The Sahara Forest Project

A proposal for ameliorating the effects and causes of climate change

THE FOUNTAIN TREE.

exploration

maxfordham
ENGINEERING DESIGN ENVIRONMENT

Seawater Greenhouse

Cover Illustration

The legendary Garoe or 'Fountain Tree' was sacred to the Bimbaches, the early inhabitants of El Hierro in the Canary Islands. The tree intercepted the rolling fog and the water dripping from its leaves was collected and channeled off to provide drinking water for the inhabitants.

The effect is most pronounced in Tenerife where the pine forests on Mount Teide contribute at least three times more water by fog capture than is provided by rainfall.

"On Tuesday, July 22nd (1494), he departed for Jamaica.... The sky, air, and climate were just the same as in other places; every afternoon there was a rain squall that lasted for about an hour. The admiral writes that he attributes this to the great forests of that land; he knew from experience that formerly this also occurred in the Canary, Madeira, and Azore Islands, but since the removal of forests that once covered those islands they do not have so much mist and rain as before."

The Life of the Admiral Christopher Columbus by his Son Ferdinand
Translated by Benjamin Keen (1978).

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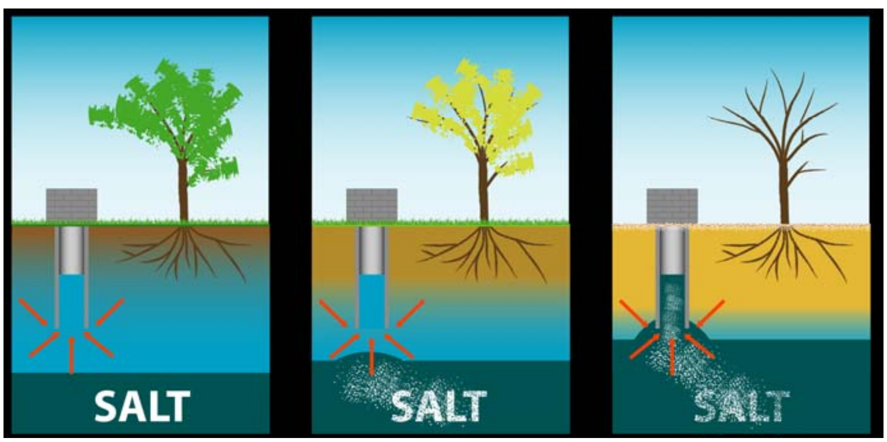
"No man, except in the first nine months before he draws his first breath, manages his affairs as well as a tree does" George Bernard Shaw.

1. Introduction

The world is running short of fresh water. With agriculture accounting for some 70% of all water used, the shortage is closely linked to food production. The provision of clean water is a pre-condition to life, health and economic development and the lack of water in many parts of the world is the root cause of much suffering and poverty. Present methods of supply in arid regions include: over-abstraction from ground reserves, diverting water from other regions and energy-intensive desalination. None of these methods are sustainable in the long term and inequitable distribution leads to conflict. To make matters worse, global warming is tending to make dry areas drier and wet areas wetter. Since the 1980's, rainfall has increased in several large regions of the world, including eastern North and South America and northern Europe, while drying has been observed in the Sahel, the Mediterranean, southern Africa, Australia and parts of Asia. In parts of India, the water table is now 150m below the surface and falling by 6m a year. The International Water Management Institute recently estimated that in India, about 250 cubic kilometres of water are abstracted for irrigation each year. That is at least 100 cubic kilometres more than the rains put back. It feeds India. But as every year passes, the aquifers get emptier. [1]



In many parts of the world, water is pumped out of the ground faster than it is replenished by rainwater. The water table drops and becomes increasingly saline. The salts then poison the soil.

The growth in demand for water and increasing shortages of supply are two of the most certain and predictable scenarios of the 21st century. Agriculture, with a high demand for water, is a major pressure point. A shortage of water will also affect the carbon cycle as shrinking forests will reduce the rate of carbon capture, and the regulating influence that trees and biomass have on our climate will be disrupted, exacerbating the situation further.

[1] http://technology.newscientist.com/article/mg18925401.500

Fortunately, the world is not short of water, it is just in the wrong place. Converting seawater to fresh water in the right quantities and in the right places offers the potential to solve all the problems described above.

The world's surface may be conveniently divided into thirds. Two thirds are covered by the oceans, and if the planet was ground flat by a giant scraper, it would be covered by seawater, a mile deep. Thus while we are short of fresh water, we have an abundance of seawater. Of the land's surface, roughly one third is occupied by mankind in various states of development, one third is forest (and shrinking) and the remaining third is desert (and growing).

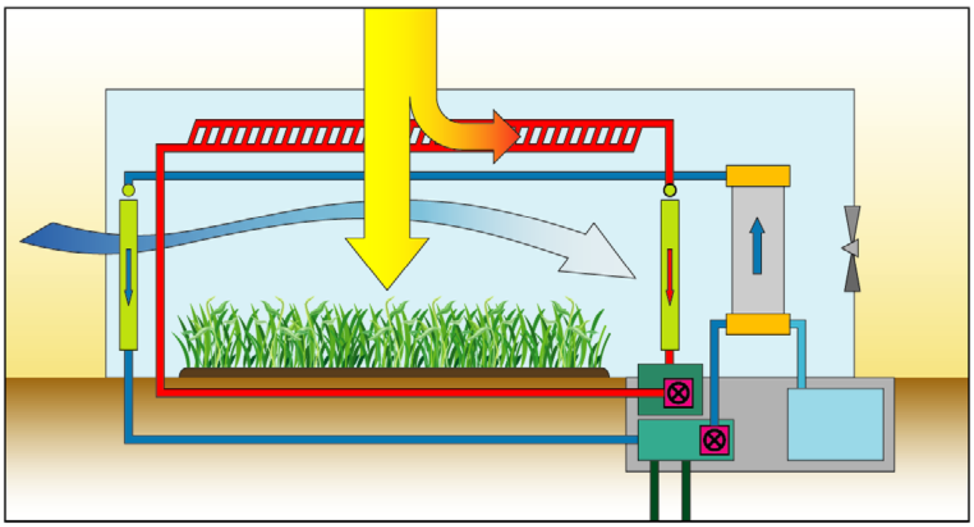
Many, if not all of the world's deserts formerly supported vegetation, and were it not for the lack of fresh water, they could do so now. We have demonstrated, albeit on a tiny scale, that it is relatively straightforward to convert seawater into fresh water, and thus enable crops and trees to grow in some of the hottest and most arid places on earth. The following notes illustrate how this process could be scaled up in a commercially viable way and seeks to identify where it could be of greatest advantage.

2. The Core Elements of the Proposal

2.1 The Seawater Greenhouse

The Seawater Greenhouse uses seawater to cool and humidify greenhouses and to convert sufficient humidity back in to fresh water to irrigate the crops. It works well in that a simple and low cost solution enables crops to be grown throughout the year in some of the hottest countries on earth.

As the diagram below illustrates, the process is reasonably simple. The air going into the greenhouse is first cooled and humidified by seawater, which is trickled over the first evaporator. This provides good climate conditions for the crops. As the air leaves the growing area, it passes through the second evaporator which has seawater flowing over it that has been heated by the sun in a network of black pipes above the growing area. Thus the air is made much hotter and more humid, such that fresh water will condense out of the air-stream when it is cooled.



In a sense, the simplicity of the process mimics the natural hydrological cycle where seawater heated by the sun, evaporates, cools down to form clouds and returns to the earth as rain, fog or dew.

The cooler and more humid conditions enable crops to grow with very little water, and as the crops are not stressed by excessive transpiration, the yield and quality is higher. It is interesting to note that part of the solution to the world's water shortage may not be to produce more water, but to use less water, yet grow better crops.

Irrigation requirements -Tenerife

In comparison with conventional greenhouses and conventional desalination, the Seawater Greenhouse uses very little electrical power, as the thermodynamic work of cooling and distillation is performed by energy from the sun and the wind. For example, 1kW of electrical energy used for pumping seawater can remove 800kW of heat through evaporation. The modest electrical demand enhances the potential for driving the entire process using solar panels, yet without the need for batteries, inverters etc, as power is only needed during the hours of daylight. Stand alone operation will enable food and water self-sufficiency, especially in remote, off-grid regions.

It has two extra qualities that become significant when scaled up:

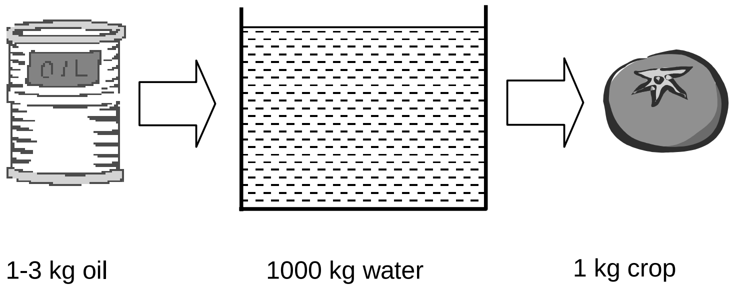
1 The evaporators are very effective air scrubbers, and in combination with the salt water, have a biocidal effect on any airborne contaminants, pests etc. Accordingly, we have never had to use pesticides inside the greenhouse.

2 It evaporates a great deal more water than it condenses back into fresh water. This humid air is 'lost' as we maintain high rates of ventilation to keep the plants cool and supplied with CO_2, but it maybe that this ‘free’ humidity becomes the most significant factor, on the assumption that what goes up, must come down, somewhere.

2.2 Large-scale application of the Seawater Greenhouse

The photograph below shows Almeria in the south of Spain, and is used here as a reference example of how to convert unsustainable greenhouses into a new and sustainable source of fresh water. The region comprises 20,000+ hectares of greenhouses in a desert. There are a further 20,000 hectares up the coast in Murcia. These greenhouses have caused considerable environmental damage as they consume 5 times more water than the region gets in rainfall, and they tend to use excessive quantities of pesticides which are becoming increasingly ineffective, especially against whitefly. The whole region is now suffering from severe environmental degradation and productivity is severely threatened.

If they were converted to the Seawater Greenhouse process, the situation would be reversed, and rather than depleting the south of Spain of fresh water, they would make a positive contribution to it. However, in considering solutions to the problem, the authorities made a choice between diverting the Ebra river in the north of Spain, and building twenty large scale, fossil fuel driven desalination plants on the coast. They have chosen to implement the latter.



Basic economy of conventional desalination for agricultural use

The energy intensive nature of conventional desalination makes this a questionable practice, as illustrated in the diagram above. The choice was driven by political and commercial motives, as the huge commercial success of the horticultural industry has taken the region from the bottom of the country's regional league table for wealth creation at number 80 to number 5.

The Seawater Greenhouse in Oman, illustrated above, evaporates around 5 tons of seawater a day from a 1000m2 greenhouse. That equates to 50 tons a day per hectare. Thus if we converted an area of greenhouses equivalent to that of Almeria to the SG process, it would take 1 million tons of water out of the sea every day and evaporate it. Assuming that what goes up must come down, the water vapour would fall back as rain or dew - but where? If it fell in the Mediterranean, it would not be much use, but if the greenhouses were located down wind of higher terrain, then some of the humidity would condense as rain or dew.

The total area of greenhouses around the Mediterranean is some 200,000 hectares, and this area has been growing at around 10% a year - ie the size of Almeria every year, so such a scheme could be both profitable and self financing, as the additional water vapour is produced as an essentially free by-product of growing crops. Greenhouse horticulture in Europe is dwarfed by that in China, where there are 2.1 million hectares of greenhouses, as well as a fast growing problem of desertification.

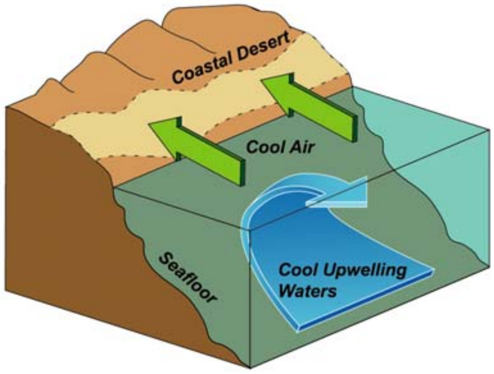
So, if this growth were concentrated where it could do most good, in say North Africa, it could increase rainfall in the Sahara and shift the delicate balance by helping to restore the vegetation that used to be there. Other locations such as the Arabian Peninsular, the Great Indian Desert and southern Australia may offer similar potential. The geographical areas identified as promising would need to be studied in greater depth, including climate modeling in order to assess their suitability and potential.

2.3 Desert Climates

The Seawater Greenhouse process works highly effectively in a wide range of climate conditions. Two examples are described here to illustrate the extremes.

2.3.1 Coastal deserts, catching the fog

Arid coastal deserts are often caused by the presence of cold ocean currents or the upwelling of cold water, Examples are found in Namibia, Chile, Peru, California and Morocco.



Even though these regions enjoy abundant sunshine, the air blowing off the sea is cooled by the chilly seawater, reducing its capacity to hold water vapour. It frequently comes ashore as fog, which is rapidly driven off by the heat of the land. Such regions often have a flat coastal plain with a mountain range further inland, e.g. the Atlas in Morocco or the Andes in Peru and Chile. As air blows up the mountain, it cools, typically by 1ºC every 100 metres, such that at some elevation, cloud or fog is formed. The effect is illustrated above.

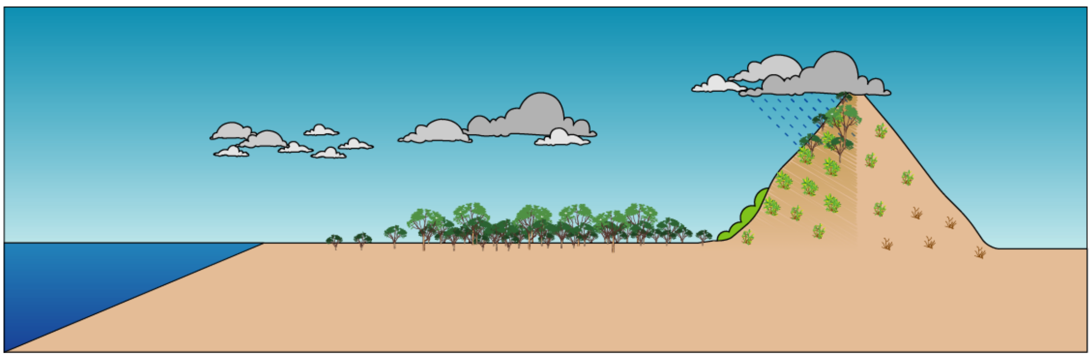
In such locations, an array of Seawater Greenhouses on the coastal plain would increase the quantity of water vapour in the air and increase the likelihood of precipitation on the mountain slope. It often happens that dew or mist will not condense on bare rock as it is too hot, while grass or trees, being cooler, will encourage condensation. The redwood forests in California for example, get most of their water from intercepting the mist that rolls in from the sea.

Enormous volumes of water are contained in the fog present in coastal and mountainous regions. The water droplets in these fogs can be collected by vegetation, as in tropical or temperate cloud forests, or deposited onto grass covered hills. In desert regions, or where tree cover has been removed, deposition is minimal and the fogs evaporate. However, these regions offer the possibility to capture fog droplets in large artificial fog collectors. This is an inexpensive, low-technology source of water for domestic, agricultural and forestry uses. If the water collected by fog nets is used to irrigate tree saplings, the trees will take over the role of the fog nets once they are established.

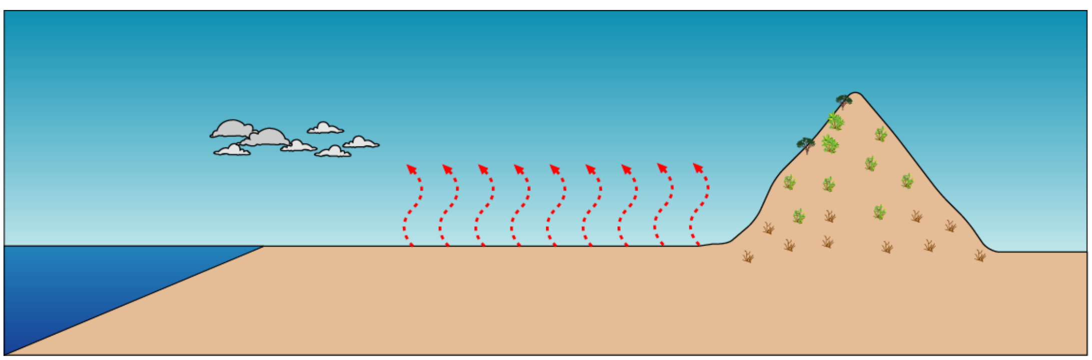
2.3.2 Inland deserts

Many of the world's deserts are located in subtropical latitudes and are characterised by dry air masses descending. Low relative humidities are produced as the air is heated due to compression as it descends into a region of higher pressure. The Sahara and the Arabian Peninsula are typical examples.

In the daytime over large land masses, the wind direction is usually onshore. Onshore breezes carry humid air that has evaporated from the sea, and this humidity is augmented by water vapour transpired by trees and vegetation. The process of evaporation cools both the land and the air as it converts the heat from sunlight into water vapour. The more humid the air, the more likely it is to form rain or dew, especially if it is cooled further by a mountain range. The effect is illustrated below.



Where there is no vegetation, sunlight heats up the ground, which in turn heats up the air. This reduces its relative humidity and causes the clouds to vaporize. The water vapour then drifts off, possibly to contribute to a more extreme weather event in a cooler or more humid location.



The effect is often the result of urbanization and desertification, two processes that have been going on since the dawn of Western Civilisation, and continues to this day. The effect is exacerbated further by the tendency towards the 'use once and discharge' approach to management of water, which is usually collected in drains and discharged to the sea by the shortest possible route, that is without being allowed to percolate into the ground. Even in a semi-arid country like Morocco for example, some 2 million tons of waste water, nutrients and all, are discharged into the sea every day.

The reuse of waste water can present problems of pathogen contact with food crops. The safest and most promising use is therefore in non food crops such as wetlands and in particular trees. Tree shelter belts stabilise the soil, reduce wind speed and increase atmospheric humidity locally, thereby reducing overall irrigation demand and increasing the occurrence of dew or rainfall.

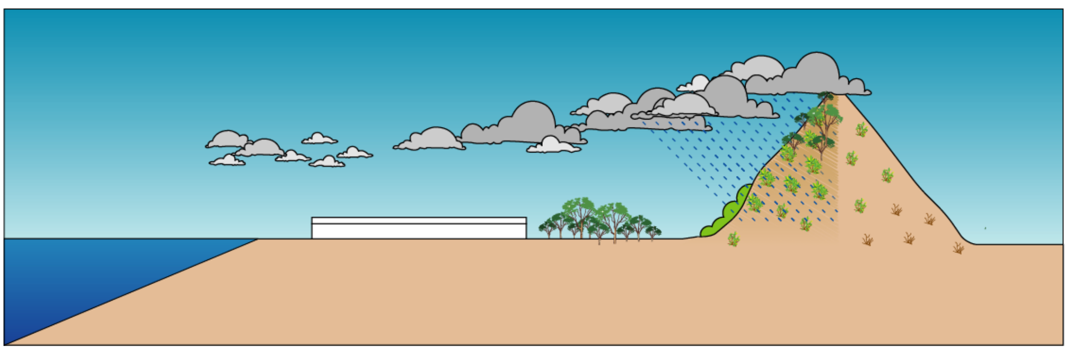
Under balanced conditions, the same amount of water flows from the land as falls on the land through rainfall. When the land loses more water than it gets through rainfall, as is often the case as a consequence of deforestation, drainage and urbanization, the land dries out – soil moisture decreases, the water table falls, plants wither and less evaporation takes place, which in turn reduces the likelihood of rainfall.

2.4 Enhancing water vapour

The Seawater Greenhouse evaporates large volumes of seawater. The quantity of water is around ten times greater than that evaporated by an equal area of land covered by grass. This 'lost' humidity has two benefits:

1. Providing a micro-climate of cooler and more humid air in the lea of the greenhouse, reducing the water demand and enhancing the growing conditions for vegetation.

2. Increasing the potential for precipitation through dew formation or rainfall.



A region of greenhouses is illustrated here, having a similar effect on the climate as a region of forest, yet providing a net input of water vapour from sea water.

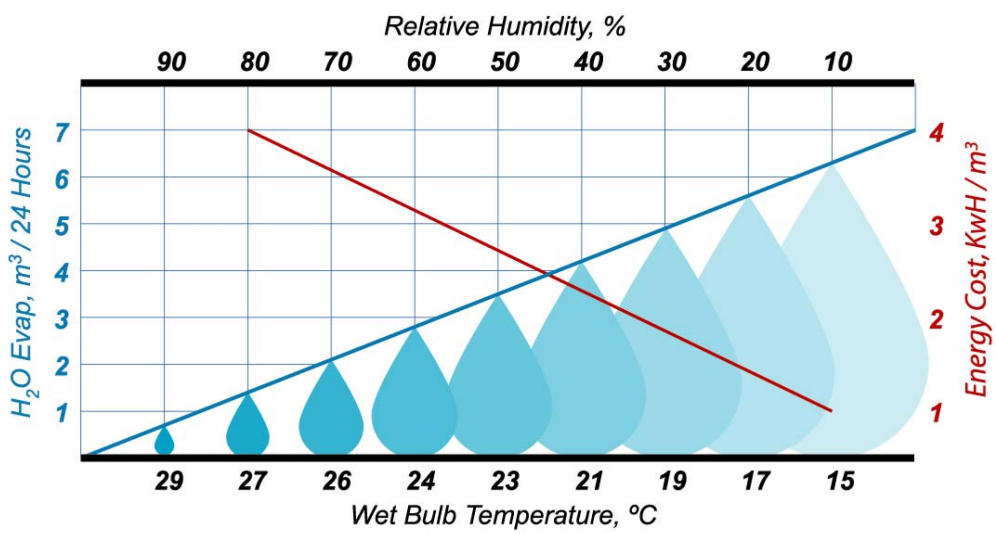
> *"To all the aristocracy and towns, I hereby issue an order to build ponds industriously, first to provide an abundance of fish to feed the people, and secondly to secure the better use of the land - to gather marsh and morass water, so that it might be evaporated by the sun and by warm winds and as a water vapor to fully benefit the surrounding vegetation.*
> *Furthermore, a pond is to retain a large amount of water in times of lasting rains or melting snow, and in doing so, shall avert the sudden flooding of downstream lands."*
>
> ***Charles IV, King of Italy and Holy Roman Emperor, 1356***

2.5 Potential to exploit land locations below sea level

There are a number of inland depressions in the Sahara in Morocco, Tunisia, Libya, Egypt and Eritrea. If these were used, there would be no pumping costs. The Qattara Depression in Egypt is 133m below sea level, and could be further exploited for hydro-electric power, as proposed by the United Nations - Managing Water for Peace in the Middle East: Alternative Strategies [2],[3]

There are depressions in the USA and Australia, and there is the Dead Sea, the lowest point on earth at some 400m below sea level. A major benefit of implementing the Seawater Greenhouse process inland is that the Relative Humidity (RH) tends to be lower further from the coast. Typically, the daytime prevailing wind blows off the sea on to the coast, and the RH in coastal regions is usually around 60-70%. This falls with increasing distance from the coast as water vapour is lighter than air and thus rises. In the middle of the Arabian Peninsular or the Sahara for example, the midday RH is typically 20% or less. At 20% RH the Seawater Greenhouse would evaporate almost three times as much water than it does at 70%RH. This would also achieve lower temperatures and increase fresh water production.

The chart below illustrates the cooling effect and potential for evaporation for air at a constant temperature of 30ºC with reducing humidity. The values are based on a nominal 1000 m2 Seawater Greenhouse.
As relative humidity falls, so too does the temperature of air that has passed over a wetted



surface (the wet bulb temperature). At the same time, both the volume of seawater evaporated increases and the amount of fresh water that can be produced also increases. This is achieved without incurring any additional cost penalty, other than that of delivering the seawater to the site. Thus the volume of water produced, and its associated cost is very specific to the location and its environmental conditions.

The red line, right hand axis, illustrates how the nominal energy cost of producing 1m3 of water falls with reducing humidity.

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[2] http://www.unu.edu/unupress/unupbooks/80858e/80858E0a.htm#2.11%20Mediterranean-Qattara%20solar-hydro%20and%20pwnped-sto

[3] http://www.unu.edu/unupress/unupbooks/80858e/80858E1J.GIF

2.6 Concentrated Solar Power

Many of the locations that are well-suited to the Seawater Greenhouse are also ideal for Concentrated Solar Power (CSP), and there are a number of potential synergies with combining both processes. Concentrated solar power is increasingly seen as one of the most promising forms of renewable energy, producing electricity from sunlight at a fraction of the cost of photovoltaics. Distributing this energy by means of high voltage DC power lines, rather than the more conventional AC, would allow northern Europe to be supplied with electricity with minimal transmission loss.

The principle of CSP involves using reflectors to focus the sun's energy to boil water which is used to drive a conventional steam turbine. The most common types are the parabolic trough collector, the solar tower and the parabolic dish. The first of these involves a trough which rotates in a single plane in order to follow the sun. The second and third types involve tracking two axis reflectors that focus the energy on a single point. The efficiency of CSP in converting heat to electricity is typically between 20% and 30% and the amount of energy generated is dependent on the solar intensity of the location. Much of the Sahara receives over $800W/m^2$ and a $150{,}000km^2$ installation of CSP, occupying around 3% of the Sahara, could provide the world's current demand for energy of all kinds.

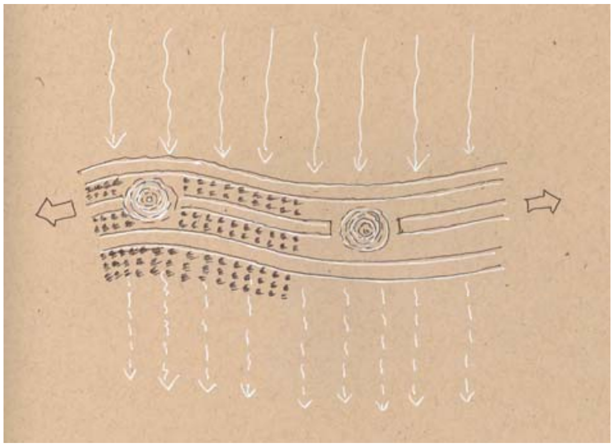
Nevada Solar 1, Las Vegas a 64 Megawatt parabolic trough system.

Solar Tower, Barstow, California

Parabolic Dish System, New Mexico

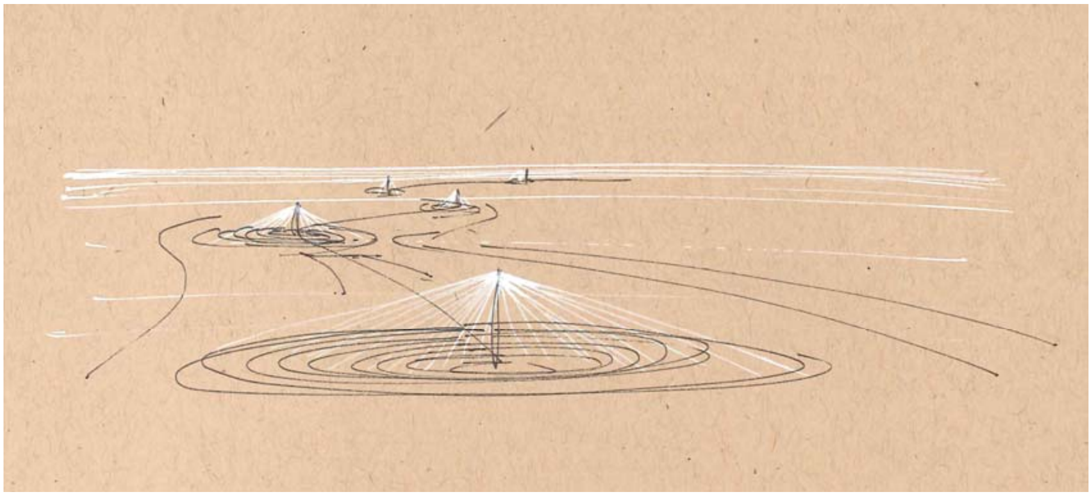
3. The Concept

The Sahara Forest Project proposes a combined CSP / Seawater Greenhouse operation, located some distance from the coast in a desert region. The scheme is proposed at a significant scale such that very large quantities of seawater can be evaporated. The greenhouses are arranged as a long 'hedge' to provide a windbreak and shelter to the outdoor planting scheme, and to maximize the area of evaporation. If the location is at or below sea level, pumping costs are minimized or avoided altogether.



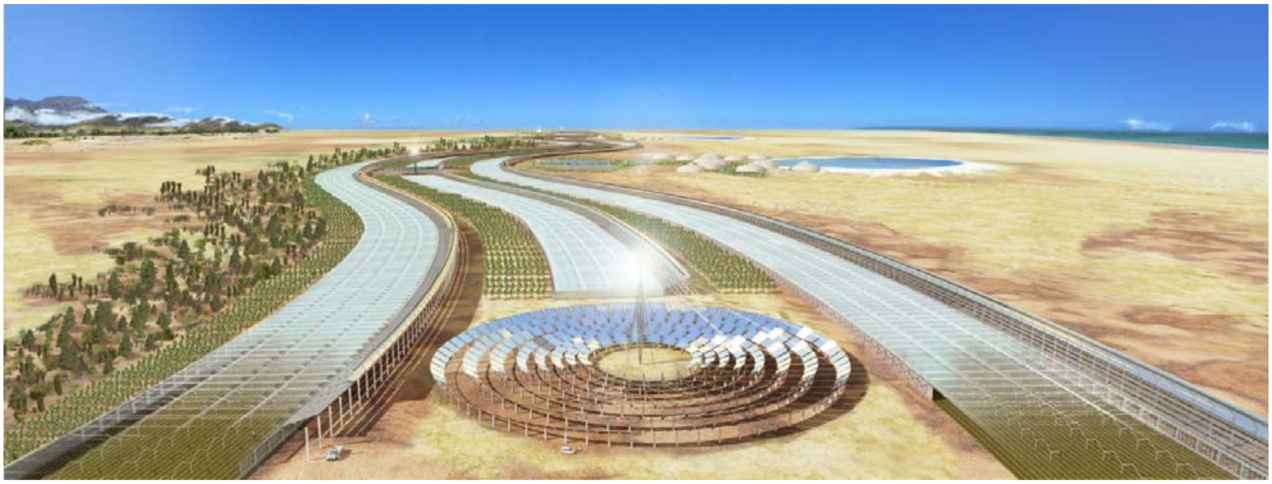
Sketch showing a long 'hedge' of Seawater Greenhouses orientated towards the wind

Solar Power Tower, Barstow, California



Perspective sketch of Seawater Greenhouses and CSP towers

At intervals along the 'hedge' of greenhouses CSP arrays would be installed. Along the windward edge of the greenhouses an elevated CSP parabolic trough collector would provide added benefits to the Seawater Greenhouses by acting as wind catchers.



Computer generated image showing the key components of the scheme: The Seawater Greenhouses provide water to the CSP systems, crops within and between the greenhouses and further vegetation grown downwind.

Orchards are planted in the vicinity of the greenhouses which provide water for their irrigation, and a micro climate of humid air. Further downwind, the planting of native species and drought tolerant energy crops such as Jatropha is envisaged as a source of bio-fuel and to enhance soil fertility.

In most desert regions, humidity falls with increasing distance from the coast. Lower humidity translates to cooler growing conditions, enhanced fresh water production and enhanced rates of evaporation. These conditions will in turn increase the rate of night time dew formation, particularly where low night time conditions are experienced. A 10,000 hectare area of Seawater Greenhouses will evaporate over a million tonnes of seawater per day. If the scheme were located upwind of higher terrain then the air carrying this 'lost' humidity would rise and cool, contributing to the occurrence of cloud and dew. This precipitation could fall as rain or be collected using fog-nets thus allowing further areas of desert to be revegetated. The new plant growth and the soils would sequester significant quantities of carbon from the atmosphere.

The two technologies have very commercially attractive synergies:

- CSP systems need water for cleaning the mirrors and for the generation of steam to drive the turbines which the greenhouses can provide.
- The Greenhouse evaporators make very efficient dust traps (as do plants that are growing outside) which benefits the CSP since the mirrors stay cleaner and therefore operate more efficiently.
- In solar thermal power plants, only about 25% of the collected solar energy is converted into electricity. If combined with sea water another 50% of the collected energy, normally released as heat, can be used for desalination. This way, up to 85% of the collected solar energy can be used, and with each TWh of power, 40 million m³ water can be desalinated in cogeneration. (http://www.desertec.org)

4. Conclusion

By combining two proven technologies, the Sahara Forest Project demonstrates the potential to create large quantities of renewable energy, food and fresh water. The scheme would also have the restorative effect of returning areas of desert to forested land and sequestering substantial quantities of atmospheric carbon in new plant growth and reactivated soils.

In stark contrast to many of the unsustainable forms of agriculture being practised in parts of the world, this scheme would bring new areas of land back to a state of biological productivity. In providing fresh water in the very areas in which there is a great deal of water stress, the Sahara Forest Project could help alleviate potential conflicts.