been involved in its planning, design and operation?

We have, in Monaco, 3 district heating and cooling networks using sea water heat pumps as their primary resource – in the areas of Fontvieille, La Condamine, and Le Larvotto. Operating under the same branding – seaWergie – the Principality has chosen to outsource to a local public services energy concessionaire, the operations of these networks.

In Fontvieille, the network is fully operated by la SMEG (Société Monégasque d'Electricité et du Gaz) since 1986. In Le Larvotto and La Condamine - seaWergie is a consortium, made up of 3 Monegasque companies SMEG, SOGET and MES, was named the winner of the call for tenders by the Monegasque Government. On October 26, 2020, H.E. Mr. Pierre DARTOUT, Minister of State and Mr. Thomas BATTAGLIONE, Representative of the consortium, signed the concession agreement for the Condamine and Larvotto thalassothermal networks.

The public service delegation was granted for a period of thirty years and was entrusted to the dedicated company, the majority of whose capital is held by SMEG, the remaining 49% being shared between the State of Monaco, SOGET and MES.

But in order to fully operated heating and cooling networks, many public entities of the Prince's Government were involved in the planning, design and operations, as the thalassothermal loops are, as mentioned earlier, at the heart of Monaco's strategy in its carbon neutral objective.

What is the capacity of the seawater heat pump system in Monaco? Which area of buildings is supplied by this system?

As the operator of the main district heating and cooling scheme in Monaco, using sea water pumps, the total capacity in heating and cooling is as follow, over the 3 networks in Monaco:

- 49 MW of cooling capacity
- 37 MW of heating capacity

It's more than 7000 housing which will be able to benefit from this carbon neutral thermal energy, by 2025, avoiding, therefore, more than 10 $ktCO_{2eq}$ every year.

MKA-Boucle Thalasso Thermique © Direction de la Communication Gouvernement Princier

What are the benefits compared with conventional heating and cooling solutions?

Many benefits to the conventional heating and cooling solutions – **the first benefits lies in the performance coefficient**, meaning the amount of electricity necessary to produce thermal energy (being heating or cooling) – seawater heat pumps usually have a performance coefficient of 2 to 5. The second benefit that can be underlined is its **low space occupation in buildings** compared to traditional air cooling and heating systems – but also **avoid urban heat island effects**. The third benefit lies with the **energy sovereignty** – seawater heating and cooling networks for districts areas, are increasing energy independence for the territory. Other benefits could be drawn from conventional heating and cooling solutions, but that directly depends on what economic solution has been chosen to operate a district network for instance.

What are the total costs of this project and how financing was met?

The thalassothermal loops project in the areas of Le Larvotto and La Condamine is structuring for the future of the Principality, the State is investing more than 60 million euros, which the concessionaire seaWergie completes, in particular by taking charge of the replacement of collective heating installations.
This investment will make it possible to deliver fully carbon-free energy at a competitive price compared to fossil fuels, stable over 30 years.

Operation and maintenance of marine energy equipment have always been a challenge for the ocean energy industry. What difficulties have been faced on O&M and how have they been resolved?

The main challenge has to do with the water pumps and pipes which are in direct contact to sea water. But we have nowadays many solutions and more specifically materials very resistant to sea water. One has to keep in mind that we only use sea water for is temperature - never sea water enters a heat pump.
Monitoring and implementing a systematic preventive maintenance strategy is crucial and is supported by partnerships with local, reactive maintenance strategies.

Many coastal cities have the possibility for seawater heat pump implementation. However, it is often mentioned that there is insufficient understanding of seawater heat pump feasibility from a techno-economic and environmental point of view. Can you comment on this point?

It's a true fact that the possibility for seawater heat pumps implementation for many coastal cities have suffered from insufficient techno-economic and environmental understanding. As we have all noticed, the global political context can quickly have an impact on the "usual" heating habits (being gas or electricity). But more than its direct and short-term economic impact, seawater heat pumps can also be perceived as a heating and cooling tool to increase energy independence. Seawater heat pump networks are a real choice of public authorities and should be encouraged, and moreover looked with a TCO (total cost of ownership) approach, encouraging a CAPEX+OPEX analysis prior to any decision making.
With regards to its impact on the environment, it's actually a topic that customers frequently ask about. Therefore, over the period of 2011 to 2015 a study supported by both the French and Monegasque Government was made – entitle OPTIMAPac – provided a detailed analysis of the impact of such systems over the course of this study – leading to the conclusion that, in open environment no impact on both flora and fauna has been observed. We are all conscious that nature is an equilibrium, and therefore as network operator, we have a constant monitoring of temperatures to preserve this specific equilibrium.

It's a true fact that the possibility for seawater heat pumps implementation for many coastal cities have suffered from insufficient techno-economic and environmental understanding. As we have all noticed, the global political context can quickly have an impact on the "usual" heating habits (being gas or electricity).

THASSALIA POWER STATION ON FRANCE'S SOUTHERN COAST

Patrick Berardi
General Director of Thassalia
ENGIE Solutions France

Thassalia is an example of innovation in the energy transition. How this project was brought to life?

The first marine geothermal power plant in France, Thassalia is part of the *Euroméditerranée* urban redevelopment project.

"***Euroméditerranée*** *was created in 1995 at the initiative of the French government and regional authorities. It is an operation in the national interest, with the goal of positioning Marseille at the level of the largest European cities.* ***Euroméditerranée*** *is designing, developing and building the sustainable Mediterranean city of the future in the heart of the Aix Marseille Provence metropolitan area. The largest urban renewal and economic development project in Europe, it has already resulted in more than 8000 new housing units and 6000 refurbished homes, and attracted 20,000 jobs and more than 800 companies."** *Euroméditerranée* received *ÉcoCité* certification in 2009.

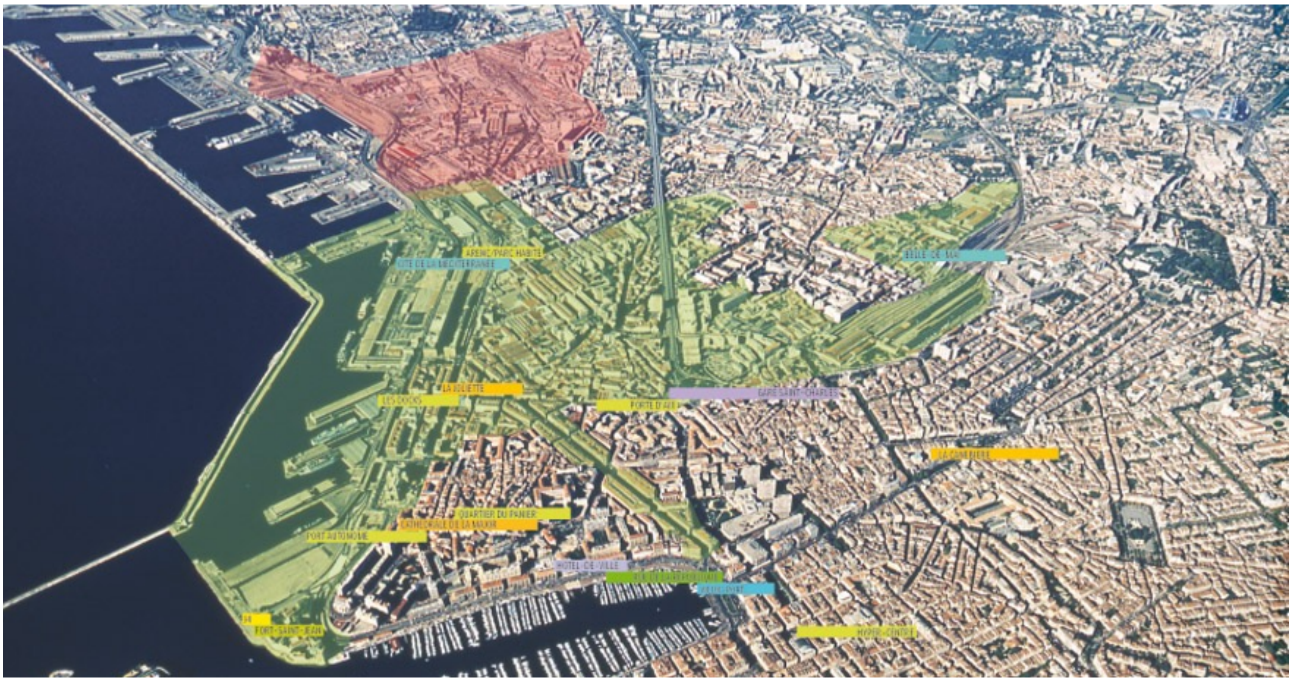
To supply buildings with sustainable energy as part of this project, an innovative solution has been developed in Marseille: the use of heat energy contained in the Mediterranean Sea through the "Thassalia" marine geothermal power plant.

The design specifications for Thassalia were as follows:

- Provide heat **AND** cold.
- Devise a production method using renewable energies: the obvious solution, given the geography, was to draw energy from seawater.
- Find an extraction point and plant location close to the buildings to be supplied.
- Supply more competitive energy than conventional energies and control increases in costs.

Marine geothermal energy makes use of the temperature difference between hot surface water and cold water from the seabed, pumped through pipes. On the coast, heat exchangers and heat pumps are used to produce heat or cold, as needed. The water is then channelled to the buildings to heat or cool them.

* Source: https://www.massiliamundi.com/letablissement-public-damenagement-euromediterranee/



Euroméditerranée urban redevelopment project

What is the capacity of Thallassia? Which area of buildings is supplied?

Thassalia's current capacity is 20 MW for heating and 20 MW for cooling.
This is sufficient to supply approximately 500,000 m² of buildings with heating and cooling: tertiary buildings and housing.
The current network covers 4 km in the *Euroméditerranée* 1 district and will be extended to the downtown of Marseille.

How did Engie cope with the diverse challenges in the implementation of this system?

ENGIE Group used all its expertise in this field to design and implement the project: in particular, its experience with the City of Paris cooling network and the Barcelona heating and cooling network.

What are the total costs of this project and how financing was met?

Out of a current investment of €44m, Thassalia has received more than €10m of public aid: ADEME, FEDER (Europe) and the four local regional authorities.

Operation and maintenance of marine energy equipment have always been a challenge for the ocean energy industry. What difficulties have been faced on O&M and how have they been resolved?

The main feature of operating this plant is the control of molluscs that grow in the facilities.
Here too, Thassalia has benefited from feedback from other similar facilities managed by ENGIE Group.
We automated the cleaning of our facilities according to the temperature of the seawater extracted.

Many coastal cities have the possibility for seawater heat pump implementation. However, it is often mentioned that there is insufficient understanding of its feasibility from a techno-economic and environmental point of view. Can you comment on this point based on the experience with Thassalia project during the past 5 years?

To carry out such an exemplary project, the prerequisites are as follows:

- Properly define the heating and cooling needs of the district to be served. Clients and their design offices often have very limited knowledge of their cooling needs and the cost of cooling in their overheads.
- Adapt the design of the plant to these needs: this is local renewable energy production and thus depends on the geography.

Can you unveil Engie's future plans?

It is intended to expand Thassalia towards Marseille downtown, to provide heating and cooling produced from green energy to an increasing number of residents.

(Courtesy: Engie)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OES OCEAN ENERGY SYSTEMS

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