Hydrothermal Energy: Sustainable Benefits for Island and Coastal Communities

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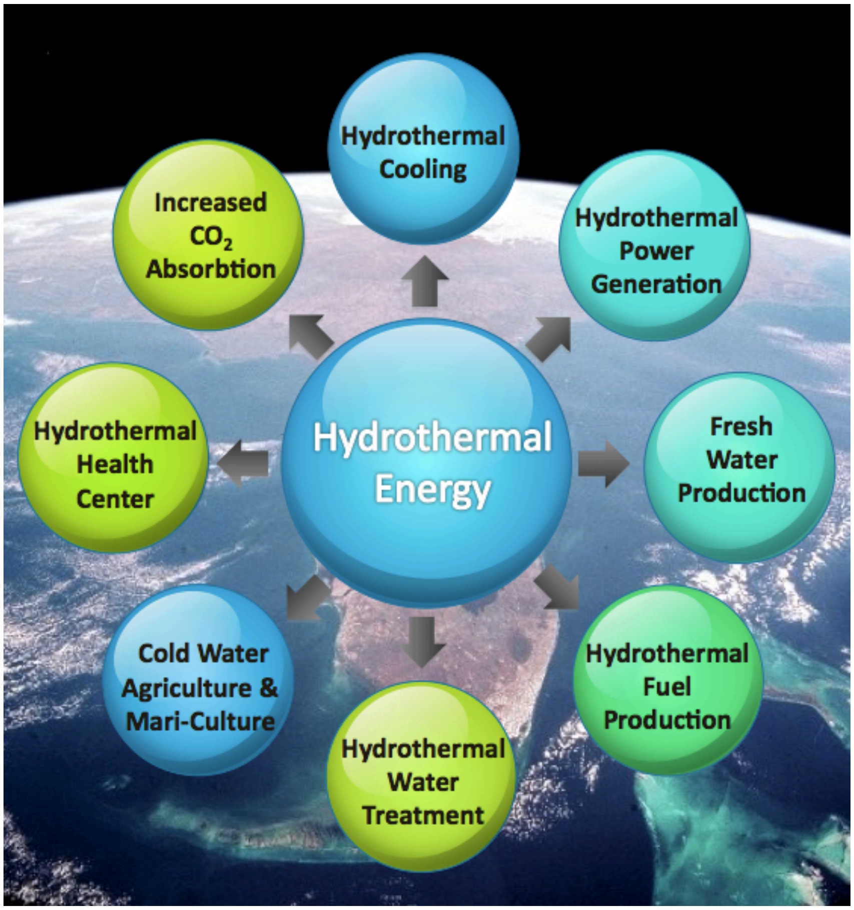
ABSTRACT

Drawing upon the common knowledge of geothermal energy and hydroelectric power, this paper introduces the general audience to Hydrothermal Energy. The paper briefly explores the history of the related art of Ocean Thermal Energy Conversion, which traditionally relies on the perilous submergence of large diameter pipes to access the deep water. The author advocates the innovation of using tunnel boring and directional drilling technology from shore to access ocean or lake water for sustainable energy, among other noteworthy benefits. Hydrothermal cooling projects in Canada and the varied businesses at Hawaii's Natural Energy Laboratory (NELHA) facility indicate that the key to commercial success is to capitalize on more than just one benefit of Hydrothermal Energy. The author proposes at least eight distinct benefits of adopting Hydrothermal Energy for coastal communities within reach of 39°F (4°C) water, referencing potential application sites in the US/Canada Great Lakes region, Florida, California, Mexico and island nations across the globe.



As of 2011, the author has 38 years experience in the HVAC industry and for the last 6 years, an innovator in renewable energy field with four renewable energy patents in the United States and Europe.
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INTRODUCTION

The challenge facing current and future generations is curbing CO_2 emissions while satisfying an increasing demand for energy, water and food. This challenge is being addressed with the use of alternative energy resources in places such as Boise Idaho where geothermal energy, or heat from the earth, is providing natural hot water to heat homes or in California where natural steam fields are producing power for buildings. Ocean Thermal Energy Conversion (OTEC) was conceived in 1881, with successful demonstration OTEC projects occurring in the latter part of the 20^{th} century. Using temperature differences that occur naturally in large bodies of water, the foremost current commercial benefit of this technology is seawater or lake-source cooling, collectively known as hydrothermal cooling. The Natural Energy Laboratory in Hawaii (NELHA) is home to ocean energy research and nearly 30 thriving tenant businesses generating revenue from ocean water. This paper proposes the integration of technologies from other energy producing fields into the process of acquiring Hydrothermal Energy, thereby effectively increasing the overall system efficiency and sustainability. In particular, the integration of directional drilling from the petroleum industry and tunnel boring in the hydro-electric industry are explored. The author cites eight commercial benefits that may be derived by taping natural resources of water with a minimum temperature difference of 20^oC (36^oF). The paper concludes with a suggested business model to spur the diffusion of this technology. The main purpose of the paper is to increase awareness of this alternative energy opportunity as a prelude to further research and eventual commercialization.

HYDROTHERMAL ENERGY

Hydrothermal Energy is the process of obtaining heat or energy from a large body of water. “Heat” should not be associated with high temperature but rather a relative temperature difference. Ocean Thermal Energy Conversion (OTEC) is a subset of what is termed Hydrothermal Energy in this paper. These OTEC plants may be applied from floating platforms or coastal bases. As a means of leveraging more commercial applicability, Hydrothermal Energy is addressed in this paper with reference to seaside or lakeside based applications. Readers should understand that water reaches its maximum density at a temperature of approximately 39^oF (4^oC). Colder, less dense water naturally exists adjacent to this heavy layer (“Properties” 2011). Many coastal regions have both deep cold water and warm surface water resources available. Most air conditioning processes are a two phase process but HVAC professionals understand that the process, in its simplest form, uses a working fluid (such as R-134a) and electricity powering a compressor, to create a temperature difference. The reverse of this process, or the Organic Rankine Cycle (ORC), is familiar to ocean energy professionals, where a minimum temperature difference of 36^oF (20^oC) in water, may be used with a working fluid (such as R-290) and an ORC turbine, to create electricity. This process, therefore, enables many coastal communities with access to cold and warm water to dual purpose the water that is transported to shore for both cooling and power generation.

The concept of generating electricity from ocean temperature difference was first introduced in 1881 by Jacques-Arsène d'Arsonval and the first practical demonstration was in 1930. French innovator Georges Claude, was enthralled with the potential of ocean energy when he convinced Cuban dictator, Gerardo Machado, to build ocean thermal power plants that “could light up not only the entire island and its new industry but also deliver surplus power to Florida by undersea cable” (Chiles 2009). Matanzas Bay, Cuba was selected for its relatively close proximity to cold and warm water. Starting in August of 1929, six foot diameter steel pipes in 70 foot sections were welded together and floated out to sea on pontoons in three sections when a storm hit and sank most of the pipe. Subsequent attempts to deploy the pipes by Georges Claude’s team similarly ended in a complete loss of the pipes. In the fourth and final attempt, Claude ordered more piping from France but this time from his own account and now dwindling fortune. In September 1930, the pipe was laid successfully but not as deep as planned and consequently with lower temperature differential. The power plant ran for 11 days and produced enough power to light forty 500 watt light bulbs (Chiles 2009). Investors viewed this as too little return compared to the risk. Although these attempts proved to be unsuccessful, valuable lessons were learned from Claude’s misfortunes. These lessons would be applied in future applications.

Ocean Thermal Energy Finds a Home in Hawaii

In 1974, the Natural Energy Laboratory of Hawaii (later named NELHA) was established by the State of Hawaii legislature on a 322 acre area at Keahole Point on the Big Island as a support facility for Ocean Thermal Energy Conversion (OTEC) research. If successful, NELHA would "prove the feasibility and usefulness of OTEC as an alternative non-polluting power source" ("Deep," 2010). In 1979, the first successful project was an at-sea, closed-cycle OTEC operation conducted aboard the Mini-OTEC, a converted Navy barge operating in waters off Keahole Point, Hawaii. This plant operated for three months and generated up to 55 kW of gross power. About 40 kW were required to pump up 2700 gallons/min of 42°F water from 2200-ft depth through a 24-in diameter polyethylene pipe and an additional 2700 gallons/min of 79°F surface water, leaving a maximum net power output of 15 kW. This preceded a shore based project by NELHA in 1980. Shore based Ocean Thermal Power Generation and seawater cooling techniques were proven at NELHA utilizing a series of pipelines that were constructed to draw warm surface seawater from 45 feet and deep cold seawater from 2000 feet. The deep ocean pipeline transitions from land under the shore break and then protrudes out the seawall where it is laid at an incline on the seabed down to the 2000 feet. On a visit to the NELHA facilities, the author learned that in 2006, the cold water pipe, which protruded from the seawall under the surf break, was experiencing unusually warmer water temperatures. This change in temperature coincided with a 2006 earthquake in the area. Subsequent investigation revealed a crack in the pipe near the protruding elbow joint. This crack has been repaired and the facility is in full operation. This experience raises a concern for the vulnerability of surface laid piping. Although there is room for improvement for the overall design of the applications, it is noteworthy that "NELHA is 'landlord' to nearly 30 thriving enterprises which generate about $30-40 million per year in total economic impact, including tax revenues, over 200 jobs, construction activity and high value product exports" ("NELHA," 2010). NELHA is an excellent model for the sustainable future necessary in the 21st century however also demonstrates the need to mitigate the vulnerability of OTEC to Mother Nature's violence.

Early Adopters of Hydrothermal Cooling

The NELHA experience spawned a group of ocean energy pioneers and, despite the US Government's abandonment of support for OTEC, these pioneers concentrated on cooling with deep lake water or deep seawater. These projects are collectively known as "hydrothermal cooling." As of 2010, there are four major hydrothermal cooling plants installed around the world. The Purdy's Wharf Complex in Halifax, Nova Scotia cooled a small office complex ("Seawater," 1992). Cornell University, has followed suit with a Lake Source Cooling (LSC) System that provides approximately 18,000 to 20,000 tons (63,300 to 70,340 kW) of cooling For over a decade, the Cornell campus

Lake Source Cooling Commercially Viable But Reveals Risk of Piping Deployment

Figure 1
The 1997 Toronto Canada, Enwave Deep Lake Water Cooling project is a breakthrough project in hydrothermal cooling. The HDPE pipe with concrete collars was floated out onto Lake Ontario and submersed in a controlled process. The 39^{o}F (4^{o}C) lake water is used to produce more than 59,000 tons (~207,500 kW) of natural cooling. The video of the historic installation told of tense moments in the installation when the wind precariously increased, perhaps risking the entire project.

has been cooled with 39°F (4°C) water from the adjacent Lake Cayuga. The previous mechanical chiller plant at Cornell in 1999 was reportedly operating at .83 KW/ton (4.24 COP). The LSC plant installed in 2000 is operating at 0.1 KW/ton (35.16 COP) or 86% less electricity (Cornell, 2011). The InterContinental Hotel in Bora Bora, of the Leeward Islands in French Polynesia, is cooled by deep seawater and is documented to provide 90% savings over an electric air conditioning system ("InterContinental," 2007).

Taking the current lead in hydrothermal cooling, the Enwave District Cooling project in Toronto provides approximately 59,000 tons (207,500 kW) of cooling from 39°F (4°C) water from the deep water of neighboring Lake Ontario ("Enwave," 2010). The project final cost was approximately $128 million dollars but one of the key return on investment strategies was to dual purpose the water, not only for cooling but also for pure drinking water. The Enwave Lake Source District Cooling project connected 3 sections of 2 kilometer long pipe and floated the 6000 meters of piping onto Lake Ontario as seen in Figure 1. To submerge the piping, they employed a controlled submergence technique developed by Joe Van Rysin and his team at Makai Engineering, Hawaii. The author viewed a project documentary video at the Enwave offices. It was noted that during the installation, the wind picked up suddenly and the vast pipeline on the surface precariously flexed as a snake. The pipe was successfully submerged but there was speculation that a further increase in wind velocity and the pipe might have snapped and been lost to the bottom. Sounding eerily similar to the misfortunes of Georges Claude, this near miss has once again indicated the need for a more robust solution in deploying pipes to access water.

DRILLED HYDROTHERMAL ENERGY

The preceding suggests that Hydrothermal Energy projects are feasible, but there is a need for innovation that lowers the risk and perhaps increases the commercial viability of Hydrothermal Energy. As an alternative means of accessing and discharging the water sources from pipes laid in the ocean, the author recommends tunnel boring machines (TBM) used to create hydro tunnels. "The largest diameter hard rock TBM, at 14.4 m, was manufactured by The Robbins Company for Canada's Niagara Tunnel Project. The machine was used to bore a hydroelectric tunnel beneath Niagara Falls, the machine has been named 'Big Becky' in reference to the Sir Adam Beck hydroelectric dams to which it is tunneling to provide an additional hydroelectric tunnel" ("TBM" 2011). Another option is to borrow the technology of Extended Reach Drilling (ERD) from the petroleum industry. Extended-Reach Drilling is the process of drilling relatively deep bores where the horizontal distance traveled is more than twice the true vertical depth. The ERD technique is generally a long-radius well. The wellbore shifts from the vertical to the

Directional Drilling and Tunnel Boring to Access Water for Hydrothermal Energy

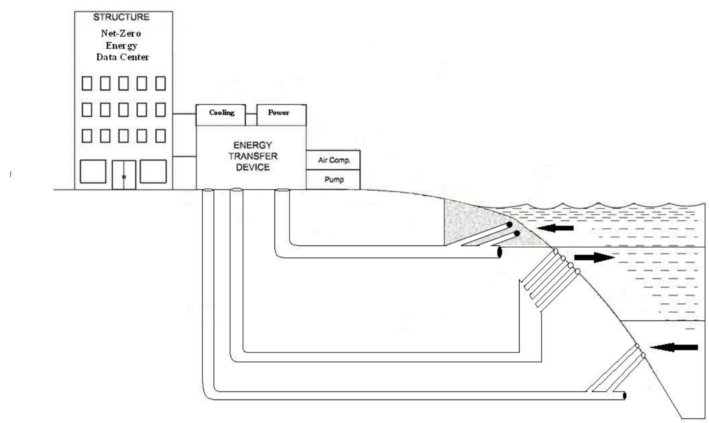

Figure 2

The above illustrates the concept of using tunnel boring and directional drilling to access and discharge cold and warm seawater or lake water. As of 2010 the longest tunnel using tunnel boring machines has a horizontal reach of 35.4 miles (57Km) while directional drilling has a horizontal reach of 7 miles (11Km) and true vertical depth exceeding 1 mile (~1600 meters). This environmentally responsible method of extraction and discharge avoids disturbing coral reefs and thermal pollution, while protecting the investment from earthquakes and hurricanes. The water resources when brought to onshore wells, will be used for space cooling and process cooling saving up to 90% of the comparable mechanical cooling cost. Clean low cost electric power may be generated from the temperature difference of warm surface water and deep cold water. This power may also be dedicated to generate low cost hydrogen fuel and a host of other benefits. Upon returning the mineral rich deep water to the upper layer, ocean atmospheric carbon absorption is increased, thereby partially mitigating anthropogenic climate change (Crews, 1997).

horizontal very gradually, with only slight changes in the degree of slope over the course of the bend. The oil company BP has documented the ERD wells drilled as of September of 2006 have a horizontal step-out reaching to 11 kilometers ("K&M," 2003).

The local conditions play a major role in determining the cost of a hydro tunneling or an ERD project. According to Tim Boulay, Senior Drilling Engineer of the K&M Technology Group, "Costs of ERD wells can vary greatly, anywhere from $3-4million up to well over $150 million. Contributing factors are overall complexity, location, geology, formation pressures, onshore or offshore, water depth, rig requirements, and industry economics" (Boulay 2010). As illustrated in Figure 2, using a combination of directional drilling and tunnel boring with current technology, indicate that distances up to 35.4 miles (57 Km) from the water resources are well within the reach of many coastal communities to construct Hydrothermal Energy plants. Not only do these techniques resolve the risks involved when submerging pipes, but the drilled conduits also protected the conduits from the violent ocean currents, unlike exposed pipes. An exposed pipe must transition from the earth to the open water underneath the shore break. During an earthquake, the pipe may be exposed to different stress levels, particularly at the junction. Provided that a drilled conduit does not cross a fault, during an earthquake, the pipe should move together with the surrounding rock encasement thereby decreasing the conduit's vulnerability. Multi-disciplined teams should evaluate the cost and the risk of various alternatives.

Pumping Water with Compressed Air with Zero Energy (From the Grid)

Ocean energy pioneer of Hawaii, Dr. Luis Vega (1999), teaches us that typically 20% - 30% of the parasitic power of an OTEC plant can be consumed by mechanical pumping of the water. To minimize or avoid this excess consumption, the author suggests using "airlift" technology to move the water with air pressure rather than mechanical pumping. In the oil industry, air or gas is injected within the down hole about one third of the true vertical depth. The bubbles expand as they rise to the surface, thereby bringing the fluid to the surface. Airlift specialist, Dr. Sam Kondo of Dublin, Ohio, has developed and demonstrated a special version of an airlift pump which can move massive amounts of water with relatively low air pressure and low power consumption (Kroeger 2010). Taking this concept one step further, a company in Massachusetts, is developing a technology to integrate an air compressor directly connected to a wind turbine to generate and store compressed air. This compressed air energy source can be used to pump water from the depths without using grid power and without the corrosion and maintenance issues of mechanical pumping of ocean water. This would also mitigate many of the concerns of harm to marine organisms as stated in the DOE report to Congress (DOE 2009). Therefore, it becomes entirely possible to eliminate the parasitic power mentioned by Dr. Vega, and be independent from the grid, if wind, wave, tidal or ocean current turbines are deployed to compress the air to transport water. Equally as important in any feasibility of Hydrothermal Energy plants are the revenue streams. A comprehensive list of revenue streams are listed and explained in the next section.

Hydrothermal Power Generation
The Closed Cycle Organic Rankine Cycle (ORC)

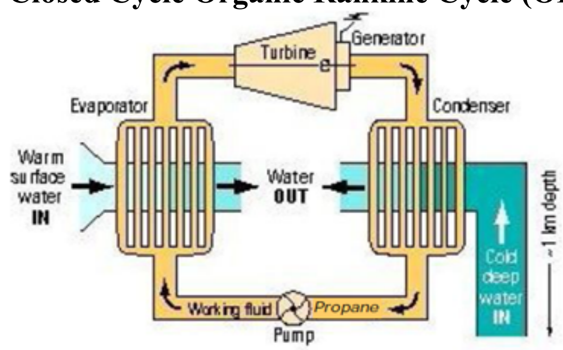

Figure 3
The above modified graphic (Inman 2009) depicts a closed cycle Organic Rankine Cycle using propane as a working fluid. The cold water heat exchanger condenser functions to have the propane change state from a gas to a liquid while the warm surface water heat exchanger evaporator turns the propane into a gas. The gas, on its way to complete the cycle, gives up its energy to a turbine which turns a generator to produce electric power.

EIGHT BENEFITS OF COMPREHENSIVE HYDROTHERMAL ENERGY PLANTS

1 - Hydrothermal Cooling

Most deep lakes have a dense boundary layer called a "hypolimnion" layer which secures a vast renewable supply of 39°F (4°C) water year around. Lake Ontario is a particularly deep lake already hosting one of the first hydrothermal cooling projects mentioned earlier. Environmental scientists studying the environmental impact of hydrothermal cooling have stated that 20,000 cubic meters per second could be extracted and replaced without harming the physical properties of Lake Ontario (Newman and Herbert 2009). At a temperature difference of 10 degrees Fahrenheit (39°F to 49°F), the amount of cooling potential for natural water district cooling plants along the shores of New York State and Ontario, Canada would be over 132 million tons (464 million kW). Lakes Superior, Michigan, and Huron have an even greater potential. Many industries use a great deal of electrical power in process cooling necessary for the production of their products. Data Centers, Flat screen TV manufacturers, micro chip manufacturing, automotive, dairy and food industry, to name a few, all use cooling in their process, the cost of which at say 1.0 KW/ton (3.52 COP) becomes part of the product cost. Coastal communities near deep cold water may consider Hydrothermal Cooling plants to attract industries to their area to increase the employment while lowering the companies cost and carbon foot print. The predecessor to the US Department of Energy, ERDA, in 1975-77, funded two studies on the "Feasibility of a District Cooling System Using Natural Cold Waters" (Hirshman and Kirklin 1977). The initial report concluded that the coast of Southern Florida, from Fort Lauderdale to Miami Beach, would be the most suitable location in the US to use naturally cold water for comfort cooling. The second report made an actual feasibility study for a Miami Beach seawater district cooling plant situated at Indian Beach Park. The conclusion of the report states that the "payoff of investment costs with energy savings is seen to be in the fifth year of operation using the recognized discount/inflation rate of ten percent and a differential energy cost escalation rate of seven percent" (Hirshman and Kirklin 1977). The feasibility site seems to be still available at the present time (September 2011). Miami, Los Angeles, Chicago, Puerto Rico, the islands of the Caribbean and Hawaii, among many other areas, are all located within reach of deep water and can therefore utilize Hydrothermal Cooling, perhaps approximating savings of electricity on the order of 86% to 90% as was documented in the aforementioned Cornell and InterContinental Bora Bora Hotel hydrothermal cooling projects. HVAC professionals, cooling customers and utilities in deep water coastal communities are well advised to consult with oceanographers to preliminarily assess the natural cooling opportunity in their locale. Once the resource is confirmed, the author recommends that a qualified, multi-discipline team make a feasibility study.

2 - Hydrothermal Power Generation

Figure 3 gives the reader a visual representation of the organic rankine cycle for producing electricity. HVAC professionals will recognize this cycle as the reverse of the air conditioning cycle. There has been some research to improve the output and efficiency of an OTEC ORC system by integrating solar energy into the cycle. Yamada et al. (2009) illustrates two methods to integrate solar thermal energy to ocean energy. The "SOTEC a" concept uses solar collectors to preheat the ocean water prior to entry into the evaporator heat exchanger thereby increasing the temperature difference and energy potential. Yamada's "SOTEC b" proposes to superheat the working fluid with solar collectors to increase the energy potential. The author decided to take the conceptual design one step further to incorporate the aforementioned concepts but emulate the design practice of an air conditioning unit to create a Hydrothermal Power Generation Plant. An innovative step in designing a cost effective Hydrothermal Energy power generation system would be to start with the turbine generator by maximizing the capacity within the physical constraint of the envelope of a 40 foot ISO shipping container. This would enable a turbine generator module that could be readily duplicated and cost effectively shipped and installed. Using a warm water resource of 76^{o}F in heat exchangers to evaporate propane (R-290) and a 40^{o}F cold water heat exchanger to condense propane, a single stage turbine generator could theoretically be manufactured to within the envelope of a 40 Foot ISO container and produce 9.6 megawatts of power. See Figure 3. Incorporating solar power indicated that over 40 megawatts of power could be generated from the same envelope. The detailed results and diagrams were documented in a previous paper by the author ("Jagusztyn & Reny 2010"). Much more work in research and development needs to be done to realize this potential but a path has been illuminated to generate power by collocating two temperature sources with a temperature difference of at least 36^{o}F or 20^{o}C.

3 – Fresh Water Production

Only one percent of the earth's water supply is drinkable fresh water. Efforts are being made to cost effectively desalinate ocean water at coastal communities around the world but these plants are energy intensive. At NELHA, John Craven pioneered "Skywater" which is basically using deep cold water in coils exposed to outside air to condense the humidity into pure fresh water. Another alternative is to dedicate a portion of the Hydrothermal Power generated to desalinate ocean water, thereby providing an abundant new supply of healthy drinking water. In the April 2010, special issue of National Geographic dedicated to water, an article outlines "three technologies to reduce the energy requirements of desalination by up to 30 percent". The technologies are Forward Osmosis (on the market 2010-2012), Carbon Nanotubes (on the market 2013 – 2015) and Biometrics (on the market 2013 – 2015) (Lange 2010).

4 - Hydrothermal Fuel Generation

Fuel to power land, air and sea vehicles may be generated from Hydrothermal Energy. The process may be initiated by exposing filtered humid air to the cold seawater in a closed circuit, generating pure liquid H_2O. Through the process of electrolysis, direct current electricity from Hydrothermal Power Generation may be used to drive off the hydrogen molecules from the water. The resulting hydrogen gas may be liquefied by another dedicated hydrothermal energy turbine, driving a compressor to produce hydrogen fuel. The downside of hydrogen fuel, however, is the relatively high cost to assure safety in transport. Alternatively, nitrogen may be sequestered from air and combined with the hydrogen gas to form ammonia NH_3, which is an excellent fuel and relatively safe in transport. This illuminates a path to a source of fuel beyond the hydrocarbon era. Island countries, such as the island of San Salvador in the Bahamas, with warm inland saline lakes, and deep cold water just off shore may then produce all their cooling and electrical power needed and be self sufficient for fuel needs. They may export the fuel that is in excess of their needs creating a new source of wealth.

5 - Hydrothermal Water Treatment

Along with hydrogen production in the electrolysis process, oxygen gas is produced as a byproduct. Oxygen gas may be collected to provide an abundant source of low cost oxygen to clean waste water for re-use or for benign re-introduction to the environment. The oxygen may also be an additional revenue source. The Linde company, a renown provider of industrial gas, gives its customers guidance for utilizing industrial gases such as oxygen. Linde's paper "Enhanced Waste Water Treatment with Pure Oxygen" ("Enhanced," 2009) may serve as a good reference to use the liberated oxygen in the previously mentioned Hydrogen Fuel Generation process.

6 - Cold Water Agriculture and Mariculture

As previously mentioned the Natural Energy Laboratory in Hawaii (NELHA) has established not only the feasibility of deep ocean technologies but demonstrated the commercial viability by their tenants of auxiliary benefits such as agriculture and mariculture ("NELHA", 2011). The use of cold natural water to increase output of agriculture and seafood was pioneered by ocean energy expert Dr. John Craven in Hawaii. ColdAG™ has the potential to triple coastal farming output. As Dr. Craven explains in a video on Deep Ocean Water Agriculture, "cold deep ocean water is pumped through irrigation pipes embedded in the soil. No salt water touches the earth but the ground is cold (10°C / 50°F). This produces condensate on the pipes just like drip irrigation. But more than that, a temperature gradient exists between root and flower that pumps phosphates and nitrates into the plant with a Carnot efficiency that is at least three times greater than nature can provide. The results are unbelievable in terms of size, sweetness and rate of growth" ("Global," 2007). Dr. Craven's team in Hawaii has grown grapes for wine in 120 days using Deep Ocean Water Agriculture. The normal gestation period for grapes is 240 days. ColdAG™ , therefore, can produce three grape crops per year instead of just one. The possibility now exists to turn coastal regions near deep cold water into very productive agricultural communities. Countries like Haiti, with deep water very close to shore, have poor soil conditions exacerbated by deforestation. Deep Ocean Water Agriculture may possibly be able to restart their agriculture industry.

Aside from the agriculture benefit, the mineral rich seawater may also be used in mariculture farms to increase algae production for biofuels and an abundant food supply of fish and shellfish. More information on this benefit may be obtained from the Common Heritage Corporation website. This corporation was founded by Dr. Craven and is based in Honolulu, Hawaii USA.

7 - Hydrothermal Health Centers

The mineral rich seawater may be used to promote health in humans. Commonly used in Thalasso therapy, trace elements of magnesium, potassium, calcium, sodium, and iodine found in seawater are believed to be absorbed through the skin. The therapy is applied in various forms, such as warmed seawater showers. Thalasso therapy may be an effective revenue and occupancy generator for deep ocean water resorts as is demonstrated in Bora Bora ("InterContinental," 2007).

8 - Increased Atmospheric Carbon Absorption

Currently, there is an estimated 8 billion tons of CO_2 outflow per year into the atmosphere while only 3 billion tons of CO_2 inflow is being absorbed by the oceans and land (Senge et al. 2008). The 5 billion tons of atmospheric CO_2 imbalance presents a serious challenge to human society. Returning the ocean water after using it thermally is an important part of environmentally responsible Hydrothermal Energy utilization. Refer to the middle conduit or outfall of the Drilled Hydrothermal Energy illustration in Figure 3. In the preferred embodiment of this innovation, the return water, which is at a higher temperature, is discharged at a middle level in the body of water at approximately the same temperature that exists at that point in the thermocline. By introducing mineral rich deep water to the upper level of the ocean, a process beneficial to the environment is enacted. In a detailed overview of the OTEC system, Richard Crews (1997) demonstrates that "OTEC is non-polluting; in fact, it is ecologically positive since it enriches nutrient-poor surface water and tends to "sink" carbon. The nitrogen, phosphorus, silica, and other nutrients raised from the deep are combined via photosynthesis with atmospheric and ocean-dissolved carbon dioxide to produce increased biomass and reduce atmospheric carbon load." Accordingly, future Hydrothermal Energy plants, in addition to lowering carbon emissions, also increase ocean carbon absorption. Properly executed and comprehensive Hydrothermal Energy plants emulate nature in that there is no waste. Moreover, there is great revenue potential in carbon trading.

A POSSIBLE BUSINESS MODEL: CHARTER CORPORATIONS

Perhaps a business model of the distant past may be combined with a modern IT business model to jumpstart the commercialization of Hydrothermal Energy Plants. In 1828, the state of Massachusetts granted a charter to the Warren Bridge Company to build a bridge over the Charles River. The bridge, once constructed, was to gain revenue by tolls until all the capital cost, operating cost, and an agreed upon profit was obtained. At that point the charter would be dissolved and the bridge made toll free to the public. In modern times, the IT industry developed a solution to the high capital cost and relative short life of IT equipment with a business model of Infrastructure as a Service (IaaS). Basically, the IT Infrastructure and service to maintain it is handled by a third party and sold as a package to a company needing computing service. To the customer, this scenario eliminates the burden of ownership and operation of sophisticated IT equipment and lets them focus on their core business. The two business models may be combined to create a Charter Corporation that Builds – Owns – Operates -Turns over (BOOT) the Hydrothermal Energy Plant. The charter corporation may be a consortium of innovators, geologists, engineering firms, tunnel boring and directional drilling firms, construction firms, environmental engineers, scientists, and financial institutions. The charter corporation may also include anchor customers such as a utility company, data center operators, and hotels. The local government grants rights to a suitable property and BOOT rights to the Charter Corporation. Once the charter corporation executes and operates the plant and all its members repay their costs and a reasonable profit from the revenues, the ownership of the Hydrothermal Energy Plant reverts to the local government providing added value to benefit the community. The Charter Corporation, after such experience, reforms the consortium and goes on to other communities in the same or even improved process.

CONCLUSION

The trials and triumphs of ocean energy from 1930 to 2010 indicate the feasibility for Hydrothermal Energy yet demonstrated that the application demands innovative ways to make the system both commercially and environmentally viable. The author introduces a concept to co-opt existing technology in directional drilling or tunnel boring with Hydrothermal Energy to create reliable access to the water resources. This method mitigates some of the risks of ocean energy extraction as was experienced by past attempts and current applications. Based on the performance of existing Lake Source Cooling Plant at Cornell N.Y. and the Deep Seawater cooling plant in Bora Bora, Hydrothermal Cooling plants may be installed in such places as the Florida coast from Stuart to Miami reducing the cost of air conditioning by as much as 90%. The coastal United States and Canadian communities of Lake Ontario could have up to 132 million tons (464 million kW) of process cooling plants using natural cold lake water to lower product cost and attract factories. In addition to cooling, accessing a warm water source of at least 36°F (20°C) temperature differential has the potential of generating electric power by using heat exchangers and organic rankine cycle turbines. Preliminary designs estimate that approximately 10 megawatts of power can be obtained from modular heat exchangers and a turbine generator designed to the envelope of two or three ISO 40 foot containers per module. Four times more power is theoretically possible by integrating solar energy provided space is available. This power may be used for many purposes including power generation for island communities without burning fuel, fresh water production, hydrogen or ammonia fuel production, oxygen waste water treatment and increasing agriculture and seafood output. Hydrothermal Energy plants address climate change by not only reducing the rate at which we currently emit CO_2 but by also absorbing the CO_2 out of the atmosphere. Hydrothermal Energy Plants represent a significant revenue potential for carbon trading. A business model for commercialization of Hydrothermal Energy Plants is suggested based on a Charter Corporation of stakeholders to Build-Own-Operate the facility until all the stakeholders have paid their costs and a reasonable profit. At that point the Charter Corporation is dissolved and the facility is turned over to the local community providing value for the long term. The Charter Corporation reforms in another community to repeat the business model with more experience. Government, NGO, commercial, academic and research institutions are invited to study and model Hydrothermal Energy Plants in areas within 35 miles (57Km) of 39°F (4°C) water and at least 36°F (20°C) of temperature difference. Engineers and entrepreneurs are well advised to consult with oceanographers, geologists, and directional drilling / tunnel boring professionals to assess the comprehensive set of Hydrothermal Energy opportunities in their local community.

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