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Review of feasible solar energy applications to water processes

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ABSTRACT

In the context of an upcoming energy crisis due to the decline of the Oil Era, water problems are expected to substantially worsen. And vice versa, due to the close relationship between water and energy issues, water problems are also expected to contribute to increased energy problems. Furthermore, environmental considerations, such as global warming, will surely add significant pressure. In this scenario, renewable energies are rapidly increasing their contribution to the global mix, with solar energy clearly having the greatest potential, and in view of the worldwide coincidence that where there is water stress and/or scarcity, there are also good solar radiation levels, the conclusion seems clear suitable technologies must be developed to permit the use of solar energy to simultaneously help solve energy and water problems. The main solar energy applications for water processes presented in this paper are: (i) solar desalination; (ii) solar detoxification and; (iii) solar disinfection.

Contents

1. Introduction: global water and energy problems

Power and water supply are widely recognised as the two major issues mankind will have to face and solve during this century. While it is clear that, in the next few decades, oil will cease to dominate, it is not yet clear today which source of energy will replace it. At the same time, water scarcity, already a serious global problem, will become critical during the first half of this century. Of all the current environmental problems, those related to energy and water are probably the hardest to approach scientifically, and those that will have the worst long-term consequences. Problems associated with water scarcity, and the gradual destruction and contamination of fresh water resources are becoming more pressing in many areas of the planet, causing concern even in countries which, so far, have not experienced such problems.

In 2005, 11,435 million tons oil equivalent (MTOE) of Total Primary Energy Supply (TPES) were consumed [1], with a planned growth of 0.7% in oil production by 2030, when it will start to decline [2], followed by the end of the era of oil as the dominant energy factor in the mid-term, mainly because half of available global conventional oil resources have already been consumed and what remains will be consumed within the coming 40 years. In fact, the most recent world (conventional) oil reserve estimates are (in billion barrels): 1210 [3,4], 1317 [5] and 1120 [6]. Taking an

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average figure of 1200 billion barrels, and considering the current (heavily increasing) consumption path of nearly 88 million barrels per day (about 32 billion barrels per year) [1], the span is clearly less than 40 years. Possible alternative primary energy sources are also very problematic. Nuclear energy, in addition to strong popular protest in many parts of the world, also has limited long-term fissionable uranium reserves, as well as security concerns (potential fabrication of weapons) in many countries. Coal involves very high CO_2 emissions and its repercussions on climate change [7] are very serious. If the energy prospect is worrisome, problems related to water shortage are even worse. Water is essential to life and today, with more than 6700 million inhabitants in the world today, about 600 million people are already experiencing chronic water scarcity, over 1 billion people lack access to safe drinking water, and unsafe water and poor sanitation cause 80% of all diseases in the developing world. Water tables are falling in the groundwater sources available to about one third of the world's population, in some cases, by 1–3 m a year, as nearly all running surface water is already in use in many parts of the world and over-exploitation of groundwater resources will clearly increase [8]. If the present trend continues, two out of three people on Earth will be living in water-stressed areas by 2025 [9], with the worst impact in arid developing countries where average water availability per person will be only about 15% of the per capita availability in 1950 [8]. Water supply for such large populations is therefore one of the greatest challenges mankind is facing today [10].

In the context of a future energy crisis, water problems are expected to substantially worsen. And vice versa, due to the close relationship between water and energy, water shortages are expected to contribute to increased energy problems and aggravate their consequences. Furthermore, environmental considerations, such as global warming, will surely add significant pressure. The consequences of this analysis are very serious, as the water problem cannot be effectively addressed without considering the implications for energy and the expected growth of human population. Not only will large unavailable additional amounts of water be needed within a few decades, but the energy to produce it will not be easily available. There is therefore no solution to any sustainable water and energy future without the strong participation of renewables in general and in particular, solar energy, which has the highest potential of all the renewable energies [11]. This potential is clearly reflected in Table 1, which shows the estimated theoretical, technical and economic potential of different renewable energy resources, with a total technical potential of about 85 TW. By comparison, the total primary energy consumption in 2005 (11,435 MTOE) as mentioned above, is equivalent to 15.18 TW. Estimated global energy consumption to 2050 is 25–30 TW, reaching 40–50 TW by 2100 [12]. Until the hypothetical arrival of fusion energy in the distant future, only solar energy has the potential to amply surpass this figure (60 TW of technically feasible estimated potential) [13].

Therefore, as solar energy has the highest potential of all the renewables, and also, in view of the worldwide coincidence that where water stress and/or scarcity exists, there are also good levels of solar radiation, the conclusion seems clear. Suitable technologies must be developed to permit the use of solar energy to simultaneously help solve energy and water problems. The main solar water process applications, under scientific and technological development at *Plataforma Solar de Almeria*, are the following:

(a) Solar Desalination, from two different approaches, combined solar power and desalination plants (MW range), and medium to small solar thermal desalination systems (kW range).
(b) Solar Detoxification, by making use of the near-ultraviolet and visible bands of the solar spectrum (wavelengths shorter than 390 nm for TiO_2 and 580 nm for photo-Fenton) to promote a strong oxidation reaction by generating oxidizers, either surface-bound hydroxyl radicals ($OH^{\bullet}$) or free holes, which attack oxidizable contaminants, producing a progressive break-up of molecules yielding CO_2, H_2O and dilute mineral acids.
(c) Solar Disinfection, which applies the detoxification techniques mentioned above, using a supported photocatalyst, to generate powerful oxidizers to control and destroy pathogenic water organisms.

2. Solar brackish and seawater desalination

The recent United Nations Human Development Report 2006 [16] alerts against an unprecedented crisis in coming years as a consequence of a growing scarcity of fresh water per inhabitant in developing countries. It forecasts that in the next twenty years, the average world water supply per inhabitant will decrease by one third, due mainly to the growing world population, environmental pollution and climate change. In the second half of this century, in the worst-case scenario, seven billion people in 60 countries are expected to face a water shortage problem. In the best-case, this scarcity will affect two billion people in 48 countries, depending on factors such as the world population growth rate and the implementation of appropriate corrective policies.

The solutions for alleviating this water shortage problem go from the necessary savings in all consumer sectors to promotion of surface groundwater treatment techniques, and reuse of wastewater [17]. However, there are areas on the planet (very arid or isolated) that require outside contributions for their development. In this case, desalination, and especially seawater desalination, is proposed as one of the main alternatives for solving the problem [18]. Desalination is quite often not just an interesting alternative, but the only feasible and practical option, as more than 70% of world population lives in a 70 km strip bordering the seas [18]. In 2003, world installed desalination capacity was 37.75 hm^3/day [19]. 64% of this is for seawater, with 10,350 plants having a

Table 1
Yearly estimated potential of different renewable energies (1 TW = continuous power production of 1 TW during the year = 8760 TWh = 31.53 exajoules) [13–15]. Total primary energy consumption in 2005 = 15.18 TW [1].

	Gross theoretical useful potential	Technically feasible potential	Current economic potential	Total installed capacity (2003)
Biomass	8–14 TW	6–8 TW	No data[a]	1.6 TW
Hydraulic	4.6 TW	1.6 TW	0.8	0.65 TW
Geothermal	66 TW	11.6 TW	0.6 TW	0.054 TW
Wind	20 TW	2 TW	0.6 TW	0.006 TW
Solar	600 TW	60 TW	0.15–7.3 TW	0.005 TW
Ocean	234 TW	No data	No data	–
Total	1030 TW (approximately)	85 TW (approximately)	7 TW (approximately)	2.3 TW (approximately)

[a] Water availability may become an important limiting factor.