# The Prospect of Hydrothermal Net-Zero Energy Data Centers

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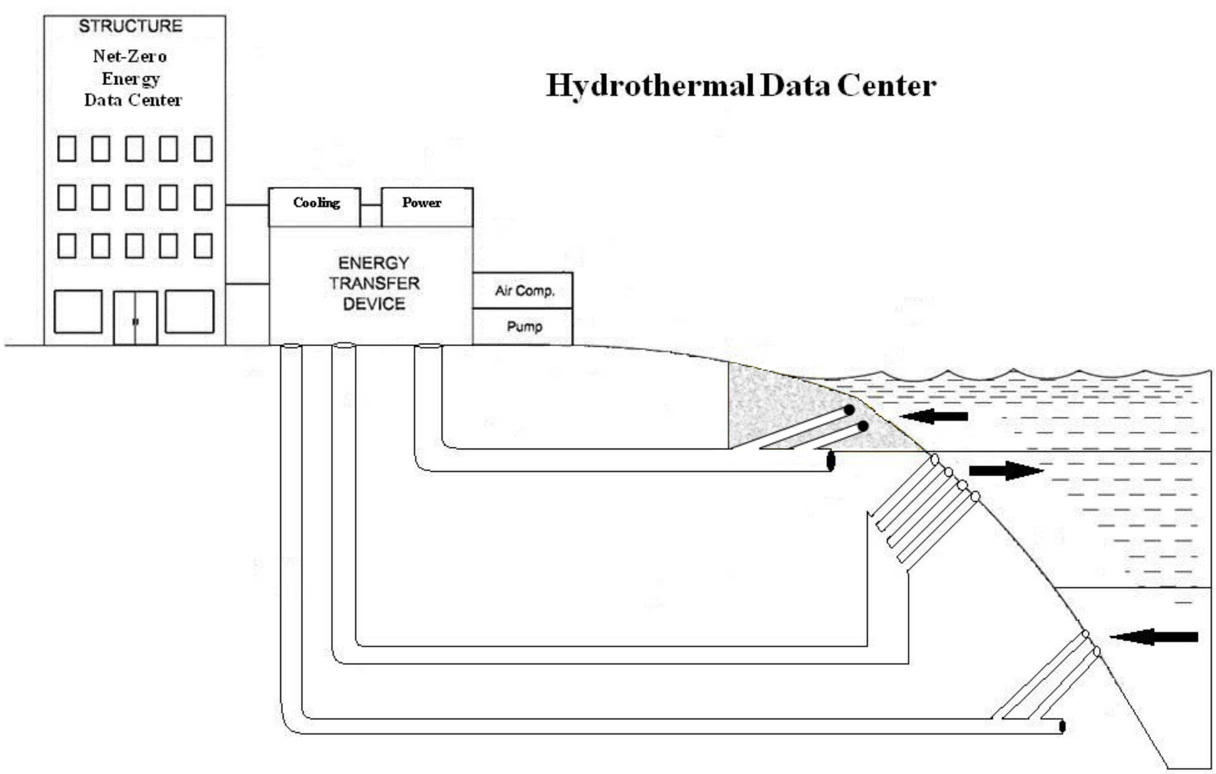
### ABSTRACT

*Data centers account for 1.5% of the energy consumption in the United States according to a recent report by the Environmental Protection Agency. These facilities' IT power and cooling requirements may increase in the future, especially with the rise of cloud computing and increased heat densities of servers. Since most utility power is generated by burning coal or fossil fuel, innovation is essential to meet the challenge of providing sustainable cooling and power for data centers. This paper proposes using Hydrothermal Energy for data centers whereby cooling and power are both sustainably generated. Coastal communities that have nearby cold and warm water resources are candidates for future data centers that can be operated completely off the grid while absorbing carbon from the atmosphere. The paper acknowledges that, while there are still challenges to be met in designing these facilities, Hydothermal Net-Zero Energy data centers are within the realm of possibility.*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## INTRODUCTION

Energy requirements for information technology are an ever-increasing part of our economy. The EPA suggested recently that IT energy represents approximately 3% of the energy consumption in the United States with data centers accounting for roughly half of that energy. Although many data centers are reducing power consumption by vitualization, IT power and cooling requirements  may still rise in the future, especially with the potential growth of cloud computing and increased heat densities of servers. In the United States, over 70% of electricity is generated by fossil fuel. Renewable energy and innovation are essential to meet the challenge of providing sustainable cooling and power for data centers. Google has responded to the need for sustainable cooling with their data center project in Hamina, Finland where, instead of using chillers, the facility will be cooled by cold seawater brought in by large pipes from the Baltic Sea. While this solution of natural water cooling sets a precedent for sustainable cooling, the need for sustainably powering the facility and the equipment has yet to be resolved. This paper proposes Hydrothermal Energy for data centers whereby cooling and power are both sustainably generated. While the paper addresses additional measures that must be taken to enable a completely sustainable approach, the author also suggests a more reliable method for transporting the water from the water source to the data center. Using tunnel boring or directional drilling technology from shore, multiple hydro tunnels can be erected to reliably access the water, protecting the pipes both during deployment and from natural disasters during the life of the pipes. The paper concludes with a suggested business model to spur the diffusion of this technology.

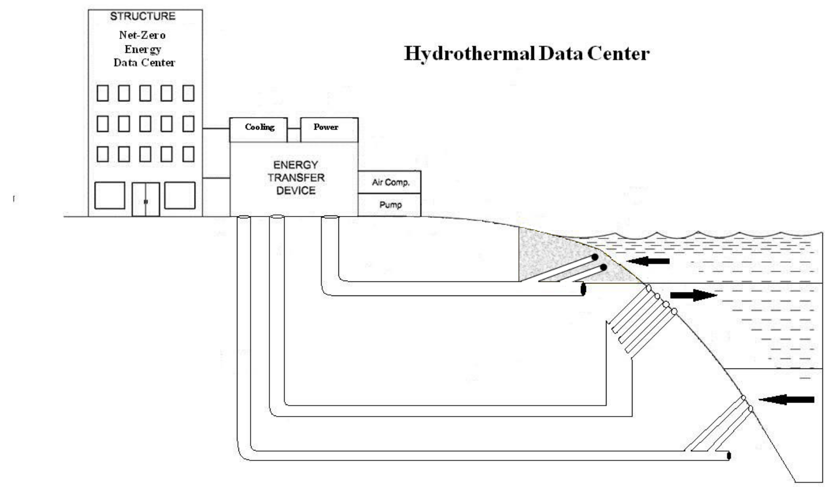



***Figure 1***

*The above illustrates the concept of a large data center 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). Many coastal regions are within this reach making them candidates for future data centers. This environmentally responsible method of extraction and discharge avoids disturbing coral reefs and thermal pollution, while protecting the investment from earthquakes and hurricanes. The cold water, when brought to onshore wells, will be used for cooling the data center thereby saving ~90% of the comparable mechanical cooling cost. Organic Rankine Cycle turbines and heat exchangers will generate clean electric power by utilizing the temperature difference of warm surface water and deep cold water. This power is used to power the IT equipment and any auxiliary power needs. Therefore this would be Net-Zero Energy Data Center. As a first look, the prospect of locating data centers near the coast may seem threatening to some data center professionals due to possible corrosion with salt laden air. There are mitigations however, such as direct liquid cooling (instead of air), coated boards used by HVAC manufacturers, and lessons learned from Google's seawater cooled "compressor-less" data center. Perhaps the most significant aspect of the application is that upon returning the mineral rich deep water to the ocean's upper layer, at the proper temperature, ocean atmospheric carbon absorption is increased, thereby partially mitigating anthropogenic climate change. (Crews 1997)*

## THE CHALLENGES AND OPPORTUNITIES FOR DATA CENTERS OF THE FUTURE

A data center facility is a building housing mission-critical systems such as computing and communications hardware. The Uptime Institute has provided guidance to design professionals as well as non-technical managers and executives for data center infrastructure by setting standards for reliability grouped in four Tiers. A Tier I, or basic data center, features non-redundant capacity components and a solitary non-redundant distribution path serving the computer equipment. The application is a building that is designed for IT equipment and an improvement over an office building with a mixture of office equipment and IT equipment. The further Tiers are performance standards for varying levels of redundancy. A Tier IV facility is a fault tolerant data center that features "multiple, independent, physically isolated systems that each have redundant capacity components and multiple, independent, diverse active distribution paths simultaneously serving the computer equipment" (Turner 2008). These are for instance "24 by forever" service data centers with a performance standard and redundancy assuring 99.99% reliability.

CAPEX is a generally accepted acronym for capital expenditures on infrastructure and equipment while OPEX is the term used to describe the operating expenses of a facility. The Uptime Institute also gives guidance of the relative capital cost per KW/square foot of IT equipment between the Tier I, II, III, and IV classifications. A Tier I facility would typically have a typical CAPEX of $10,000 per IT KW/SQFT whereas a Tier IV facility may be $23,000 per IT KW/SQFT (Schmidt 2011). OPEX is a major concern for data center owners and operators. IBM's Chief Engineer for Data Center Energy Efficiency, Roger R. Schmidt, Ph.d, P.E. claims that his firm's data center experience that OPEX exceeds CAPEX by a factor of 3 to 5 times over a 20 year period (Schmidt 2011).

In the IBM Jeopardy Challenge game show, "Watson", an IBM computer, bested two top human Jeopardy champions in response to questions read by Jeopardy host Alex Trebec. The event opened up future possibilities of healthcare professionals querying computers like Watson in a human voice and getting the advice of all the world's medical journals. The system of 90 linked servers of computers like Watson represent the challenge of cooling future data centers because of the increasing level of heat density. "Typically only about half the power entering the data center is used by the IT equipment. The rest is expended for power conversions, backup power, and cooling. Peak power usage for data centers can range from tens of kilowatts (kWs) for a small facility to tens of megawatts (MWs) for the largest data centers" (Data Center Energy Forecast 2008). The Green Grid (2009) introduced a metric called the Power Usage Effectiveness (PUE) to give a snapshot of the power usage within a data center. PUE is defined as the total annual energy use by the data center divided by the total annual energy used by the IT equipment. A recent survey of over 120 data centers submitting information for the US Energy Star program averaged a PUE of 1.9. A data center's cooling load for just the IT equipment ranges from 75 to 150 watts per room square foot for low-density designs to over 300 watts/sqft for high-density servers (Patterson 2011). To highlight the energy intensity of the data centers, one may compare the cooling load per square foot to the best practices of green buildings, which are in the range of 3 to 6 watts per room square foot according to the ASHRAE Green Guide (2003).

The overall challenge posed by the increasing energy demands of data centers and other human inventions is the overall impact on the environment in terms of carbon emissions causing what is generally termed anthropogenic climate change. Environmental scientists, such as MIT's Peter Senge, help us understand the magnitude of the situation. 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 naturally absorbed by the oceans and land. The 5 billion tons of atmospheric $CO_2$ imbalance is the serious challenge at hand. Ice core samples at the poles allow scientists to document the portion of Carbon Dioxide and Oxygen dating back as far as 666,000 years. Periodic large disparity of excess $CO_2$ proceeded the ice ages in past history and this is perhaps a natural process. Documenting the parts per million of $CO_2$ and $O_2$ in recent history indicates that our atmosphere is at an unprecedented level of $CO_2$ excess, suggesting the need for a collective mitigation to sustain our survival (Senge et al. 2008). In regards to data centers in particular, a number of initiatives are being taken to meet the aforementioned environmental and financial challenges. Efficiency gains are being made in data centers with state of the art facilities achieving a PUE of 1.2 "Typical equipment in a state-of-the-art facility includes: 98% efficiency transformers; 95% efficient UPS; Liquid cooling to the racks; Cooling tower; Variable-speed drive pumps; CHP" (Data Center Energy Forecast 2008). Google's data center in Finland is using cold seawater and heat exchangers for cooling without any compressor driven cooling equipment. While these and other initiatives lower the OPEX and decrease the environmental impact of data centers, a totally sustainable approach has yet to be found.

## THE OPPORTUNITY OF HYDROTHERMAL RENEWABLE ENERGY

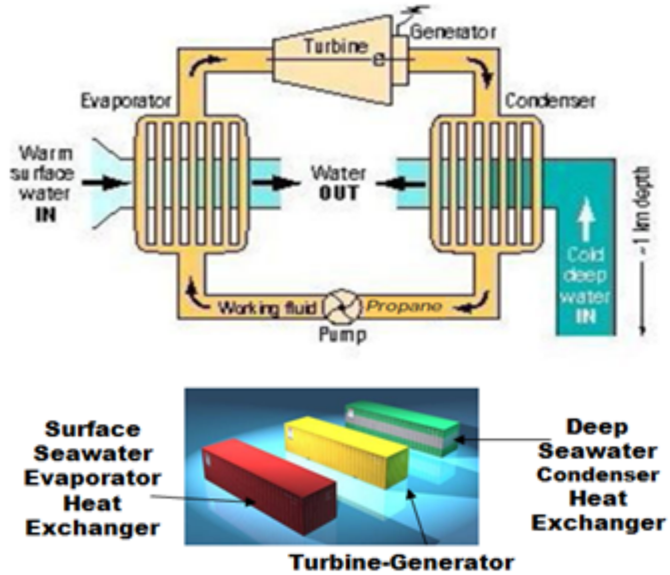
The concept of Net Zero Energy Buildings (NZEB) has gained traction in engineering and building design communities around the world. To help us understand the concept, ASHRAE (2009) defines "Net-Zero" as "Buildings which, on an annual basis, use no more energy than is provided by on-site renewable energy sources." Renewable energy sources such as heat from the earth or geothermal energy and hydroelectric power are commonly known. Solar and wind renewable energy sources are intermittent and need expensive storage to keep up with the 24/7/365 operational needs of most data centers. Hydrothermal Energy is a less known renewable energy source and one of the goals of this paper is to illuminate the potential as applied to data centers. In certain coastal communities, Hydrothermal Energy is available in abundant quantity 24/7/365 and consistent with the needs of data centers. HVAC professionals understand that air conditioning, in its simplest form, uses a working fluid and electricity powering a compressor, to create a temperature difference. The reverse of this process is familiar to ocean energy professionals, where a minimum temperature difference of 36$^{o}$F (20$^{o}$C) in water, may be used with a working fluid and an Organic Rankine Cycle (ORC) turbine-generator, to create electricity. Water reaches its maximum density at ~39$^{o}$F (4$^{o}$C), colder, less dense water may be adjacent to this level. In deep water regions of oceans or lakes this naturally heavy layer of water at 80 to 1000 meters (262 to 3281 feet) of depth, is called the "hypolimnion layer." This layer is like a blanket, that secures a yet to be tapped abundant natural resource. The Organic Rankine Cycle as applied to ocean thermal energy was conceived in 1881 when French physician Jacques-Arsène d'Arsonval first proposed using a heat engine based on the work of Scottish engineer William Rankine. D'Arsonval surmises that "if pumps pull enough water through two separate sets of pipes, the warm seawater will evaporate a heat transfer liquid (such as ammonia or propane) in one part of the plant; elsewhere, cold seawater recondenses the gas to liquid. But as it blows from the first point of phase change to the second, the gas stage will drive a turbine" (Chiles 2008). The physician, turned ocean scientist, knew that coastal areas close to deep cold water and warm surface water could produce power from the temperature difference. The abundance of this renewable energy source was testified by eminent ocean energy scientist of Hawaii, Dr. Hans Krock. "The energy flowing through the surface layer of the tropical ocean is about 10,000 times greater than the energy used by human societies. As such it is the only energy resource on earth that is large enough to replace fossil fuel" (Krock). While the practical application of Ocean Thermal Energy Conversion (OTEC) was first demonstrated in 1930, this event by George Claude in Cuba was preceded by three previous attempts that resulted in the complete lost of the investment of pipe. This highlights the precarious nature of laying pipes in the ocean. Makai Engineering of Hawaii devised a controlled submergence method of deploying pipes. Projects at Natural Energy Laboratory in Hawaii, NELHA, as well as the lake source cooling projects in Toronto Canada and Cornell University in New York, proved the viability of the method with respect to Hydrothermal Cooling (Jagusztyn & Reny 2010). The NELHA project, however, exposed a possible flaw for laying pipes for intakes. After a 2006 earthquake, the polymer pipe cracked at the elbow at the seawater to earth junction of the cold water intake. This allowed warm water to enter this intake pipe compromising a cooling or ORC system. This junction was later repaired but the event served notice indicating the need for a more robust solution. In addition, a US Department of Energy report to the US Congress in 2009 pointed out environmental concerns of an assortment of ocean energy technologies and suggested various mitigations. For ocean thermal resources, one concern was the laying of cables or pipes on sensitive sea floor environments. Thermal pollution was yet another concern. In the former case, the mitigation of using horizontal directional drilling was suggested (DOE 2009). The preceding was given as background to introduce the reader to an innovation for the data center industry.

## AN INNOVATION: NET-ZERO ENERGY HYDROTHERMAL DATA CENTERS

In a joint UNEP-ASHRAE conference in Cairo, Egypt in September 2010, an idea was introduced to mitigate the aforementioned concerns and mishaps of past applications by erecting Drilled Hydrothermal Cooling Plants. (Jagusztyn & Reny 2010). This concept adopts mature technologies from other industries and applies them to the Hydrothermal Renewable Energy. For instance, the process of applying tunnel boring machines to create hydro tunnels is used in the hydroelectric industry. The process of directional drilling, and more specifically extended reach drilling, is used extensively in the petroleum industry. Also used in the petroleum industry is a process to move fluids without mechanical pumping. This process is explored later in the paper.

A case study of the Melink manufacturing facility and their quest to become a Net-Zero Energy Building (NZEB) or a Zero Energy Building (ZEB) is documented by Minor (2010). By optimized building control and an energy management plan, NZEB is attainable using a combination of renewable energy technologies such as solar photovoltaic (PV), solar thermal, a wind turbine, biomass stoves and ground source heat pumps. However, this manufacturing facility is a very low energy intensive building needing to match the load to the available renewable energy source. Doug Reindal (2011) points out that a prototype Net Zero Food Processing Plant situated either in Madison, Wisconsin or Phenoix, Arizona using mainly solar technologies is not viable because “the use of renewable energy sources to achieve a “net-zero” plant presents significant challenges □High capital costs □Ongoing maintenance costs can be significant □Large area requirements.” On the other hand, Hirshman (1977) suggested the feasibility of a natural seawater cooling district cooling plant situated at Miami Beach. “The coldest water near shore (below 46$^{o}$F) may be obtained at a depth of 750 feet and 3 ½ miles from the beach.” All the costs to erect such

**Theoretical Sizing for a Nominal 10 Megawatt Modular Hydrothermal Power Generating Plant**




| Condition | | A<br>Night time operation No solar Boost |
|---|---|---|
| Deep seawater source temperature (entry) | °F | 40 |
| Condenser Heat Exchanger waterside temperature difference | °F | 2 |
| Saturated HC Condensing Temperature oF | °F | 44 |
| Condenser Subcooling | °F | 3 |
| Surface Seawater Entry Temperature | °F | 76 |
| Evaporator Heat Exchanger waterside temperature difference | °F | 2 |
| Turbine HC Inlet Saturation temp | °F | 73 |
| Turbine Inlet HC superheat | °F | 1 |

* HC = Hydrocarbon working fluid

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| | | |
|---|---|---|
| Power | kw | 9850 |
| Power | MWe | 9.65 |

***Figure 2***

*The above depicts and quantifies the concept of creating a hydrothermal power plant citing the above typical conditions for sizing of a modular ORC system. The author worked with a renowned US manufacturer of hydrocarbon turbines and expanders (Elliott Company), to maximize output but confined the design to the envelope of 40 foot shipping containers. Propane (R-290) was selected as the most optimum working fluid. The theoretical output is 9.65 MWe which can service a large size data center. The modular design lends itself to scalability and cost effective manufacturing.*

a natural water district cooling plant versus the revenue from selling chilled water and advantageously displacing mechanical cooling were estimated in this feasibility study. Besides saving "70% of the electricity presently used for air conditioning" and being able to "significantly smooth peaks of electrical demand," the conclusion stated that "the system has a five-year (from start of operations) pay-off period on investments." This was the feasibility study lending credibility to the Hydrothermal Energy Plants installed at NELHA, Hawaii and Toronto, Canada. However, as Jagusztyn & Reny (2010) point out, in practice, Hydrothermal Energy Plants lower the payoff period when the resource is multi purposed. Figure 1 conceptualizes the future data center by illustrating the idea of using tunnel boring machines and directional drilling to collocate the energy resources directly underneath or proximate to the data center for multiple purposes.

### 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 startup 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.

### Data Center Hydrothermal Cooling

The intense heat densities of the servers of future data centers may be cooled by closed loop heat exchangers. The heat exchangers may be advantageously located on shore but below sea level to lower the head necessary to move water. On one side is 39$^{o}$F (4$^{o}$C) seawater (or lake water). In the closed loop is a controlled temperature clean fluid, to suit the requirements of the servers. A double wall heat exchanger may be used to eliminate the possibility of cross contamination. This hydrothermal cooling lends itself to very efficient direct liquid cooling of server racks. The use of airside economizers in colder climates are also an excellent means of "compressor-less cooling" of data centers. However, ASHRAE Technical Committee 9.9 for data centers, after considerable research, cautions owners with data centers located in areas with microclimates of high levels of sulfur dioxide. These contaminants, as would possibly be caused by smog from automobile exhaust, may cause gaseous corrosion compromising server reliability. Hydrothermal cooling would eliminate this possibility. The thermal guidelines for cooling servers are being raised to accommodate more sustainable practices and not compromise server reliability. This opens the opportunity for future Hydrothermal Data Center owners to sell very cold water to neighboring properties such as hotels or office buildings and then use the return water for data center cooling. This is both a revenue opportunity and the beginning of a Net Zero Energy Campus (NZEC). The heat from the servers may also be advantageously used or marketed. As an example, Groll (2010) is exploring organic rankine cycle power generation using the heat generated from the IT equipment. To truly dual purpose the Hydrothermal Energy resource, and make the application commercially viable, a cost effective ORC turbine generator must be developed. This is discussed in the next section.

### Hydrothermal Power Generation

Jagusztyn & Reny (2010) introduce a theoretical turbine generator plant configured with the assistance of a respected manufacturer of turbines and expanders typically utilized in the petrochemical industry. The task was to theoretically package existing technology turbines and generators to fit within the envelope of a 40 foot ISO shipping container. After some examination of possible working fluids, propane (R-290) was chosen for its excellent thermal properties and relatively high output within a compact space. Typical water source temperatures and heat exchanger approach temperatures were set to design the compact turbine-generator. Also contemplated was the benefit of integrating solar thermal energy as both a possible preheater to the warm seawater or a working fluid superheater. The study suggests that from just 76$^{o}$F (24.4$^{o}$C) warm water and 40$^{o}$F (4.4$^{o}$C) cold water and 2$^{o}$F (1.1$^{o}$C) approach heat exchangers, a single stage turbine generator may be constructed to output 9.65 Mega Watt of power. By adding solar thermal energy over 40 megawatts of power may be output from the same 40 foot container design envelope (Jagusztyn & Reny 2010). Figure 2 depicts the theoretical system that can be configured to provide power for a Hydrothermal Data Center. By combining hydrothermal cooling and pumping with stored compressed air generated by renewable energy, a net zero energy data center is within the realm of possibility. Multiple modules may be used as back-up or expansion of capacity. Excess power may be distributed to the grid or sold to neighbors creating a sustainable Net Zero Energy Campus.

## THE PROSPECT THAT HYDROTHERMAL DATA CENTERS CAN ENHANCE THE ENVIRONMENT

Returning the ocean water after using it thermally is an important part of the innovation as depicted in Figure 1. Using guidance from the DOE report to Congress (DOE 2009), the mixed return water 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." A diligently executed Hydrothermal Data Center has the potential to not only lower the carbon emissions of power generating plants but also increases ocean carbon absorption. The more Hydrothermal Data Centers and the more Net Zero Energy Campus' based on Hydrothermal Energy, the more we can partially mitigate the anthropogenic climate change for the benefit of present and future generations.

## 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 Data Centers. 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 Data Center. The charter corporation may be a consortium of innovators, geologists, engineering firms, tunnel boring and directional drilling firms, construction firms, environmental engineers and scientists, financial institutions, utility company, data center operators and IT equipment manufacturers. The local government grants rights to a suitable property and BOOT rights to the Charter Corporation. Once the charter corporation and all its members repay their costs and a reasonable profit from the revenues of the data center, the ownership of the Hydrothermal Data Center 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

Data centers are energy intensive structures mainly due to the power necessary for the IT equipment, cooling and other auxiliary equipment. The heat densities of servers are increasing, thereby demanding more cooling energy. At the same time, the demand for high-density data centers is increasing with the rise of such technologies as cloud computing. All this is pointing to more fossil fuel generated electric power necessary for these data centers at a point in our history when we need to curb or reverse our carbon emissions. This is the challenge posed in this paper. The response to this challenge to date has been mainly in the cooling area with "compressor-less cooling" strategies such as air economizers, cooling towers and natural water cooling. Power Usage Effectiveness (PUE) is a metric used to ascertain the percentage of energy used outside of the IT equipment. The state of the art is a PUE of 1.2 meaning that 20% of the IT power is needed for other equipment. This is down from a historical trend of a PUE of 2.0. Data centers come in different varieties depending on their needs from a basic Tier I facility to a Fault Tolerant "24 by forever" Tier IV facility. The possible solution for sustainable future data centers is to utilize renewable energy. "Net-Zero" is defined as "Buildings which, on an annual basis, use no more energy than is provided by on-site renewable energy sources." Solar and wind renewable energy sources are intermittent and need expensive storage to keep up with the 24/7/365 operational needs of most data centers. Hydrothermal Energy, or obtaining energy from large bodies of water, is available in coastal areas 24/7/365. There are successful applications using naturally cold water for cooling known as hydrothermal cooling. There have been demonstration projects of obtaining electrical power from ocean temperature difference but the process of laying pipes in the ocean has proven risky in both deployment and operation. The paper introduces the innovation of using directional drilling and tunnel boring machines to construct deep wells and conduits to intake and discharge the water resources. This method mitigates many of the financial risks and avoids environmental risks. The lessons from past hydrothermal projects in Hawaii and Toronto indicate that the project becomes viable when the resources are multi tasked. Hydrothermal Data centers are proposed to use naturally cold 39$^{o}$F (~4$^{o}$C) water to cool the facility and the temperature difference of at least 36$^{o}$F (20$^{o}$C) warmer water in heat exchangers and Organic Rankine Cycle turbine generators to provide the power for the facility. A modular nominal 10 Mega Watt hydrothermal power generation plant is proposed based on designing heat exchangers and turbine generators to the envelope of 40 foot ISO containers. While this is still theoretical, a path is illuminated for cost effective manufacture and deployment. A business model for commercialization of Hydrothermal Data Centers 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. Clearly, to realize Hydrothermal Data Centers or the Net Zero Energy Campus, there needs to be a great deal of diligent study by a multi disciple team. Government, NGO, commercial, academic and research institutions are invited to study and model Hydrothermal Data Centers in coastal areas within 35 miles (57 km) of 39°F/4°C and 76°F/24°C water. The locations with these resources close to shore are good candidates for early adoption. Engineering professionals are well advised to consult with oceanographers, geologists, tunnel boring and directional drilling professionals to assess the Hydrothermal Data Center opportunity in their local community.

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