Novel Optimal Concentration Solar Distillation System

"A significant solution to the global challenge of providing access to potable water."

- Professor Ali Sadegh
  Founder & Director
  The Center for Advanced Engineering Design & Technology
  The City College of New York

Our Goal: To optimize, manufacture & deliver to market a sustainable, scalable, “bottoms up”, water desalinization system.

- System Qualities:
  - - Sustainable
  - - “Bottoms Up” Approach
  - - Scalable
  - - Portable
  - - Inexpensive
  - - Easy to operate & maintain
  - - Effective
  - - Enhances health & provides significantly reduced health costs
  - - Economic Development

- **Sustainable**: With the oceans as the source of the potable water and with the sun supplying the energy, the supply of raw material is virtually limitless and clearly sustainable.
- **“Bottom’s Up” Approach**: The system approaches the challenge of providing access to potable water from the perspective of an individual household, that is, our objective is to provide potable water sufficient to satisfy the daily needs for a nuclear family.
- **Scalable**: The system is entirely scalable. Modular base units are connectible in any desired number. The system for an individual household will consist of from one to ten base units. Conversely, a “water farm” sufficient to supply adequate potable water to several households, a village, or small to medium farms, will consist of from one hundred to several thousand base units.
- **Portable**: The base unit is one meter in length and lightweight rendering it easily transportable. The portability of the system provides geographically disenfranchised peoples access to a sustainable source of potable water
- **Inexpensive**: With a projected cost of $100 US/Base Unit, the system is readily affordable

Easy to Operate and Maintain: Operation of the system is simple and only requires ensuring saltwater to the system (Maintaining saltwater in the exterior reservoir.); periodic system observation; harvesting the potable water and regular cleaning. A system adequate for an individual household will be maintained by that household with minimal effort while a “water farm” will require continual attention to operation and maintenance.

Effective: With adequate to good ambient conditions, production of 5.8 1/m2/day is currently typical. With system optimization production of 14 1/m2/day is projected. Therefore, once optimized, a residential system of 10 base units may produce as much as 140 liters of potable water/day, and a “water farm” consisting of 1000 base units may produce as much as 14,000 liters of potable water/day.

Significant Health Improvement with Reduced Health Costs: Pick a number between 4,000 & 8,000. Pick a number, any number. That’s the range of the number of people who die daily from not having adequate access to potable water. These deaths were horrible and resulted from Malaria, Cholera, Dengue, Typhoid & others. The human costs of the failure to provide access to potable water are horrific and range from four thousand to eight thousand **per day!** That’s now. Without a viable solution, that number will increase. Even a fractional reduction in this unacceptable human cost is significant. And the savings on health care costs will increase with every drop of potable water produced. The value to the people whose health is improved can not be quantifiable.

“Water IS Life!”

The conclusion of professor Sadegh is correct, this system is:

> **“A significant solution to the global challenge of providing access to potable water.”**

Is this a complete, perfect solution? No. But it is a significant solution as it fills a great void in providing access to potable water.

Filling the Void.

Reverse osmosis is a tremendous technology providing millions of people access to potable water. However, the viability requirements of RO are stringent and include substantial resources in terms of people, energy, industry and money. Absent any one of these requirements and RO becomes prohibitive. The result is a huge void in providing access to potable water as globally there are many places without the necessary resources to sustain reverse osmosis. This void consists of small, rural, geographically isolated areas. Areas for which a simple, inexpensive, portable system is ideal.

Health: The Prerequisite for Economic Development.

Access to an adequate source of potable water provides the foundation for good health and good health provides the foundation for economic development and enables people to perform tasks, fill jobs, and develop businesses.

Examples:

- **Individual Households.** Having adequate access to potable water beyond sustenance of household members provides the potential for the development of food sustenance resources. Home gardening is an excellent start to establishing a sustainable food source, it reduces stress on food supplies and enlightens people to the fact that food comes from the ground and NOT the grocer!
- **Small Farms.** With adequate access to potable water the vitality of small farming operations is possible. Such operation provides sustenance to the operators, a source of income from the sale of produce, and enhances economic development generally.
- **Hydroponic Farms.** Again, with adequate access to potable water hydroponic farming is not only possible, but it provides a viable means of food sustainability. While the distilled water produced from the purification system under discussion will need to have nutrients added to provide for hydroponic crop production, this obstacle is easily overcome.
- **Water Farms.** In addition to providing sustenance for a community, a village, or a small farm, the development of water farms also will contribute to economic development through the sale of water. This economic development includes retail water sales – the sale of 16 ounce bottles of water to tourists, to supplying bottled water to small retail shops, restaurants and hotels. Additionally, water farms create the potential for the wholesale of water throughout an entire economy.

Executive Summary

Conventional flat solar water distillation (SWD) systems apply the solar energy to the saline water and heat the water until it evaporates. The water vapor condenses at the inner surface of a cover, releases its latent heat due to evaporation and the condensed water trickles down due to gravity and is stored in a collector. While more recent SWD systems employ hemispherical concentration, linear concentration, and compound parabolic concentration (CPC) devices, the water production of the CPC systems are not satisfactory.

What we have developed is a novel optimal concentration solar distillation system where we employ a linear solar thermal concentration with adaptive focal point i.e., linear parabolic Fresnel system. The proposed evolutionary SWD is portable scalable and of high production. Specifically, the proposed SWD takes advantage of linear concentration, and optimizes water production in the absorbing chamber. Unlike the conventional and CPC systems, in this new approach the absorber material receives energy from below and transfers the heat to the evaporation chamber. The evaporating surface will be treated to enhance the boiling process. As a pilot study, we have built basic units and conducted preliminary testing in Florida, with production of up to three times more than reported flat systems and up to two times more than reported CPC experiments. The expected energy savings are enormous when compared to the benchmark of the alternative of reverse-osmosis, where energy usage is about 5 kWhe/m3, ref [25].

Our specific aim is to optimize this technology, characterize the performance, and develop a commercially ready unit for a large scale deployment. The primary intended markets for our technology are small to mid-size farmers in coastal California, Texas and the Caribbean, the coastal eco-tourism sector, and residential applications in these coastal regions. Secondary markets may include military applications, expedition cramps, and water purification for sanitation purposes.

Background & Introduction

- Water is the basic necessity for human existence along with food and air.
- There is almost no water left on Earth that is safe to drink without purification.
- Only 1% of Earth's water is in a fresh, liquid state, and nearly all of this is polluted by both diseases and toxic chemicals. For this reason, purification of water supplies is extremely important.
- A potential technological clean energy solution for water purification and distillation is solar energy, in the form of solar water distillation (SWD). SWD is not a new process, but it has not received the attention that it deserves for technological advancement and/or scalability.

Solar desalination systems are classified into direct and indirect collection systems. As their names imply, direct-collection systems use solar-energy to produce distillate directly in the solar collector, whereas in indirect collection systems, two subsystems are employed. Conventional desalination systems are similar to solar systems because the same type of equipment is applied. The primary difference is that in the former, either a conventional boiler is used to provide the required heat or mains electricity is used to provide the required electric power, whereas in the latter, solar energy is applied.

The principle of pure water production from saline water consists in allowing saline water through an absorbing surface of the solar radiation that is transmitted through a transparent cover. Thus, the saline water is heated up until it evaporates. The water vapor density of the humid air increases due to evaporation from the water surface. The water vapor condensed at the inner surface of the cover, releases its latent heat due to evaporation. Finally, the condensed water trickles down due to gravity and is stored in a collector [21]. Figure-1 shows the basic configuration of earlier version of a flat collector solar distillation system, while Table 1 shows corresponding production for this type of flat solar stills in terms of clean water produced per day per unit area of the still, with maximum production close to 3,000 mL/day/m^2.

Background & Introduction (cont.)

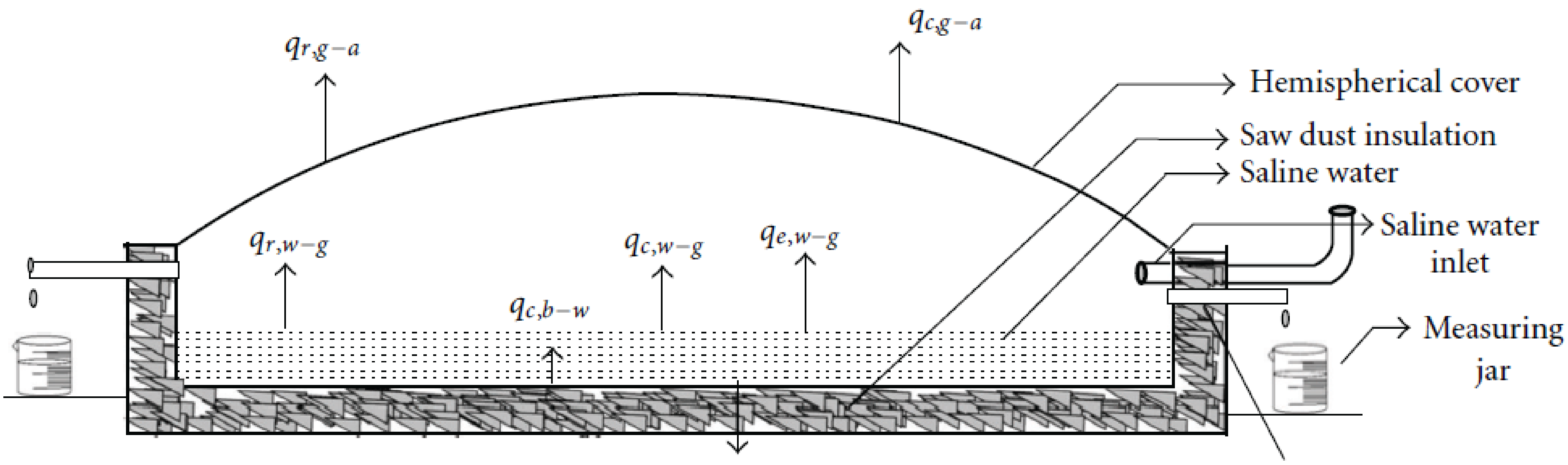

Fig 1: Traditional Solar Flat Water Distillation System with Hemispherical Cover [22]

Table 1: Water Production from Traditional Flat Solar Stills [ref]

Still	Construction System	Area m^2	Cost US $\$/m^2$	Average Yield $L/m^2/d$
A	Aluminium double surfaced	8.9	118	2.5
B	Aluminimum double surfaced	11.1	101	2.5
D	Galvanised mild steel	4.5	79	2.5
E	Galvanised mild steel	4.5	79	1.9
F	Aluminium	2.2	101	2.2
G	Aluminium	2.2	182	2.8
CC	Concrete	1.9	72	1.8

Table 1: Water Production from Traditional Flat Solar Stills [ref] (cont.)

Recent designs for SWD systems have evolved to use solar concentration technology (Figure 2), where production of water can be as high as twice that of traditional flat technology. Arunkumar et al. [23] recently researched production of different configurations of hemispherical concentration, linear concentration, and compound parabolic concentration (CPC) solar stills and summarized daily production, and results are replicated in Figure 3 below. It is clearly evident that production using CPC shows the largest potential. CPC are low concentration devices proposed by Winston [24] in 1974 where the light is concentrated on a flat receiver as opposed to a focal point, allowing for concentration of sunlight under partial cloudy skies, or large acceptance angle. Typical concentrations of CPC are in the range of less than 10X.

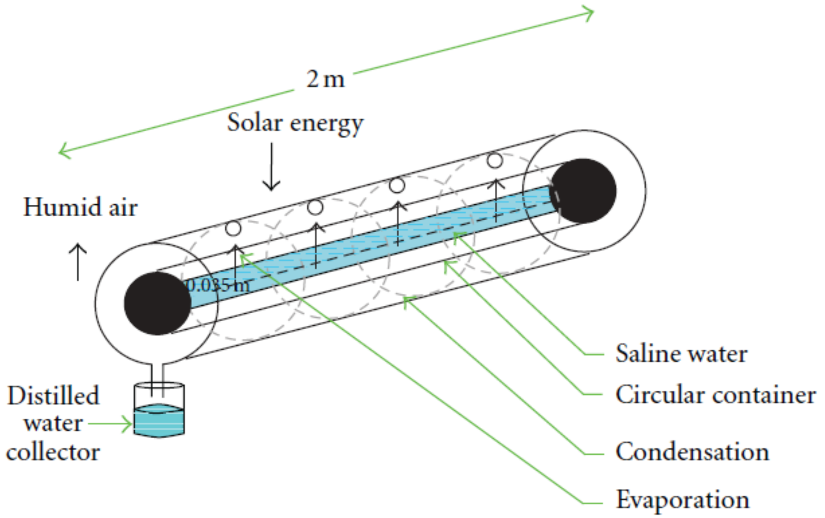

Fig 2. Schematic of Tubular Solar Still [23].

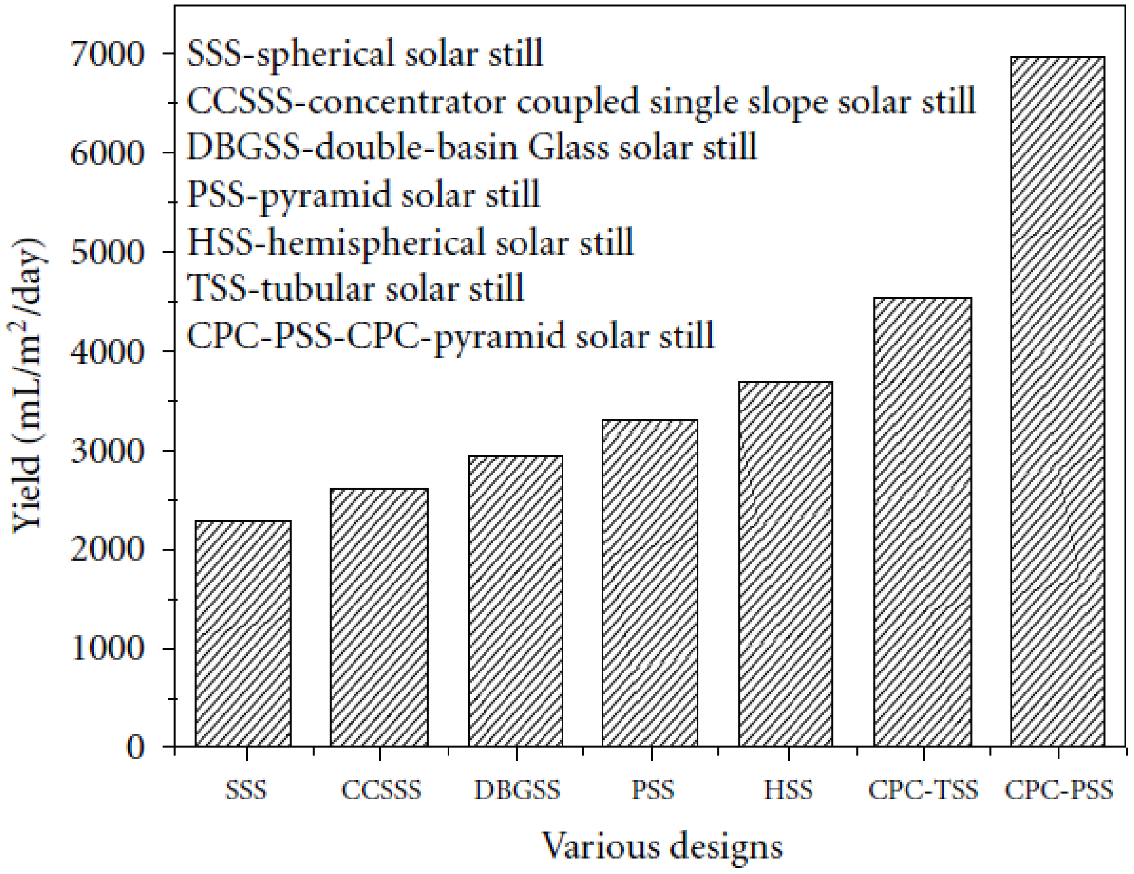

Figure 3: Water production of several concentrator solar stills as reported by Arunkumar et al. [23].

We assert from these past studies and our own experiences, that there is large potential in linear concentration with adaptive concentration point. We are therefore developing a water distillation system using linear solar thermal concentration with adaptive focal point. We propose an evolutionary SDW that is portable, scalable, and of high production. The basic configuration of our proposed system is shown in Figures 4 and 5. Our approach is to take advantage of linear concentration, and optimize water production in the absorbing chamber. The absorber material received energy from below, transferring the heat to the evaporation chamber. This is a radical diversion from traditional linear concentration where the evaporation chamber is the same as the absorbing surface. The heat transfer section can be optimized by using vacuum technology, while the evaporation chamber can benefit from enhanced surfaces. As a pilot study, we have built basic units and conducted preliminary testing in Florida, with production of up to 3X from reported flat systems, and up to 2X from the reported CPC experiments. We therefore intend to optimize this technology, characterize performance, and develop a commercially ready unit for large scale deployment. The primary intended markets for our technology are small to mid-size farmers in coastal California, Texas, South America (initially Brazil and Columbia), the Caribbean (Trinidad & Tobago, Haiti, Dominican Republic, Puerto Rico, and others), the coastal eco-tourism sector, and residential applications in these coastal regions. Secondary markets may include military applications, and water purification for sanitation purposes. The expected energy savings are enormous when compared to the benchmark of the alternative of reverse-osmosis, where energy usage is about 5 $kWhe/m^3$, ref [25].

Technical Approach

Objectives

Our primary objective is to demonstrate the technical and economic feasibility of optimized solar thermal linear concentrating technology (OSTLCT) for water distillation process. The specific objectives are;

- To develop a thermal performance tool through thermo-fluid modeling and analysis of the unit.
- To design and optimize a unique absorbing/evaporating surface for the dual purpose of collecting solar energy, and to increase surface evaporation.
- To design and optimize the unit for the best performance.
- To develop a manufacturing process for the proposed OSTLCT that uses variable linear concentration, vacuum technology, and optimized evaporative surface.
- To build several units and test thermal performance under controlled and uncontrolled conditions.
- To quantify and optimize production costs for competitive benchmark markets, i.e. Reverse Osmosis (RO).
- To align specific markets, design and optimize technology for these markets.

Testing the Thermal Performance of Units

We will test the units above for thermal performance, water production, and water quality. The thermal efficiency, h_i, will be quantified by the ratio of energy used for evaporation, q_e, to the incoming concentrated solar radiation, G, or,

G = Incoming radiation (w or w/o concentration).

$$\eta_i = \frac{q_e}{G}$$

Actual performance will be compared against theoretical performance, given by the equations below [33].

Theoretical evaporative heat of still

$$q_e = \dot{m}_D h_{fg}$$

$$\dot{m}_D = \text{mass transfer rate} = 9.15\text{x}10^{-7} h_c^{'} \left(p_{wb} - p_{wg}\right)$$

$$G\tau\alpha = q_e + h_c^{'}\left(T_b - T_a\right) + \left(\dot{m}C_p\right)\frac{dT_b}{dt}$$

$h_c^{'}$ = convection coefficient of still

$$= 0.884\left[\left(T_b - T_g\right) + \frac{\left(p_{wb} - p_{wg}\right)}{2016 - p_{wb}}T_b\right]^{1/3}$$

p_{wb}, p_{wg} = partial pressures of water vapor at basin and cover temperatures.

τ, α are the effective transmitance and absortance of the collector.

Testing the Thermal Performance of Units (cont.)

- These equations will be modified to adapt for the concentrating collector, and to account for the linear energy gain as water flows along the axis of the collector. Customized and commercially available analytical tools (Fluent, Comsol and Solidworks) will be developed and/or employed for detailed analysis of the system. The results will be compared with the theoretical results using the above equations.
- The experimental setup will consist of solar radiation sensor at the receiver, flow meters, temperature sensors inside and outside the collector, and wind sensors. The partial pressure of vapor will be estimated from basic thermodynamic equations (i.e. Clasius-Clapeyron) using wet bulb temperatures. Tests will be conducted for several units, for fixed and variable tracking, and for optimized concentration.
- Further, we will test the units for a range of initial water quality including sea water (~ 35,000 ppm), and will measure the output in terms of ppm of salinity levels. Our goal is to reduce salinity levels to less than 300ppm. In summary, our quantifiable goals are;
  - water production > 14L/m^2-day
  - thermal efficiency > 50%
  - water quality < 300 ppm.

Develop a Manufacturing Process for Units

As a pilot study we manufactured a Linear Elliptical Water Purification System, known as Linear Tube System (LTS) with the longitudinal cross-sectional area of 48” X 8.5", including a sun light reflector below the tube as shown in Fig. 10 (below). The water was fed through a controlled valve from the top end of the LT and with the gentle slope of LT the purified water was collected at the lower end. Our plan was to conduct tests of the system to ascertain the amount of potable water production per day. To enhance water evaporation and to increase water production, we plan to add Fresnel lenses on the top of tube. Our primary results -without any optimization of the system- revealed that on a sunny day in Central Florida we were able to collect as much as 0.75L of purified water, and in a semi cloudy day 0.5L ounces of water were collected. It is anticipated with the proposed analysis and optimization the production will be significantly increased.

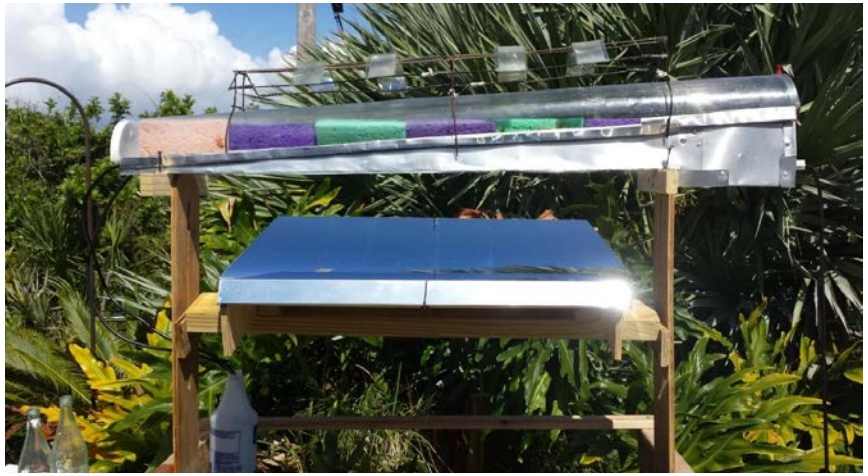

Figure 10. Exploratory System Designed and Built by SFW

Cost Optimization

We will optimize the cost of the unit, using reverse osmosis (RO) as a benchmark. Water distillation of RO costs are estimated in $0.001/L in energy costs, with additional equivalent costs for installation and O&M. Our goal is to provide a scalable system far superior from these existing technologies. We project costs per unit in less than $100/collector, with projected production of more than 5,000L/m^2-yr. This will result in projected savings of $0.002/L-year, and paybacks of less than five years when benchmarked with RO. Key to cost optimization is scaling of the technology to multiple sizes and production units, and efficient use of materials (i.e. reflective coating, absorbent material, cover tubes, and vacuum process). For units w/optimal control, the cost will be elevated, to be offset by production.

Market Exploration, Validation, and Business Plan

Sun Fresh Water, LLC (SFW) was founded in February 2012 for the purpose of developing the concept of utilizing concentrated solar energy as a means of enhancing the efficacy of the vaporization/condensation process to provide a sustainable means for the desalination/purification of contaminated water.

SFW was established in Ormond-By-The-Sea, Florida, and is believed to be the first company to utilize solar concentration via lens array, to enhance the efficacy of the vaporization/condensation process. The company has extremely well qualified personnel and consultants in the areas of engineering, research, design and development. This attribute has been enhanced tremendously since entering into a partnership with The Center for Advanced Engineering Design and Development of The City College of New York in 2013.

In addition to utilizing the concept of concentrated solar energy, SFW is also unique in its **"molecular" or "bottoms up" approach** to addressing the critical global need of access to portable water. This "molecular" approach is to develop an inexpensive, easy to use and maintain, sustainable, scalable, portable purification system, to satisfy the water needs of a single family.

Our testing to date indicates that we are the standard for sustainable, potable water production per square meter, as our technology represents a 300%+ increase over the status quo as reported. Additional embodiments are now under development with other embodiments envisioned.

Moreover, with optimization of the system - design, components and engineering, it is believed that the production results achieved to date can be significantly improved. A projected target of production is 14 L/m2/Day.

Market Exploration, Validation, and Business Plan (cont.)

SFW has also pursued the development of inexpensive solar powered water purification systems, excluding desalination, for areas with access to fresh, but contaminated water; a hydroponics system for reducing water consumption in agricultural applications; and a hybrid water heating system to utilize solar energy to simultaneously provide water heating capabilities for personal hygiene and in swimming pools. Also envisioned by SFW is utilizing concentrated solar energy to recycle water for hygiene or sanitation purposes in refugee camps, emergency response situations, and in areas of limited availability of potable water.

SFW and CCNY have a joint Patent Pending at US20140231327 A1, for its dome design for a water purification system; a Patent Pending at 14/969,076 on its linear design for a water purification system; and a Patent Pending for its linear design with nanotechnology, nano fluids, and solar tracking.

Markets for the proposed product are primarily small and medium sized communities with a need for potable water including California, Texas, and the Caribbean. However, the scalable aspect of the system may make it viable for larger communities and agricultural entities as well. The Military also represents a potential market. While there are other organizations utilizing solar power for desalinization purification, these entities have approached the issue from a much larger perspective as opposed to the “molecular” approach utilized by SFW.

Market Investigation

Having completed an exploratory sojourn to Trinidad & Tobago from May 26, 2016 to June 5, 2016, and to attend the **CaribDA 2016 Biennial Conference & Exposition "Developing and Affording New Water Sources"**, valuable firsthand insight was gained. Five days were spent in rural Speyside, Tobago, a picturesque village in northern Tobago within St. John Parish. At the census of population in 2000, the town had a population of 59. The remaining six days were spent in Port of Spain, Trinidad, with an urban area with a population of 37,074 while the island of Trinidad had a population of 1,754,897 as of January 2016. There are 2 distinct seasons of precipitation in Trinidad and Tobago – The Dry Season, which extends from December to May and the Wet Season, which extends from June to November, The past dry season was consistently reported to have been the "worst" in memory.

The lack of access to potable water had a profound effect on individuals, agricultural production and small businesses alike, It was reported that there were times where all went without water, sometimes waiting up to a week before water was delivered. The Monday, February 22, 2016 issue of the **Tobago Newsday** newspaper contained a headline that blared:

"WATER CRISIS – London warns Tobagoians to brace for hardship if WASA cannot fix supply, Hotels report guest check-outs due to water shortage. Water levels at reservoirs at an all time low."

The toll on agricultural production was also apparent to residents – as production is reduced, prices & competition for food increase. "A very viable solution to this issue is hydroponics" proffered **Joel Joelfield of Greenwave Gardens** who presented at, and with whom a meeting was held at **Carib2016,** "But," he added: "we need water." He was most enthusiastic about the system under development herein as a means of providing a sustainable source of potable water which, in turn, will enable the increased production and expansion of hydroponic agricultural food sources.

Also while in Speyside, Tobago, communications occurred with **Sean Robinson,** a landowner of 740 acres. Discussions included the water situation and the prospect of establishing a **"water farm"** on his property. He was most interested.

In Trinidad there's a major Reverse Osmosis facility there operated by **DESALCOTT – The Desalination Company of Trinidad & Tobago.** In 2012 **DESALCOTT** was contracted by **WASA (The Water and Sanitation Administration of Trinidad & Tobago)** to increase its production from 24 million imperial gallons of water per day (MIGD) to 40 MIGD. Despite this, it was reported that there were numerous geographically isolated portions of Trinidad that experienced severe water stress during the recent Dry Season.

Additionally, The Global Water Partnership – Caribbean (GWP-C) has expressed interest in the concept and has offered to share information on the work with its partnerships with a view to getting feedback and comments. They also indicated that if a successful pilot project is executed in the Caribbean, that GWP-C would be interested in producing a case study as part of its knowledge sharing activities.

Also while at CaribDA, President of the International Desalinization Association, Dr. Emilio Gabbrielli expressed interest. He spoke of the dire need for access to potable water in areas of Brazil and stated: “Don’t forget Brazil. They are counting on initiatives like yours!”

Likewise, the dire need for access to potable water was expressed by representatives of R3 Protek who spoke of the children in the northern villages of Columbia being forced to drink contaminated river water resulting in serious health issues. People from several other Caribbean Islands also expressed similar concerns.

The immediate commercialization plan is to have the system optimized and manufactured in New York, Florida and Trinidad (Discussions have been initiated with Ansa MCal, the largest Corporate conglomerate in the Caribbean); and have the component parts of the system distributed to venues in the US and throughout the Caribbean Community. Recognizing the dire need throughout the Caribbean Community the initial focus for test marketing and product application will be in Speyside, Tobago as a venue for a pilot project.

Simultaneously, with the pursuit of a manufacturing arrangement in locations including Trinidad, continuous development of enhancing embodiments will conducted at the City College of New York while further prototype development and testing takes place at the Sun Fresh Water facilities in Ormond By-The-Sea, Florida.

The Future of Water

The World Bank

High and Dry: Climate Change, Water, and the Economy

A new World Bank reports finds that water scarcity, exacerbated by climate change, could hinder economic growth, spur migration, and spark conflict. However, most countries can neutralize the adverse impacts of water scarcity by taking action to allocate and use water resources more efficiently.

Key Findings

• Water scarcity, exacerbated by climate change, could cost some regions up to 6% of their GDP, spur migration, and spark conflict.

• The combined effects of growing populations, rising incomes, and expanding cities will see demand for water rising exponentially, while supply becomes more erratic and uncertain.

• Unless action is taken soon, water will become scarce in regions where it is currently abundant - such as Central Africa and East Asia - and scarcity will greatly worsen in regions where water is already in short supply - such as the Middle East and the Sahel in Africa. These regions could see their growth rates decline by as much as 6% of GDP by 2050 due to water-related impacts on agriculture, health, and incomes.

• Water insecurity could multiply the risk of conflict. Food price spikes caused by droughts can inflame latent conflicts and drive migration. Where economic growth is impacted by rainfall, episodes of droughts and floods have generated waves of migration and spikes in violence within countries.

The Future of Water (cont.)

- The negative impacts of climate change on water could be neutralized with better policy decisions, with some regions standing to improve their growth rates by up to 6% with better water resource management.
- Improved water stewardship pays high economic dividends. When governments respond to water shortages by boosting efficiency and allocating even 25% of water to more highly-valued uses, such as more efficient agricultural practices, losses decline dramatically and for some regions may even vanish.
- In the world's extremely dry regions, more far-reaching policies are needed to avoid inefficient water use. Stronger policies and reforms are needed to cope with deepening climate stresses.
- Policies and investments that can help lead countries to more water secure and climate-resilient economies include:
    - Better planning for water resource allocation
    - Adoption of incentives to increase water efficiency, and
    - Investments in infrastructure for more secure water supplies and availability.

The Next Generation

The prospect for using the Linear Tube Concept for providing adequate access to potable water is significant. The current objective is to utilize this concept not simply for residential use but also for larger uses such as the development of “water farms” for small to medium size communal/village use as well as similar agricultural production. Additionally, there is demand for use on off-shore oil and gas wells. Such use requires a more durable system that provides enhanced potable water production.

This next generation system will include the use of larger tubes that will increase potable water production and incorporate principles of evacuation, nanotechnological surfaces, nano fluids, along with solar tracking mirrors. While such a system will produce significantly greater volumes of potable water, they will also be more complex and expensive than the modular system designed for residential use.

Conclusion

The systems under development by Sun Fresh Water, LLC and The Center for Advanced Engineering Design and Development of the City College of New York provide a “significant solution to the global challenge of providing adequate access to potable water”.

A system that provides a sustainable source of potable water and is portable, inexpensive, and easy to use and maintain, will be of great value to many areas globally.

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