

# Desalination of sea water, nature's way

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## Abstract

Earth is facing an existential crises like none we have ever witnessed. This is not simply a matter of global warming, which in 50 years predicts an average temperature increase of a few degrees. Such news, while highly disturbing, is a dramatic understatement of the seriousness of our problems.<sup>1</sup> These problem may start with the earth's population. The resources required for life on Earth may not up to the demands of more than 8 billion people. Potable water and food are as serious a problem as the implications of global warming (e.g., rising oceans, extreme weather patterns, fires, etc.). Both will be devastating for the earth's population, for all species, on both land and sea.<sup>2</sup>

Here we propose an interleaved multi-tasking plan to solve most, if not all of these problems, packaged into one solution. While a specific plan is outlined, it is envisioned that there are many alternatives, not discussed.<sup>3</sup> The proposal is a highly innovative approach. We look at several thermodynamic alternatives for separating ocean water into its 96.7% potable water and 3.5% salts, followed by decomposing the remaining 3.5% of salts into NaCl (85.6%), Magnesium (3.7%), Sulfate (2.7%), and the final target, Calcium Carbonate & Calcium Bicarbonate (1.2%) (left panel of Fig. ??). The right panel of the figure outlines the five processing steps proposed to convert the sea water (OCEAN) into potable water with the sun as the sole source of thermal energy (1.37 [kW/m<sup>2</sup>]) contained evaporation, creating thousands of huge lakes (FRESH WATER LAKE) in all the many arid deserts throughout the earth. As these deserts are converted to jungles, they will remove the remaining CO<sub>2</sub> from the air, through natural processes, solving the problem of global warming over the long term. One of the key components of this proposal is to bring together the faculty and students, drawing upon on the vast composite knowledge within our university population.

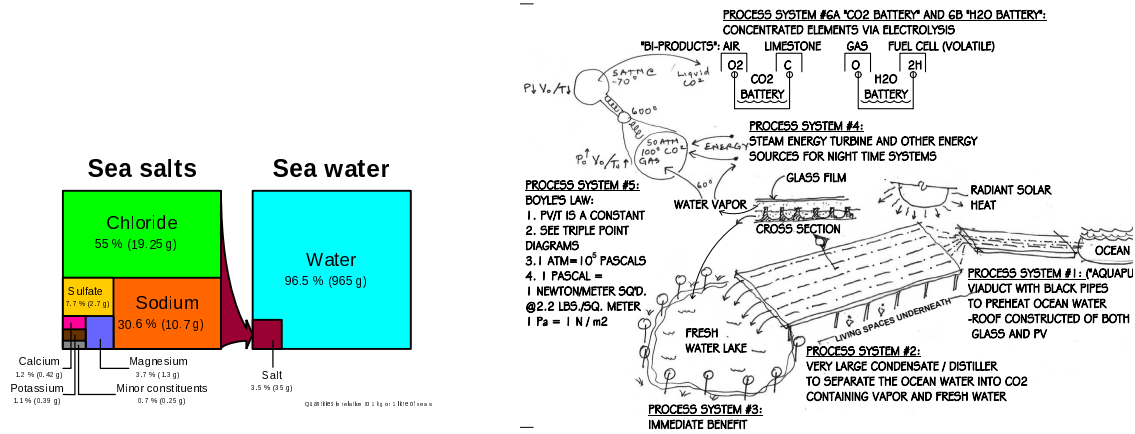


Figure A: LEFT: Sea water is 96.5% H<sub>2</sub>O with NaCl being the largest contaminant. B: RIGHT: Outline of the 5 PROCESS SYSTEMS (PS) required to convert the ocean water into potable water and various salts. The 3.5% of ocean salts are extracted from the water as a solid and broken down into their various components, by one several possible PSs, as outlined in the proposal. The extraction of the CO<sub>2</sub> is the most expensive step because Ca is a highly reactive element, and the most difficult to purify. Fortunately carbon is present in only trace amounts (300-400 [ppm]).

## Overview

The basic concept is to take water from the ocean and separate the pure water from the CO<sub>2</sub>, hopefully solving the water crises. The water will be used to grow plants (trees, grass, food, etc.) on a massive scale.<sup>4</sup> The goal here is to replace our many arid deserts with jungles, returning them to an earlier (e.g., 200,000 years ago) state. Given sufficient plant life, the CO<sub>2</sub> will be absorbed naturally. Given enough water, this is a feasible long term plan, but will take at least decades before this can be functional. In the mean time we need to directly deal with reducing CO<sub>2</sub> in the ocean, where it is doing the greatest damage.

Much of the trapped heat and CO<sub>2</sub>, due to our increased burning of fossil fuel over recent centuries, has been absorbed by the oceans. This has obscured our awareness of the severity of the problem, and, at the same time,

<sup>1</sup><https://www.nytimes.com/interactive/2019/11/25/climate/india-monsoon-drought.html>

<sup>2</sup><https://www.quantamagazine.org/cloud-loss-could-add-8-degrees-to-global-warming-20190225/>

<sup>3</sup>The guide should be "Whatever works best should be tried and the winning alternatives adopted."

<sup>4</sup><https://www.goodnewsnetwork.org/using-sewage-water-to-grow-trees-in-egyptian-desert/>

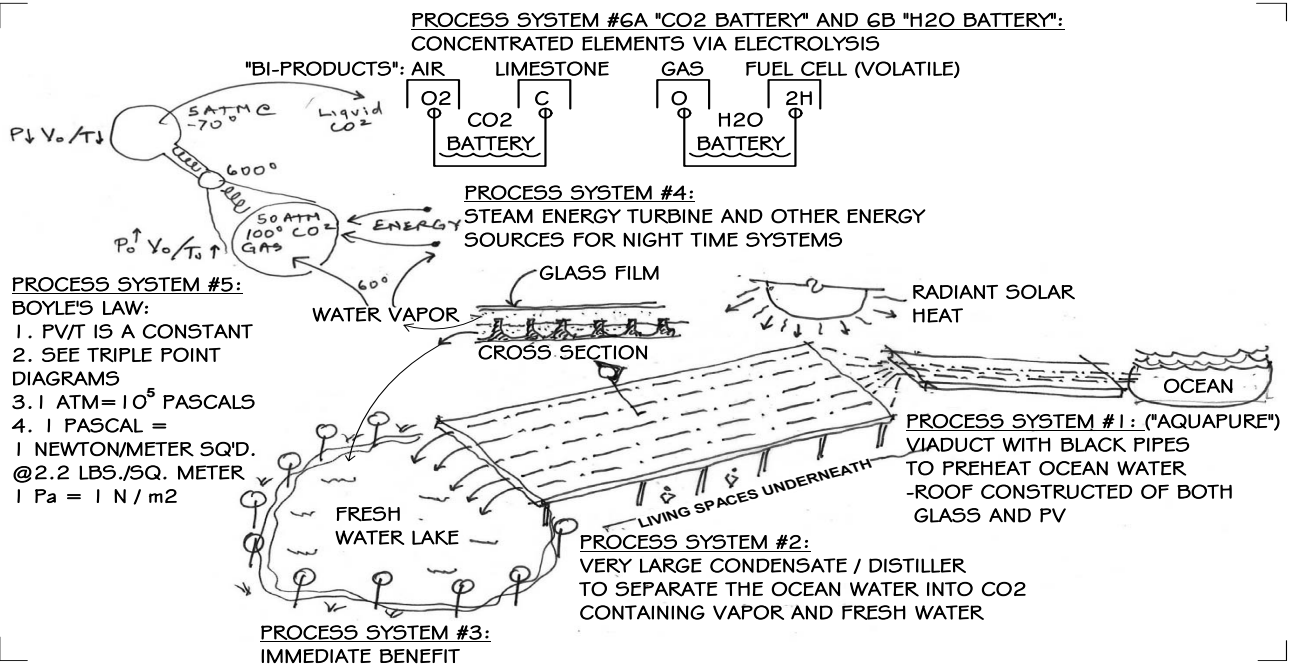


Figure 1: Process diagram showing the five different proposals for converting sea water into pure water and liquid CO<sub>2</sub>, to prepare it for electrolysis to split it into O<sub>2</sub> and graphite, or alternatively limestone. Also shown is the electrolysis of H<sub>2</sub>O to split it into 2H and O<sub>2</sub>.

lowered the PH of the ocean. Presently the PH is 8.1.<sup>5</sup> While the ocean is base, acid rains and absorbed CO<sub>2</sub> have severely lowered the PH, causing the destruction of the coral, critical to life and diversity in the ocean (i.e., on the planet). Life on earth is very dependent on a healthy ocean. Thus besides desalinating ocean water, we need to concentrate the CO<sub>2</sub> so that it may be reduced and converted into one of several possible inert compound substances, such as graphite and oxygen, or perhaps better, limestone. If we removed all the potable water from ocean water, only 3.5 [gm] of salt per liter of sea water would remain. This is what happens in salt evaporation ponds.

The driving principle for doing this is energy efficiency. Is it possible to do this using only solar and wind as sources of energy, with close to 100% utilization and efficiency? The maximum amount of water is determined by the solar constant (1.3 [kW/m<sup>2</sup>]) and the efficiency of the Carnot cycle in reclaiming the latent heat energy of the water and vapor. This is the achievable goal of our proposal.

**A specific proposal:** Our proposal is presented in Fig. ???. On the far right 15° ocean water is piped in and fed to an aqueduct, which we call an *aquipure*, denoting a conduit used to extract pure water, to concentrate, and eventually reduce the dissolved salt. The aquipure is slightly angled, so as to gravity-feed the water inland. Ocean wind farms could provide the electricity to run the deep-water pumps. Once available systems are prototyped, it would be replicated on a massive scale, creating thousands of fresh water lakes and jungles.

There are numbered *process systems* (PS) indicated in the diagram labeled as PROCESS SYSTEM #N, with N = 1, 2, ..., 5. Process System #1 (PS-1) delivers the ocean water to the aquipure, shown in PS-2 is the heart of the desal system, where the ocean water is heated by the sun's radiant energy (solar heat), raising the water temperature causing it to evaporate. The aquipure is covered by a thin transparent glass or plastic sheath that lets the sun's rays through but traps the water vapor.

PS #4 shows a cross-section of the aquipure, with corrugated channels to transport the ocean water. PS-4 further describes the inner workings of the system, for extracting the desalinated water, leaving behind the sea salts and CO<sub>2</sub>. A few centimeters above the water surface is a film (e.g., a transparent layer) to contain the water vapor.

To the right and above the aquipure is the sun, which provides the only energy source to heat, and thus evaporate, the sea water. The ideal strategy is to raise the humidity to 100% within the air space between the water surface and the cover sheet. As shown in Fig. ??, 100% humidity, known as the dew point, at 94 [°F]

<sup>5</sup>I'm told that somewhere between 8.2 and 8.3 is ideal. Neutral is 7.

corresponds to 5% [kg/kg] water vapor. By dropping the temperature to 59° F the humidity drops to 1.5%, yielding 3.5% desalinated water. If the humid air is reduced to 39 [°F] the humidity would drop to 0.5%.

This water vapor is then sucked down through small holes in the ducts, where it meets a cold plate, having a high heat capacity and thermal conductivity. When the water vapor comes in contact with the cold plate,<sup>6</sup> the lower dew point is met, and the water vapor turns into liquid water, where it is collected, and by gravity, transported to the fresh water lake (PS #3).

This low temperature for condensation could, in theory, be obtained from 1) cold ocean water that has not been heated by the sun, via 2) heat pump buried deep in the earth, or by 3) electrically driven air conditioning. These various methods have different efficiency limitations, thus are not equivalent. In the case of the air conditioner, the heat expelled from the AC unit could be used to further heat the water, somewhat raising the net efficiency. If the system is in a arid desert, the dry hot air can be used to evaporate the water. This might even be an even simpler system to implement.

For this system to convert sufficient water/hr, the humidity needs to be close to 100% and be a rapid process. It is believed that misting the water above the aquipure would increase the rate of evaporation, accelerating the water distillation rate. Work needs to be done to determine the efficiency of the water-vapor creation rate. Of course sun-based evaporation is how rain is naturally made. Natural atmospheric pressure and temperature variations (i.e., a cold front) trigger the release of the vapor to liquid water. This is all well know, and is the main source of most natural fresh water. However this process is not under our control, and happens randomly, leading to long periods of drought. Figure ?? is envisioned to give us precise control of this natural process.

All commercial desalination systems use reverse-osmosis (RO), which requires large amounts of electricity. Solar panels to provide the electricity are only 22% efficient, greatly limiting the efficiency. There is research on using evaporation, but I do not know the status of such proposals.

In the case that supplementary electricity (e.g., at night) is needed, a safe nuclear reactor technology is presently under development, called *small modular reactors* (SMR).<sup>7</sup> The claim is that SMR solves many of the problems of older technology. For example SMR is claimed to be 100% free from melt-down incidents due to its use of molten salt rather than water as the coolant.

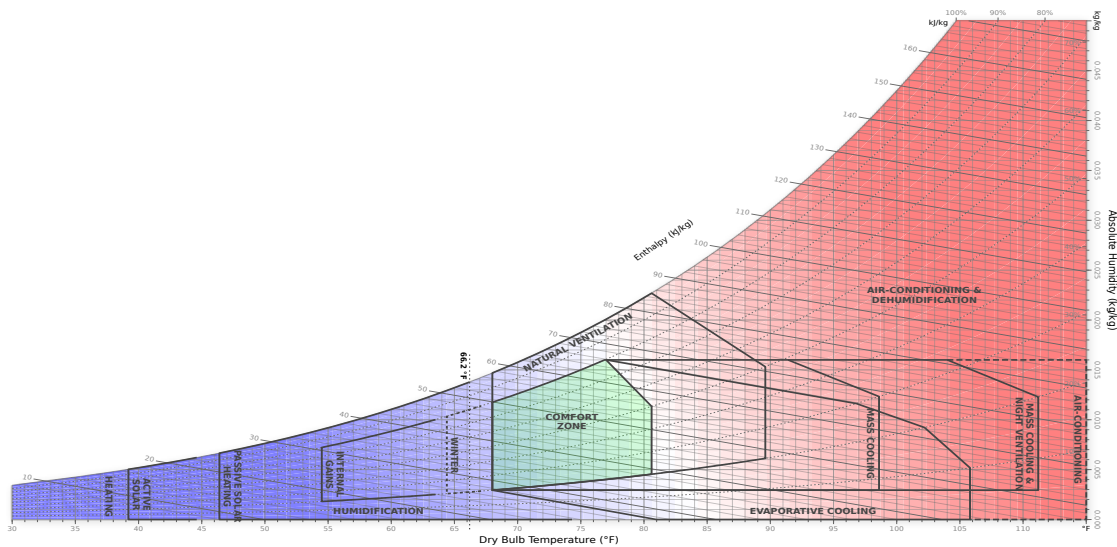


Figure 2: This psychrometric chart provides the quantitative relationship between the temperature, humidity, the vapor pressure and dew-point (?). The exponential growth with temperature is known as the Teten's equation (?). For example (see upper right corner of chart) given a dry-bulb temperature of 105 [°F] (40 [°C]) and a relative humidity of 100%, the absolute humidity is 50 g/kg (5.0%). If the temperature were to drop to 38 [°F] (3 [°C]), the humidity would drop to 5 [g/kg] (0.5%). This would release 50-5=45 [g] of water per [kg] of air, or 4.5% of the air mass in water. The key question is, how fast can this reaction take? The answer depends on the power input from the sun required to raise the air temperature two 100 [°F], as the humid air is removed from the vessel, to be replaced from the liquid water surface. Namely how quickly can the humidity return to 18% as it is passed to the chill-plate at 38 [°F] and replaced by less humid air. Based on this chart, it is a table-lookup to find the ratio of input energy [Joules] to water recover ratio [g/kJ] via the enthalpy, which at 92 [°F] is 41 [kJ/kg], as shown in the upper right corner of the chart. Ref: <https://drajmarsh.bitbucket.io/psychro-chart2d.html>.

<sup>6</sup>Stainless steel wool would be better, but more costly.

<sup>7</sup><https://www.energy.gov/ne/nuclear-reactor-technologies>

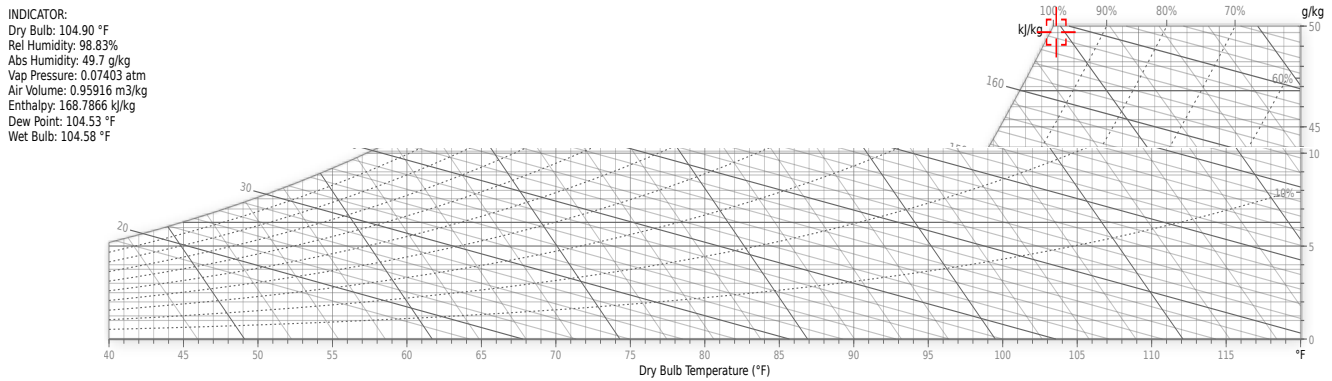


Figure 3: This version of the chart from Fig. ?? expands the top and bottom portions, for greatly improved readability. The axes for the two figures are the same, only the middle portion of the chart has been removed. The bottom axis is the dry-bulb temperature, from 40 to 120 [°F]. On the right most ordinate is the maximum humidity (dew point) in [gms] of water vapor per [kgm] of water. The top-left axis is the relative humidity, from 100% (dew point) on the left to 60% on the right. The the cross-hair values are given in the upper left corner of the chart which marks 50 [g/kgm] (5 vapor water mass).

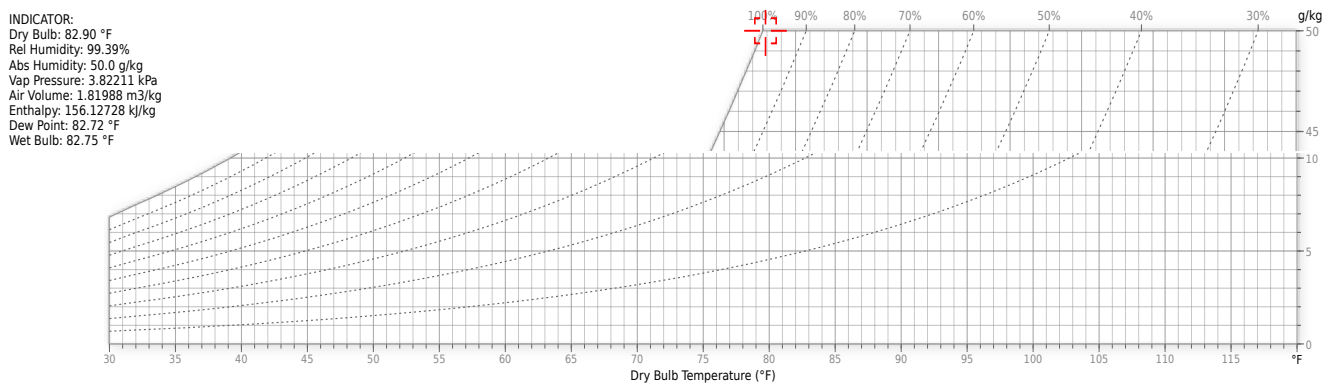


Figure 4: This is dramatically different because of the much greater vapor pressure (3.8 [atm]) vs. Fig. ?? for which it was 0.074 [atm]. With increased pressure the 5% point is reached at only 80° F (19° C).

**CO2 scrubbing:** The second step (PS-4) in this process is scrubbing the CO2 from the brine. There a number of approaches to this problem:

1. Once large portion of the water is removed. The ocean is 96.5% pure water and 3.5% salts. If a large percentage of this wather has been removed as potable water, for sake of argument, say 75% were remove, the remaining volume would be 25% and the concentration would increase by four times to 15%. The exact percentage of residual CO2 is presently unknown, and needs to be determined experimentally. We assume it increases by four fold as well, from 0.400 to 1.5 [ppk] (0.15%). If it were possible to remove remove 7/8 water and 1/8 brine, the concentration would increase by 8 to 0.3%.
2. An alternative is to remove all the water leaving the 3.5% salts. Then using SMR technology (?) we can heat the salts to the melting point. Once the salt is a liquid it might be possible to use either fractional distillation to separate the various salts, or electrolysis. These alternatives need further research. It is likely the answer is well known.

There are several possible ways to remove the carbon from the CO2 enriched brine.<sup>8</sup> This CO2 enrichment process requires much more energy than the desal process since we must heat the brine to either (1) a gases state (boiling temperature)<sup>9</sup> (??) or (2) by removing all the water and converting the salt to a molten mass, followed by a fractional distillation process to dissociate the elements.<sup>10</sup>

<sup>8</sup>This step assumes that most of the CO2 stays with the brine rather than with the condensed water vapor. CO2 that escapes with the purified water is harmless for desal production.

<sup>9</sup>Think what happens in a pressure cooker.

<sup>10</sup>Using proposed *Small modular reactor* technology:

<https://www.energy.gov/ne/nuclear-reactor-technologies/small-modular-nuclear-reactors>

Assuming scenario (1), the liquid brine will be hot due, to the solar heating. For sake of argument, assume it is between 60 and 80 [°C] and 0.2% brine. The exact values are key experimental variables. This process is shown as PS-4, just below the words “Energy Turbine” in Fig. ??.

Once the brine is in the gaseous state the steam is highly compressed, raising the temperature, for example, to 600 [°C] (eight-fold increase in temperature). This high-pressure super-heated brine-steam could be used to drive a steam turbine to generate electricity, raising the efficiency of the overall process. Once cooled to atmospheric temperatures, the pressure is released, causing an eight-fold decrease in temperature, from 75 to 600°[F]. It is then further cooled to -70[°C] at 3 [atm], which is the CO<sub>2</sub> triple point. In this way the CO<sub>2</sub> is converted to a liquid. It is assumed (and confirmed) that if electricity is applied to the liquid CO<sub>2</sub>, graphite will attach to one electrode (moving to reduce a graphite buildup) and O<sub>2</sub>, which is saved or released into the environment.

If the salt or enriched brine has not been processed to remove CO<sub>2</sub> then a method of disposing of the salt needs to be described. There are a number of alternatives, including 1) converting it to molten salt, 2) mining the salt for valuable minerals and precious metals, or 3) returning it to the sea to assure the ocean’s NaCl balance is unmodified. In this third case, we do not want to return the CO<sub>2</sub> to the sea, thus it must first be removed.

**Hydrogen generation:** A second electrolysis could optionally be used on the remaining water to produce hydrogen (and salt), which could be used as the alternative to fossil fuel. When hydrogen burns the byproduct is, of course, water, releasing much of the energy used to create it. This is believed be a relative efficient store of the electrical energy. The alternative would be fuel cells or traditional batteries, but that is believed to be a more expensive technology (and much greater weight). This is a trade-off that must be further explored as the future replacement for fossil fuels.

## A Desalination for India

“Water is a local problem and it needs local solutions,” said Priyanka Jamwal, a fellow at the Ashoka Trust for Research in Ecology and the Environment in Bangalore.<sup>11</sup>

But to solve this world wide crisis we need to go where the water is, the ocean. Of course we need fresh water, not the ocean’s saltwater. Desalination plants around the world are base on reverse osmosis (RO), an expensive resource that is not ideal to the huge demands of fresh water. The oceans are become less acidic due to the build up of CO<sub>2</sub>, which is highly soluble in water. In fact a third of the CO<sub>2</sub> generated by the burning of fossil fuels ends up in the ocean, where it acidifies the ocean, killing the coral.<sup>12</sup>

Life in the ocean, one of our main sources of food, depend on this coral. Of course the main problem is the large population on the earth, which has amplified these many intertwined problems. If we don’t reduce the population, it will be reduced by extinction. If we can find a a more efficient method than RO, we might solve the water shortage problem, for ever. Until then we must continue to reduce the build up of CO<sub>2</sub> and other green house gases, and ultimately the world’s population.

Where does rain come from? The sun evaporates the surface water from the ocean, forming clouds, which eventually dump the moisture as rain. Can this process be captured under our control so that we can make rain as needed rather than depending on natural processes, which are random unreliable sources of water? In this presentation I shall present a scenario for how to convert sea water into fresh water, and at the same time extract the CO<sub>2</sub> and convert it into either limestone or pure graphite, directly from the energy from the sun.

Figure ?? is a proposal on how to solve the many world stress problems. It starts with a wide (perhaps hundreds of meters) and very (thousands of meters) long aquifers, which we call aquipures, into which sea water is pumped in large quantities. The aquipures then transport the seawater to remote desert locations. A related idea, but based on RO has been implemented in Aba Daubi. But there much more to this proposal, which is not based on RO.

On the way to the final destination of the aquipure the sunshine evaporates the water, converting the sea water into water vapor (think high humidity). To trap the water vapor the aquipures are covered by a thin sheet of plastic, transparent to the sun’s light. The water in the aquipures is continuously vaporized into an aerosol (small sub-millimeter sized droplets, to accelerate the evaporation, by increasing the water’s surface to the air.

<sup>11</sup><https://www.nytimes.com/interactive/2019/08/06/climate/world-water-stress.html>

<sup>12</sup><https://www.epa.gov/ocean-acidification/understanding-science-ocean-and-coastal-acidification#self>

Compared to that required for RO desalination, each of these processes only take small amounts of electricity. Once the humidity is raised to close to 100%, the moist air is sucked down channels by a low pressure vacuum, where it comes in contact with a chilled pores ceramic surface having high thermal conductivity. The cooling of the surface could be done by the ocean water as it comes in from the sea, which is typically much colder than the air. The slightly warmed sea water would then be used to flush the concentrated brine, resulting from the removal of H<sub>2</sub>O and CO<sub>2</sub> from the sea water.

There are several scenarios for separating the CO<sub>2</sub> from the sea water or from fresh water. CO<sub>2</sub> is twice the mass of H<sub>2</sub>O, thus centimeter size very high speed rotating centrifuges would naturally separate the two liquids, or gases. Such a process is used today to separate uranium 235 from 237. In that case the mass difference is slightly less than 1%, so the 2:1 ratio of CO<sub>2</sub> over H<sub>2</sub>O can be much more efficient. The separation is enhanced by rotating the centrifuge at a high speed, increasing the radial forces on the molecules.

The above methods needs to be tested on a small scale, and once the many logistic details are worked, deployed on a mass scale. Over the last hundred years it is said that about 1/3 tera-ton of CO<sub>2</sub> has been released into the environment by various human activities. It seems likely that it will take all the energy we generated from the fossil fuels, and more, to now remove them. Perhaps the energy from the sun is insufficient to do the job. In this case we will need additional energy from modern nuclear reactors. This new technology is much safer and smaller in scale, making it a practical option to solar. One source claimed it would be cheaper and cleaner than natural gas energy.<sup>13</sup>

**Management of the aquipure:** The aquipure will need people to manage it. This is not a minor detail. This could be a way to manage displaced people. Of course such a proposal is not a scientific problem, thus will not be further explored here. But such a source of labor has certain positive benefits. It could, in theory, solve much of the worlds displaced people problem, which is as serious as the fresh water, energy and food shortage problems mentioned in the introduction.

The motto that has been suggested for this grandiose proposal is

*To be, or not to be, that is the question.*

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<sup>13</sup><https://www.youtube.com/watch?v=5HL1BEC024g>(April13, 2013)