SOLAR ENERGY AND PHOTOCHEMICAL ENERGY SYSTEMS

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Summary

This Theme level contribution provides a comprehensive review about all solar energy related technologies (Section 4) and applications (Section 5), being some of them today under normal commercial and practical applications and other still under research and demonstration level. The article also provides an analysis and discussion about what are the reasons behind the current efforts of our society, considering both developed and developing countries, to accelerate the introduction of the huge solar energy potential into our normal daily lives (Section 2). Finally, some basic information about the solar energy potential, history and the amazing trip of a photon from its creation in the Sun

until its arrival to the Earth, is provided (Section 3).

1. Introduction

The 20th century brought unprecedented development in the history of mankind with extraordinary advances in every discipline of science and technology. However, we are now realizing that the associated evolution of human society has not always been the best, and the overall price "paid" may be considered excessive from certain points of view. The key concept which appeared late in the last century, and which nobody doubts will be of capital importance within the present one, is "sustainability". Indeed, the cost associated with that impressive past development and (so-called) progress, if "business continues as usual", places the future of mankind at severe risk.

The main factor behind this unsustainable path is undoubtedly global population growth, which is also the main factor behind all the major problems mankind will face in the 21st century. As may be seen in Table 1, it took 1200 years for the population to double from 500 million to 1 billion people (in 1800), but just 130 years to double again (to 2 billion, in 1930), and another 46 years to double once again (to 4 billion people, in 1976). There were already 6 billion people in 1999 (the United Nations gave this honor to a child born in Sarajevo, in October 12th 1999) and at the end of 2008, there were about 6.7 billion people on Earth.

Year	**Population**	Δt
600	500 millions	
1800	1000 millions	+ 1200 years
1930	2000 millions	+ 130 years
1976	4000 millions	+ 46 years
1999	6000 millions	+ 23 years
2009	6700 millions	+ 10 years

Table 1. Growth of the human population since 600 A.C.

This dramatic population increase in the 20th century has many current serious implications and consequences, as the pressure on natural resources, negligible in previous centuries, is now on the verge of reaching the limit (if not yet surpassed) of the planet's sustainability. This pressure is the main reason for the most serious problems we now face, which are, in order of their relevance to mankind:

1. Water
2. Energy
3. Climate change, as direct consequence of the above

We must realize that all these problems are closely related, and that any one of them by itself is a serious threat to the quality and way of life (when not to the survival) of billions of people in many areas and regions of the planet. Therefore, the simultaneous existence of all 3 problems, a fact that today seems nearly impossible to avoid, poses a challenge without precedence in human history. Throughout the discussion of this topic and subsequent articles, it will be shown how renewable energies in general, and solar energy in particular, is a powerful tool that can significantly contribute to the solution of these global problems.

2. Problems for Sustainability in the 21st Century

2.1. The Water Problem

Of all challenges mankind will have to confront in the coming decades, water is without doubt the most serious problem. Even though access to water is essential to life and a fundamental human right, today more than 1 billion people are denied clean water and 2.6 billion people lack access to adequate sanitation, and these figures capture only one dimension of the problem. At the start of the 21st century, unclean water is the world's second largest killer of children, as every year some 1.8 million children die as a result of diarrhea and other diseases caused by poor water quality and lack of sanitation. Every day, millions of women and young girls spend many hours collecting water for their families, a ritual that reinforces gender inequalities in employment and education. In addition to all this, the ill health associated with deficits in water and sanitation undermines productivity and economic growth, reinforcing the strong inequalities that characterize current patterns of globalization and trapping vulnerable households in cycles of poverty.

The United Nations has therefore posted an alert for an unprecedented crisis in the coming years as the consequence of the growing scarcity of fresh water per inhabitant, especially in developing countries. By 2025 the per capita water availability in developed countries is expected to have been reduced to less than 60 percent of the 1950 level. Where developing countries are humid, this figure will be reduced to about 25 percent and, in the worse case, to about 15 percent in arid or semiarid developing countries. In the next twenty years, the average world water supply per inhabitant will drop a third. The main reasons for this severe problem are the growth of the world population, environmental pollution, inappropriate management policies and, very probably, climate change. The forecast for the second half of this century is even more worrisome; depending on factors such as the world population growth rate and the implementation of appropriate corrective policies, from 48 (best case scenario) to 60 countries (worse case scenario) are expected to face serious water shortages and scarcity, affecting a significantly high percentage of the population.

The world is not running out of water, but nevertheless many millions of its most vulnerable people live in areas subject to mounting water stress. Some 1.4 billion people live in river basins in which water use clearly exceeds recharge rates. The symptoms of overuse are disturbingly clear. Rivers are drying up, groundwater tables are falling and water-based ecosystems are being rapidly degraded. Put frankly, the world is exhausting one of its most precious natural resources and running up an unsustainable ecological debt that will be inherited by future generations. Around the globe, nearly all running surface water is already being used and, as many water stress indicators point out, groundwater aquifers are heavily overexploited in many regions of the world.

Global water extraction has significantly increased since 1970 (from 2500 to nearly 4000 km^3 per year) to irrigate also increasing areas (from 170 to 280 million hectares worldwide) for food production. Consequently, groundwater tables are falling in many regions, in some cases, by 1 to 3 meters a year, a trend that, due to the absence of alternatives, will probably continue in the coming years, leaving two out of three people on Earth living in water-stressed areas by 2025. Clearly this path cannot be sustained in the medium to long term, as the very negative examples of the disappearance of the Aral Sea and Lake Chad shows. Therefore, competition for water will intensify in the decades ahead.

To summarize, population growth, urbanization, industrial development and agriculture are driving up the demand for water, a finite resource, with the serious associated problems, posing history's greatest challenge to mankind, ensuring a water supply for the world's population.

2.2. The Energy Problem

Energy is another serious challenge. In 2007, Total Primary Energy Supply (TPES) consumed reached 12029 million tons oil equivalent (MTOE), of which oil is the most important fraction (see Figure 1). This figure is equivalent to a yearly constant consumption of 15.97 TW power which means a 100% increase over the initial existing figure of 8.01 TW of 1973; as consequence, mankind has doubled its primary energy consumption in just 35 years. Due to the dramatic increase in oil prices in 2007 and 2008 (doubling its price in just a few months, and causing people to seriously start thinking it could rise to 200 USD per barrel), the world is now recognizing that the oil era is nearing its end, and we now urgently need to adapt the overall economic system to alternative sources of energy.

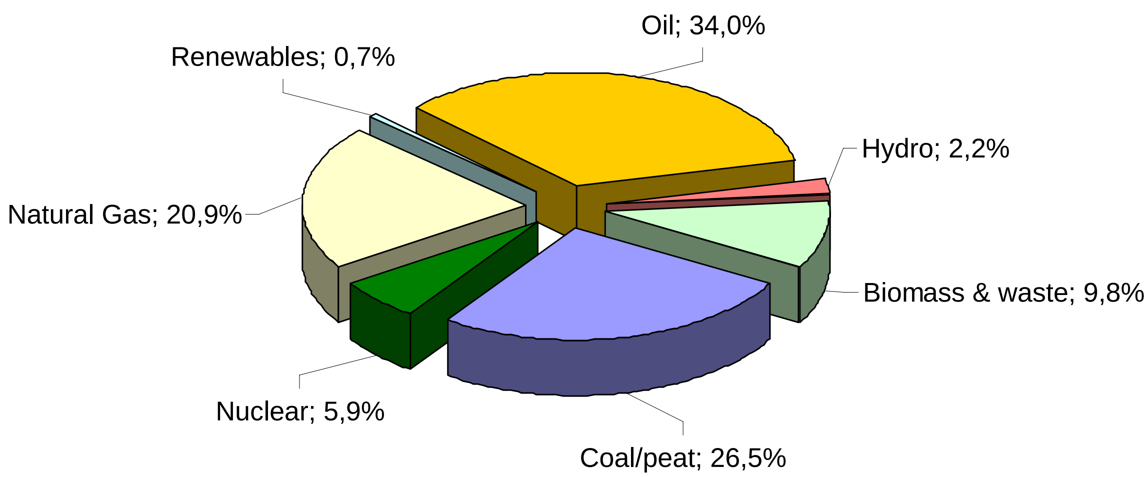

Figure 1. Distribution of Total Primary Energy Supply consumed by mankind in 2007 (International Energy Agency data)

The arguments seem very clear, as 2006 conventional world oil reserves are estimated at around 1200 billion barrels (specific figures reported by some of the largest oil companies were 1210, 1317 and 1120 billion barrels), and considering the current (heavily increasing during recent years) consumption path of nearly 88 million barrels per day (about 32 billion barrels per year), the reserves clearly cover less than 40 years. This, and no other geopolitical reason, is the main argument behind the acute increase in oil prices observed in 2007 and 2008. The gas situation is similar, except that expected duration of presently known reserves would be a little longer (around 70 years by the same calculation as oil).

However, the date of most concern with regard to the issue of the end of oil is not when oil will be exhausted, but when the so called "oil peak" will be reached. This concept indicates when total oil production capacity (limited by internal well pressure) will not be able to match the global demand (continuously increasing). This moment, according to the International Energy Agency, is expected to be reached by the year 2020 at the latest and will mark the definite decline of the oil era.

It should be pointed out that, in addition to conventional oil, there are other vast oil resources. These are the very heavy oil, bitumen, oil underwater at very low depths and in the Arctic, and oil shale. However, in addition to any possible environmental consideration, it is not clear whether the energy finally produced would justify the energy needed to extract, transport and process some of these resources. If this overall energy balance is not clearly positive, the final economic balance will be negative.

Therefore, in the next few decades, we will be forced to change our global energy scheme, with the important associated economic consequence of higher (or much higher) energy costs. In this scenario of future energy crisis, water problems are expected to substantially worsen. And vice versa, as 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 population growth. Not only will unavailable large additional amounts of water be needed within a few decades, but neither will the energy to produce it be easily or economically available.

2.3. The Global Warming Problem

Closely associated with the energy issue and a direct consequence of the continuous burning of carbon-based fuels, global warming has gained very significant momentum and importance in recent years. Due to the previously mentioned end-of-oil horizon, many countries are looking for alternative primary energy resources suitable for maintaining the economy with the minimum possible disturbance.

This, today, can only be achieved by massive use of coal, as shown by countries such as China and India, which have increased their coal consumption by 75 percent in the last few years. China the first world producer of coal with nearly 50 percent of global coal production, is also the seventh hard coal importer and, as a consequence of its huge energy needs, during 2007 China opened an average of one new coal power plant per week.

Coal, second in the current primary energy ranking, the most abundant fossil energy resource on Earth, has very large reserves. However, its massive use involves very high CO_2 emissions with a serious negative impact on climate change issues, as the relationship between average air temperature and carbon dioxide concentration in the atmosphere has been clearly demonstrated and is widely assumed by the entire scientific community.

The consequences of this sharp increase in global coal consumption is that the most unfavorable scenario of average world temperature increase by 2100 is today considered about 6ºC (by the International Energy Agency, IAE) compared to the 4ºC estimated in 2001 by the Intergovernmental Panel on Climate Change (IPCC), if no CO_2 mitigation policies are implemented. The potential implications of these figures are so severe that today all relevant institutions consider that stabilization scenarios between 450 to 550 ppm CO_2 (the current level is already 380 ppm, surpassing 300 ppm for the first time in 450.000 years) are inevitable. All this has resulted in important ongoing international initiatives to limit the maximum temperature increase to 2ºC, which is the temperature at which it is assumed the process would become irreversible.

Widespread research in clean coal combustion is underway, but is still very expensive and far from possible mass implementation. The possibility of nuclear fission, still just a potential partial solution in the global energy supply, has its drawbacks: nuclear energy, in addition to strong popular rejection in many parts of the world, has limited fissionable uranium reserves (in the long term) considering the current available technology; its use cannot be generalized (due to the economies of scale and technological capacities required), and there are important security concerns (potential fabrication of weapons).

Important improvements to classic power plant operating safety designs have been proposed, but not waste (main nuclear energy problem), as the more advanced designs (the so-called Fourth Generation Plants) are still very far from industrial operation. And nuclear fusion is still a hypothetical possibility, still very far from today's reality.

Greenhouse gas concentration in the atmosphere increases, and in addition to its implications for climate change, it is also expected to negatively affect water availability in many already water-stressed regions of the globe , demonstrating that all these problems are closely related to each other and pointing out that effects and interactions which may be marginal to one could be very severe and significant to another and, therefore, global approaches will always be needed for the proper assessment of any potential solution.

It can thus be concluded that none of the present conventional energy technologies are sustainable, as they are all inefficient and none of them meet the basic criteria of not burdening future generations. In this context, what would the role of renewable energies and its contribution to the definitive solution of these problems be? How can we meet the expected 30 TW of global energy needs in 2050?

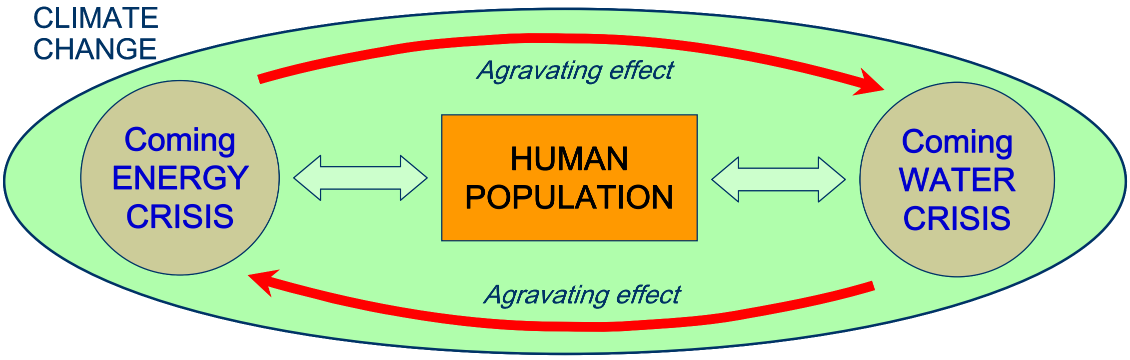

Figure 2. Interrelationship of the major problems expected to face mankind in the 1st half of the 21st century

Figure 2 represents the current status quite fairly and how all these problems interact, making the overall situation much more complex and of deeper concern. Exponential population growth is at the root of both energy and water problems, but with the special characteristic that each of these problems significantly reinforces the others. The water problem can be significantly reduced in a context of cheap and abundant energy and something similar could also happen with energy and water. However, the opposite situation has the contrary effect. Water problems will be significantly worsened in a context of scarce and costly energy, and energy will be more difficult and costly to be produced in a context of water shortage. In addition, this entire situation will take place in a context of climate change and global warming with all indicators pointing to all possible scenarios worsening.

Finding a suitable and affordable solution to this complex interlocking puzzle will not be an easy task due to the many issues involved (of which financing is just one). But is it very clear that no adequate and sustainable solution will be found without the strong participation of the following three components:

- Reduction in the per capita consumption of energy and water (increased efficiency)
- Substantial introduction of renewable energies into the energy mix
- Continuous scientific and technological research and development

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Biographical Sketches

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He works at the Plataforma Solar de Almeria (PSA-CIEMAT) in all the projects linked to water treatment. Concretely, he has been involved in 15 EU and 15 National related to the development of solar wastewater treatment technologies, and has been involved in the design and construction of all the experimental pilot plants for solar detoxification of industrial waste water in Europe. He is author of 1 book and co-author of 8 books as well as 36 chapters in others. He has also co-authored more than 130 publications in indexed international journals and 4 patents. The Jury's Grand Prix of "European Grand Prix for Innovation Awards". 2004, Mónaco.