Vision for Producing Fresh Water Using Space Power

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Abstract. An escalating climate crisis is stressing the Earth's environment. One significantly affected area is the global water infrastructure that includes hydropower, flood defense, drainage, and irrigation systems. The effect of adverse climate change on freshwater systems aggravates population growth and weakens economic conditions. In the western U.S., for example, reduced water supplies plus increased demand are likely to provoke more interstate and urban–rural competition for over-allocated water resources. Seawater desalination has existed for decades as a proven technology for supplying water in coastal areas; however, desalination processes are energy intensive and this has reduced their widespread use. It is noted that California offshore oil and gas platforms already use seawater desalination to produce fresh water for platform personnel and equipment. It is proposed that as California coastal oil and gas platforms come to the end of their productive lives, they be re-commissioned for use as large-scale fresh water production facilities. Solar arrays, mounted on the platforms, are able to provide some of the power needed for seawater desalination during the daytime. However, for efficient fresh water production, a facility must be operated 24 hours a day. The use of solar power transmitted from orbiting satellites (Solar Power Satellites – SPS) to substantially augment the solar array power generated from natural sunlight is a feasible concept. We discuss the architecture of using a SPS in geosynchronous orbit (GEO) to enable 24 hours a day operations for fresh water production through seawater desalination. Production of industrial quantities of fresh water on re-commissioned oil and gas platforms, using energy transmitted from solar power satellites, is a breakthrough concept for addressing the pressing climate, water, and economic issues of the 21st Century using space assets.

Climate Change and Water Shortage

Climate change is stressing the Earth's environment. It is occurring because of increasing accumulation of two trace-species "greenhouse" gases in the lower atmosphere, i.e., carbon dioxide (CO_2) and methane (CH_4). These long-lived stratospheric gases are very effective at trapping the re-radiated infrared radiation from the surface. Carbon dioxide and methane are not equal in their heat-retention capacity and methane is 20 times more effective at trapping heat than is carbon dioxide.

The Intergovernmental Panel on Climate Change (IPCC) reports that the 1906–2005 trend in the global surface-to-stratosphere temperature is a warming of 0.74°C per century (IPCC, 2008). Measureable effects of this temperature rise include melting polar cap ices, rising sea levels, and more severe storms. The warming rate has escalated over the past 50 years and, in that period, the sea level has risen about 150 millimeters (6 inches) with a continuing rise of approximately 3 millimeters (1/8 inch) per year (NAP, 2008). One reason for the acceleration of global warming may be the increase in methane where, as the arctic permafrost thaws, more methane is released.

The consequences of climate change on fresh water are severe. By 2050, climate change will likely decrease the annual average river runoff (less water available) in mid-latitude drier regions and the dry tropics. In addition, there will likely be increasing runoff (flooding) at high latitudes and in some wet tropical areas. The average person in semi-arid areas such as the Mediterranean Basin, western USA, southern Africa, Australia, and northeastern Brazil will likely see decreased water supply. In contrast, people in northern Europe, central and northern USA, northern China, and the wet tropical regions in Southeast Asia, Africa, and South America will see increased flooding events even during the winter.

Climate change affects the global water infrastructure including hydropower, flood defense, drainage, and irrigation systems as well as water management practices (IPCC, 2008). The drought and flooding effects on freshwater systems adds to other stresses such as population growth, changing economic activity, land-use changes, and urbanization. These stresses occur because water demand will grow globally in the coming decades due to increased population and affluence.

For the western U.S., the projected warming by 2050 will likely cause large decreases in snowpack, earlier snowmelt, more winter rains, increased peak winter flooding, and reduced summer water flow. Secondary consequences will be increased drought conditions, lower crop yields, greater agricultural unemployment, and more pervasive forest fires. Reduced water supplies, coupled with increased demand, are likely to exacerbate state-to-state and urban–rural competition for over-allocated water resources.

Seawater Desalination as a Coastal Solution

It is no coincidence that the world's population centers, along with those in the U.S., are heavily concentrated along coastal areas. Moderate climates plus access to global seaports and commerce have accelerated this historical population growth trend. Approximately 153 million people (53 percent of the U.S. population) live in coastal counties as of 2003 (NOAA, 2004) and 3 billion people worldwide live within 200 kilometers of a coastline (PRB, 2009). The large growth of coastal populations makes it feasible to consider seawater desalination as a source for metropolitan water supplies, a trend that has accelerated in California coastal communities.

Seawater desalination is a mature technology. Fresh water is reclaimed from seawater with an efficiency of 15-50%, depending upon the production process of either distillation or reverse osmosis (RO). Distillation plants do not shut down their operations for cleaning or replacement of equipment as often as RO plants although tube bundles do need occasional replacement and cleaning. The requirements for water pretreatment in distillation plants are less because coagulants are not needed to settle out particles before water passes through the membranes as in RO plants. Additionally, distillation plants do not generate waste from backwash of pretreatment filters. On the other hand, feedwater into RO facilities does not require heating, which means that the thermal impacts of discharges are lower. RO plants have fewer problems with corrosion, they usually have lower energy requirements, and they tend to have higher recovery rates for seawater, e.g., around 45%. The RO process can remove unwanted contaminants, such as trihalomethane-precursors, pesticides, and bacteria and they take up less surface area than distillation plants for the same amount of water production.

Fig.1. The Charles Meyer Desalination Facility located in Santa Barbara, CA.

There are 12 existing desalination facilities along the California coast with another 19 proposed. The facility sizes vary according to design, ranging from 80 square feet to 7.5 acres. Heights are from 15–20 feet for typical reverse osmosis equipment and 30–45 feet for typical distillation equipment.

Fresh water production ranges from 20-112,000 acre-feet yr^{-1}. For example, the Santa Barbara Charles Meyer Desalination Facility (figure 1) can produce a maximum of 30,000 m^3 of fresh water per day. In comparison, the Santa Barbara facility maximum production rate is about 3% of the Colorado River water flow (1×10^6 m^3 per day at the Yuma Arizona 4th St. Bridge), <1% of the Owens Valley water flow into Southern California (5×10^6 m^3 per day), and

0.003% of the California aqueduct water flow into Southern California (1×10^9 m^3 per day).

Oil Platform Decommissioning and Their Re-use for Water Production

There are 27 offshore oil and gas platforms (figure 2) operating along the California coast. Ten are nearing the end of their productive lives and the U.S. Department of Interior, Minerals Management Service estimates that decommissioning will begin in 2010 and be complete by 2025. Complete removal is the only decommissioning option allowed under current regulations. A high percentage of these platforms are deepwater structures in water depths of 300–1200 feet; their sizes make removal both technically challenging and costly to the industry. Initial estimates for complete removal of all remaining platforms ranged from $1.2 to $2 billion. However, since current technologies are inadequate to remove the deepest platforms, the actual costs will likely be substantially higher with estimates reaching $1 billion per platform.

Some of the offshore oil and gas platforms have small seawater desalination facilities already in operation producing fresh water for platform personnel and equipment. Their existence demonstrates the technical feasibility of seawater desalination on offshore facilities.

Recently it has been proposed (Tobiska, 2009) that as the California coastal oil and gas platforms come to the end of their productive lives they be re-commissioned for fresh water production. While not all platforms may be suitable due to age, size, and scheduled decommission-date, the platforms are generally capable of supporting industrial scale seawater desalination. In addition to successful small-scale desalination demonstration, they are ideally located for contributing to a California coastal fresh water supply.

Assuming that technical and environmental concerns are properly answered, the re-use of these platforms for fresh water production would benefit: i) the coastal populations by providing an inexhaustible water supply; ii) the agricultural industry by enabling the diversion of some existing urban water sources to agricultural use; iii) the oil and gas industry by enabling it to realize a tremendous cost savings by not removing the platforms and generating lease revenue from water production; and iv) the environment by preventing local sea floor damage that would occur during platform removal and by reducing the global carbon footprint if the energy source described below is utilized.

Fig.2. Offshore oil platform located off the California coast.

Seawater Desalination Water Production can be Energy Intensive

Energy requirements for desalination plants are high. It is estimated that 20 million kWh yr^{-1} is required for full-time backup (reduced production) operation of the City of Santa Barbara's facility in order to produce 3,000 acre-feet yr^{-1} of water. This is 11,000 m^3 per day that can serve about ½ the population of Santa Barbara (total population 90,305 in 2004) using 70 gallons per capita per day. The daily energy cost is near 2.3 MW. In contrast, the energy needed to pump over twice that amount (7,500 acre-feet yr^{-1}) from the Colorado River Aqueduct or the State Water Project to the Metropolitan Water District of Southern California is about the same (26 million kWh yr^{-1}). Thus, desalination energy requirements are about double other water energy costs and greater than the energy use of small-sized industrial facilities (refineries, small steel mills, large computer centers) typically using 75,000 to 100,000 kWh yr^{-1} (CCC, 1993).

The cost can vary, depending upon technology and capitalization expenses. In fact, high costs of capitalization and electricity are two reasons often cited why conventional seawater desalination can be prohibitively expensive. However, compared to new fresh water sources, the California Coastal Commission (CCC) estimates the cost of seawater desalination rapidly becomes equal to or less than other sources.

Solar power for fresh water production

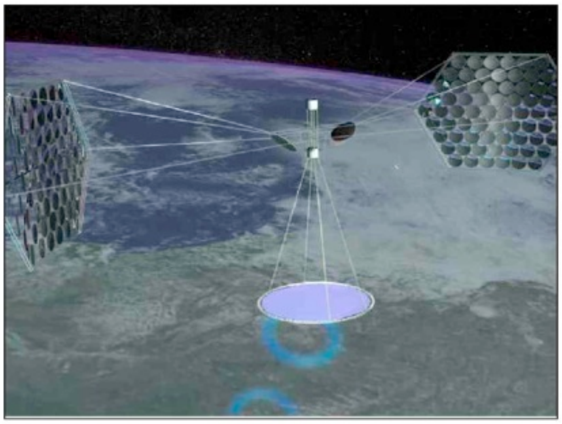

Fig.3. Credit Solar Power Satellite concept by John Mankins with image by Kris Holland.

The use of solar arrays for powering seawater desalination is not new nor is the idea of using heat flow tubes in the distillation process. Solar arrays are coupled with seawater desalination in the eastern Mediterranean and Persian Gulf. The prime disadvantages of using solar arrays are that solar energy is limited to approximately half a day (no solar power at night), seasonal Sun angles reduce solar array efficiency, and clouds reduce power from solar arrays.

If fresh water production were implemented using an offshore platform, solar arrays are one feasible method for generating electrical power for either RO or distillation processes. However, for efficient fresh water production, a facility must be operated 24 hours a day. The use of solar power from orbiting satellites (Solar Power Satellites – SPS) is a method that can substantially increment the solar array power generated from natural sunlight.

SPS systems (figure 3) have been conceived and designed for nearly 4 decades but not yet demonstrated. The design concept is straightforward – use a large solar array structure in space, collect the electrical power needed to power a microwave or laser transmitter on the spacecraft, direct the transmitted energy to a solar array receiving antenna at the Earth's surface that is sensitive to the transmitted microwave or laser frequency, and convert the received power at the Earth solar array into electricity. The advantage of a SPS in geosynchronous orbit (GEO) is that it is able to produce power 24 hours a day and, thus, power can be transmitted at night to the surface of the Earth. Minor outages of up to 1½-hours per day over a 2-week period occur during the spring and fall equinoxes.

Historically, SPS were envisioned for providing large-scale electricity to towns or small cities. This is based on the fact that a single kilometer-wide band of space at GEO experiences nearly enough solar flux in one year to equal the amount of energy contained within all known recoverable conventional oil reserves on Earth today. The size of an orbital solar array is still technically prohibitive to provide power for cities. However, the concept described here would use a satellite conceptually similar to existing commercial communication satellites but with a much larger solar array (Potter, *et al.,* 2009). In comparison, the International Space Station (ISS) has a total power of 120 kW using 16 solar panels of approximately 5600 m^2. A 2 MW SPS would require approximately 16 times the number of solar panels as the ISS, i.e., a configuration that is technically challenging but not unfeasible. Without considering inefficiencies in the system or advances in solar cell technology, a single 2 MW-class satellite can provide power for a Santa Barbara-class seawater distillation plant on a converted offshore platform during the night and can supplement the power for operations during the day. An added advantage of SPS is that power sharing in 100-ms bursts can serve up to 10 geographically isolated locations every second. SPS power received at the Earth's surface is about ½ Sun in the center of the beam, day and night.

The cost of a SPS at GEO is more than a communications satellite, which costs around \$100–200M. However, it should be much less than a direct linear scaling by size. The complexity is less although the structure is larger, requiring additional attitude control and surface charging mitigation. While a more realistic cost needs to be determined, we estimate it to be around \$500$^+$M for one satellite using existing technologies.

Table 1. Summary of gross metrics for an ISS-class solar power satellite

ISS-class solar power satellite	Gross metric with no inefficiencies
Fresh water production	700 m^3/day or 170,000 gal/day
Population served	3000 people
Power required	120 kW

Benefits derived from Space Water

There is a strong argument presented here – *produce industrial quantities of fresh water for semi-arid Southern California (SoCal) using decommissioned offshore oil and gas platforms that are fitted with solar arrays for diurnal power and augmented by space-based solar power for around-the-clock operation.* This argument makes novel use of space-based assets to solve 21st Century problems.

Global benefits can be derived from Space Water and they include i) a clean, no-carbon footprint energy legacy for centuries to come; ii) a credible method for global fresh water production; and iii) a transformative solution to the global climate crisis. U.S. benefits include: i) a clean energy source for water production and for electricity; ii) military energy and water independence at forward bases; and iii) asserting global leadership for space asset development and utilization in the 21st Century. SoCal benefits include: i) an unlimited fresh water source; and ii) new jobs creation in aerospace, energy, water, and agricultural industries. Industry benefits include: i) new, unlimited resources for the water, power, and mineral industries; ii) lease revenues and minimal-cost decommissioning for oil and gas platform owners; and iii) major program development for the aerospace industry.

Next steps

During 2009, a broad interest group for Space Water introduced this concept to oil/gas, aerospace, space weather, military, and legislative policy-makers at national and California levels. Due to the beneficial implications of Space Water, proposals have been submitted to U.S. government agencies for an initial demonstration of new technologies and for holding an international workshop on the topic. A common consensus is that a detailed feasibility study on this concept should be conducted. Candidate sponsors include i) the National Security Space Office (NSSO), which sponsored the 2007 *Space-Based Solar Power As an Opportunity for Strategic Security, Phase 0 Architecture Feasibility Study*, also known as SBSP (NSSO, 2007), ii) the California Ocean Science Trust, which issued a 2008 *Request For Proposals: Study to Provide Information Related to Oil and Gas Platform Decommissioning Alternatives in California* (COST, 2008), iii) the National Research Council, iv) the National Science Foundation, v) NASA, vi) the Department of Defense, vii) the Department of Commerce, viii) the Department of Interior, and ix) the Department of Energy. Expertise from organizations familiar with seawater desalination, coastal environmental and land-use policy, water and power economics, oil and gas platform operations, and solar power satellite manufacturing must be included.

A first feasibility study could start with an assessment of the maturity level of the architecture's components. For example, i) climate change affecting the water infrastructure is generally understood scientifically but predictions are still evolving; ii) continued population growth in coastal areas is an expected, defined trend but modifiers need investigation; iii) the use of seawater desalination as a source for metropolitan water supplies is a mature technology but implementation issues tied to energy costs must be studied; iv) disposal of California coastal oil and gas platforms that reach the end of their productive lives is a well-defined policy direction but is tempered by concerns about the decommissioning costs and the probable sea floor disruption that accompanies removal; v) platform re-commissioning for alternative uses is a possibility but there is a continuing debate about the options (the concept for a large-scale fresh water production facility has not previously been considered); vi) solar arrays on offshore platforms to generate electrical power for desalination is a mature technology but its efficient implementation needs further improvement; vii) industrial fresh water production requires 24 hours a day operation and the use of solar power from orbiting solar power satellites must be studied as an implementation option; and viii) SPS is a mature concept with an immature implementation (no system proof-of-concept has been demonstrated).

The least mature element is space-based solar power. The NSSO's SBSP study has laid significant groundwork for a follow-on study by outlining fundamental next-step SBSP tasks, including the need i) to identify clear targets for economic viability in markets of interest; ii) to identify technical development goals and a risk roadmap; iii) to select the best design trades; and iv) to fully design and deploy a meaningful SPS demonstrator.

The above topics provide a framework for bringing together the study areas of SBSP, seawater desalination, solar array use on platforms, and policy, economic, societal impacts. A starting point for study-team building is the activity to organize an international expert workshop on Space Water in the spring of 2011. This workshop would address technical, policy, economic, and societal impact issues. Feasibility reports are needed for each area and conference papers could be used as a natural starting point for these studies.

References

California Coastal Commission, *Seawater Desalination in California,* http://www.coastal.ca.gov/desalrpt/dtitle.html#TOCDesalination, October 1993.

California Ocean Science Trust, *Study to Provide Information Related to Oil and Gas Platform Decommissioning Alternatives in California*, Request For Proposals, Oakland, CA, 2008.

Intergovernmental Panel on Climate Change, *Climate Change and Water*, Tech. Paper VI, 2008.

National Academies Press, *The National Academies Summit on Summary of a Meeting: America's Energy Future,* Committee for the National Academies Summit on America's Energy Future, Washington, DC, 2008.

National Oceanic and Atmospheric Administration, *Population Trends Along the Coastal United States: 1980-2008*, September 2004.

National Security Space Office, *Space-Based Solar Power As an Opportunity for Strategic Security, Phase 0 Architecture Feasibility Study*, Report to the Director, Interim Assessment, Release 0.1, 10 October 2007.

Population Reference Bureau Measure Communication, *Ripple Effects: Population and Coastal Regions*, www.measurecommunication.org or www.prb.org, 2009.

Potter, S., M. Bayer, D. Davis, A. Born, D. McCormick, L. Dorazio, and P. Patel, *Space Solar Power Satellite Alternatives and Architectures*, AIAA ASM, AIAA 2009-462, 2009.

Tobiska, W.K., *Vision for producing fresh water using space power*, Space 2009, AIAA 2009-6817, 2009.