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Solar-thermal powered desalination: Its significant challenges and potential

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ABSTRACT

Throughout the world, there are regions of vast extent that have many favorable features, but whose development is principally limited by the lack of fresh water. In arid areas where large-scale development has already occurred, e.g. parts of the Middle East and North Africa, the extraction of fresh water via desalination plants requires very large energy consumption. This motivates the development of *solar-desalination* systems, which are desalination systems that are powered by solar energy. With the goal of identifying key technical challenges and potential opportunities solar-desalination, we review a variety of solar energy technologies used for capturing and concentrating heat energy, and also review various technologies for desalination systems including advanced techniques for energy-recovery. Existing solar-powered desalination plants have generally been *indirect solar-desalination* systems that first (i) transform solar energy into electrical energy and then (ii) employ the resulting electrical energy to drive desalination systems. Other, potentially more efficient *direct solar-desalination* systems directly convert the solar energy to pressure and/or heat, and use these to directly power the desalination process. We compare the cost-effectiveness, energy-efficiency, and other relevant quantities of these potential technologies for solar-desalination systems. We conclude that the direct solar-desalination systems using solar-thermal collectors appear to be most attractive for optimization of the energy-efficiency of solar-desalination systems. Further, we consider the economics and other practical issues associated with employing solar-desalination systems to provide for economic water sources for urban and agricultural areas. We consider factors that have significant impact to the use of solar-desalination systems: including location, climate, the type of water source (ocean water or brackish water sources), as well as land-use and ecological issues. We observe that the most favorable locations are those with high solar irradiance, lack of fresh water, but access to large brackish water sources and/or proximate seawater. We review the known locations of global brackish water reserves and areas with proximate seawater. Finally, we determine what appear to be the most favorable candidate locations for solar-desalination systems, which include considerable sections of North and East Africa, the Middle East, Southern Europe, Western South America, Australia, Northern Mexico, and South-West USA. We conclude that the development of cost-effective and energy-efficient solar-desalination systems may in the immediate future the key to a future "terraforming" of otherwise desert and near-desert regions of the world, providing a "greening" of these regions.

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1. Introduction

1.1. A historical prospective: prior greening of the world at the end of the pleistocene

Interestingly, many areas such as the Middle East and North Africa were not always arid. At the end of the Pleistocene, roughly 12,000 years ago, the melting of glacier ice allowed many such areas have considerable fresh water. These conditions persisted to a degree even up to the Classic period 2000 years ago, and in those times for example certain areas that are now deserts in North Africa were a significant source of grains for Rome.

1.2. Green terraforming

We use the term “Green Terraforming” to describe the goal of transforming now arid areas of the world (e.g., sections of North and East Africa, the Middle East, Southern Europe, Western South America, Australia's interior, and South-West USA) to areas with considerable available fresh water. We will be discussing technology that with further improvement and the overcoming of some considerable technical challenges may lead to such as “Green Terraforming” of arid regions.

1.3. Goals and organization of paper

It should be noted that there is a very extensive existing literature (which we shall cite) both for desalination technologies and for solar powered technologies, and it our goal to provide a brief introduction and overview of those technologies sufficient to discuss them in conjunction.

In this Section 1 we have motivated our survey paper on solar-powered desalination. In Section 2 we briefly discuss known solar technologies, as well as their cost-efficiency, energy-efficiency, and technological challenges, and in particular how to best adapt these solar technologies to provide power for desalination. In Section 3 we discuss known desalination technologies, as well as their cost-efficiency, energy-efficiency, and technological challenges: in particular, the challenge of adapting desalination technologies to best utilize the power supplied by solar energy. In Section 4 we conclude the paper with a discussion of future challenges.

2. The rapidly increasing need for desalination

2.1. Freshwater reserves

We will use the term *fresh water* to denote water with no more than approx. 500–100 ppm salinity; fresh water constitutes only 3–5% of the world's water. To determine the areas where desalination is of use, see the above Fig. 1, which provides a world map of freshwater water reserves.

2.2. Rapidly diminishing accessible freshwater reserves

The high rate of population growth and climate change presents increased need for freshwater, and in the next decades many further areas of the world are expected also to require substantial use of desalination. Agriculture currently uses approximately 70% of fresh water, and overall agricultural water use will increase substantially with population growth, perhaps by 50% within 15–20 years. Agriculture use of fresh water competes with the industrial (approx. 20%) and household (approx. 10%) use of freshwater. A number of arid areas (e.g., much of the Middle East) already completely utilize all available sources of fresh water, and need to rely on desalination. In the future, with demand for fresh water approx. doubling every