POLYGENERATION OF POWER AND DESALINATION WITH SOLAR ENERGY

Julián Blanco, Diego Alarcón, Wolfgang Gernjak, Elena Guillén
Plataforma Solar de Almería. P.O. Box 22, E-04200 Tabernas, Almería, Spain
Phone: (+34) 950287939; Fax: (+34) 950365015;
Email: julian.blanco@psa.es; URL : www.psa.es

ABSTRACT

All relevant international institutions recognize that power and water supply will be two major issues mankind will have to face and solve during the present 21st century. During next decades the oil era will arrive to its end without being clear today which source of energy will replace it. In parallel, water scarcity is already a global problem which will become of capital importance during the 1st half of current century, being seawater desalination, in many cases, the only existing alternative to this element essential to life. Despite the energy efficiency advances reached during the last decade, seawater desalination continues to be an intensive fossil energy consumer. In a context of coming energy crisis, due to the end of 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 increase the energy problems. In addition to all this, environmental considerations such as global warming, will surely add significant pressure in all these matters. In this scenario renewable energies are rapidly increasing its contribution to the global mix, being clearly solar energy the one with higher potential. This article provides a comprehensive review of power and desalination technologies and how the polygeneration of energy and water by means of solar energy could became a reality still with higher cost than conventional technologies

but providing a sustainable path for the development and offering a possible contribution to this complex problem.

1. THE GLOBAL WATER AND ENERGY PROBLEM

In the year 2004 mankind consumed 11059 Mtoe (million tons oil equivalent) of Total Primary Energy Supply (TPES) [1] and, in the same year, it was scheduled an scenario of growth of 0.7% in the oil production until 2030 and then start to decline [2], realizing that the oil era as dominant energy factor will be over by mid of current century. Main reason to that is the fact that half of available conventional oil resources of the globe have already been consumed by mankind and the rest will be consumed within the following 40 years (see Fig. 1).

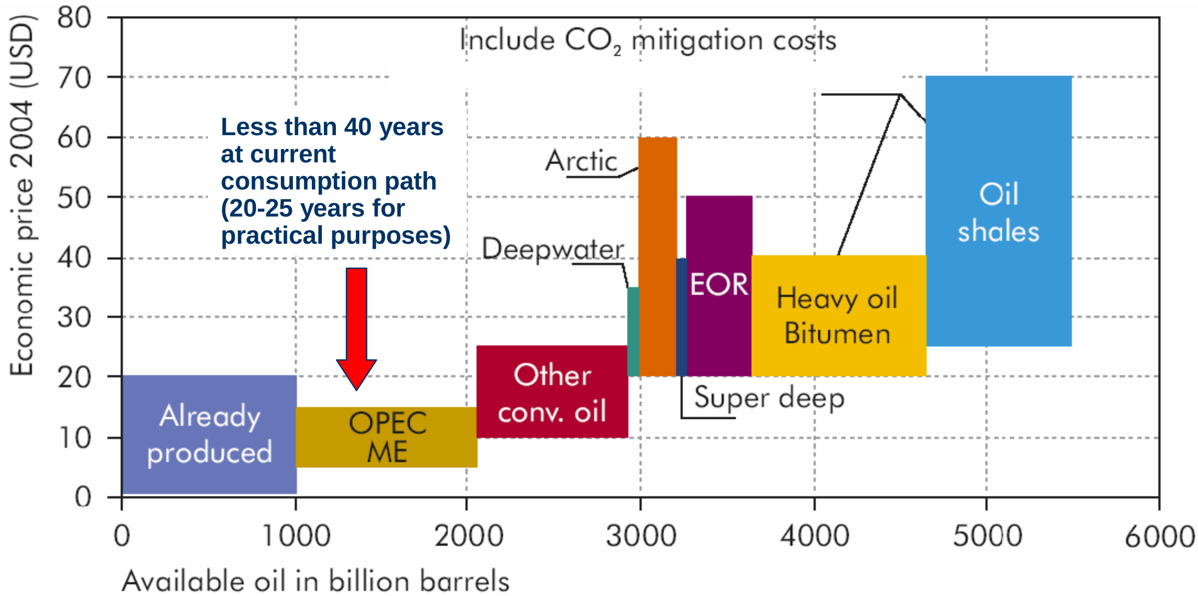

Fig. 1. Available oil resources as a function of 2004 economic price [3]

Possible alternative primary energy sources are also very problematic: nuclear energy in addition to the strong popular contest in many parts of the World, has also limited fissionable uranium reserves (in the long term) and the security concern (potential fabrication of weapons) of many countries, and coal has the problem of very high CO_2 emissions and its repercussions over climate change issue [4]. If this was the prospect in 2004, today many people would agree that this forecast is even more worrisome with the main conclusion that there seems to be no solution to any sustainable energy future without a strong participation of the renewables in general and the solar energy in particular, due to its highest potential among all existing renewable energies [5]. This potential is clearly reflected within the Table 1. Total equivalent mankind energy consumption in 2004 (11059 Mtoe) is equivalent to 14.68 TW. Mankind estimated global energy consumption is 25-30 TW to the year 2050, reaching to 40-50 TW by 2100 [7]. Until the hypothetical long term future arrival of fusion energy, only solar energy has the potential to clearly surpass this figure.

Table 1. Yearly estimated potential of different renewable energies compared with the status of nuclear energy in 2004 (1 TW = 10^{12} W = 1000 power plants of 1 GW each continuously producing during the whole year) [6]

	Global theoretical	**Technically feasible**	**Total Installed capacity (2003)**
Hydraulic	4.6 TW	4.6 TW	0.3 TW
Biomass	7 to 10 TW	5 TW	1.4 TW
Geothermic	12 TW	0.6 TW	0.054 TW
Wind	50 TW	2 to 4 TW	0.0063 TW
Solar	600 TW	60 TW	0.0051 TW
TOTAL (Aprox.)	**676 TW**	**70 TW**	**1.73 TW**
Nuclear	17.5 TW	10 TW	0.845 TW

If the energy prospect is worrisome, much worst is the problematic related to water shortage. Water is essential to all life and today more than 1 billion people lack access to safe drinking water, being unsafe water and poor sanitation the cause of 80 percent of all diseases in the developing world, causing many million deaths annually. Groundwater supplies about one third of the world's population with water tables falling, in some cases, by 1 to 3 meters per year as nearly all surface running water is already in use in many parts of the world and over-exploitation of groundwater resources will clearly increase [8]. Today about 600 million people face water scarcity and if the present trend continues, two out of three people on Earth will live in water stressed areas by 2025 [9]. Most worrisome factor is the human population growth: depending on future rates of population growth, between 2.7 and 3.2 billion people may be living in either water-scarce or water-stressed conditions by 2025 [8], with the worst impact at arid developing countries where average water availability per person will be only about 15% of the per capita availability in 1950 [8].

Desalination is, quite often, the only feasible and practical option to palliate water problems as about 70 percent of world population lives in a 70 km strip from sea border [10]. In 2003, world installed desalination capacity was 37.75 hm^3/day [11], being 64 percent of them from seawater, with 10350 plants having a capacity higher than 100 m^3/day. Today, total production of desalinated water could cover the necessities of a population of about 100 million people [12]. First desalination country is Saudi Arabia, followed by Arab Emirates, United States of America and Spain. Market studies (Global Water Intelligence) showed estimated investments of more than 30 billion US$ in new desalination plants worldwide in the period 2005-2015, 70 percent of which would be of seawater. In the Mediterranean area, the estimated figure is 9.6 billion US$ (90 percent seawater).

However, desalination needs huge amount of energy and the consequences of this analysis are very serious as the water problem cannot be effectively addressed without considering the energy implications as both factors are always very closely related: energy problems worsen when there is no water and water problems simply become without solution when there is no energy available. In the present context of human population growth it is clear that large additional amount of water will be required within a few decades and, if the energy also become a big problem itself, then the conclusion seems clear: "present energy will not be able to solve tomorrow's water problems" [13]. Therefore, if solar energy has the highest potential among all the renewables and there is also the coincidence, all over the world, that where water stress and/or scarcity exists, also there are good levels of solar radiation, the conclusion seems also clear: why not use solar energy to, simultaneously, solve the energy and water problems by means of the polygeneration of power and water?

2. SOLAR ENERGY POWER GENERATION TECHNOLOGIES

Power generation by means of solar energy, at MW scale, implies the use of Concentrating Solar Power (CSP) technology. There are, basically, four types of CSP technologies being promoted internationally (Fig. 2). All of them are based on glass mirrors, which continuously track the position of the sun to get the desired concentration ratio. The concentrated sunlight is absorbed on a tube that is especially designed for reducing heat losses. Heat transfer fluid (i.e. oil) flows through the absorber tube and transfers the heat to a power cycle, where high pressure and high temperature steam is generated to drive a turbine, within a conventional power cycle. Recently also directly generated steam is used for power generation [14].

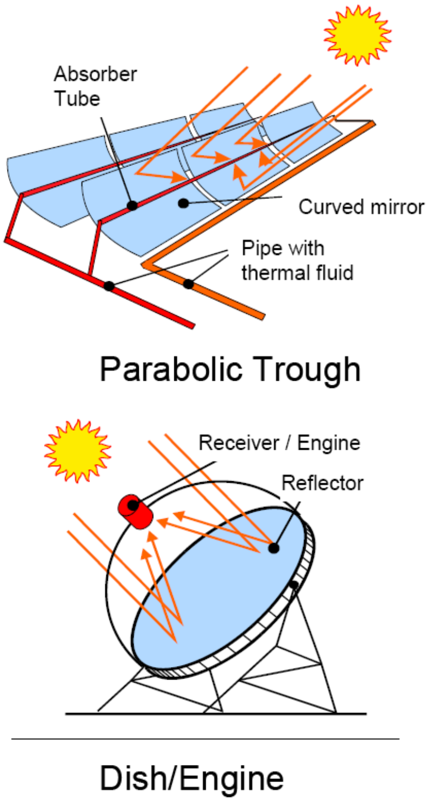

Fig. 2. Different CSP (Concentrating Solar Power) technologies: Parabolic Troughs, Linear Fresnel Central Received Systems and Parabolic Dishes

Besides the recent (March, 2006) inauguration of the first commercial ever CSP plant based on a Central Receiver System (CRS), the PS10 promoted by the Spanish Group Abengoa [15], existing commercial CSP technology is mainly based on Parabolic Trough Collectors (PTC). Solar power towers are estimated to reach slightly higher efficiencies but, due to the reduced commercial experience to date, the technology is considered as less mature. With regard to parabolic dishes technology, to date, no commercial plant has ever been installed, although some interesting initiatives are under development [16]. Parabolic troughs and linear Fresnel systems [17] can be coupled to steam cycles of 5 to 200 MW of electric capacity, with thermal cycle efficiencies of 30 – 40 %. Today, parabolic trough systems achieve annual overall solar-electric efficiencies of about 10 – 15 %, with the perspective to reach about 18 % in the medium term [18]. No commercial Linear Fresnel plant is operative to date, but several interesting initiatives are under way, such as the 6.5 MW saturated steam Tavira power plant in Algarve (Portugal) [19].

The solar parabolic trough technology is a proven technology; today there exist nine parabolic trough solar power plants in the California Mojave desert (total capacity of 354 MWe). They are known collectively as the Solar Electricity Generating Systems (SEGS), and they were designed, developed and constructed over the period 1984-1991 ranging from an initial 14 MWe up to the last-built 80 MWe [19]. The gas-fired back-up burners are used to maintain the temperature of the heat transfer fluid in hours of insufficient sunshine. A typical solar parabolic trough collector is shown in Fig. 2 (upper left); the collector axis is located in the North-South direction; the collector is tracked in one dimension to follow the sun from East to West and the solar rays are concentrated on the heat collection element (HCE). The heat transfer fluid is circulated in the through and heated to the required temperature. The collectors are arranged in parallel rows, each one typically over 150 m long, so that the heat transfer fluid is circulated in loops. The power blocks use a highly efficient steam turbine fed with steam from the solar field for power generation, the so-called Rankine cycle as used in many fossil power plants (Fig. 3).

With more than 2 million square meters of glass mirrors, the plants have generated over 12 billion kWh of solar electricity since 1985. Due to further technological advances these plants are producing today more power than they did when new. The US$ 1.2 billion raised to build these plants came from private risk capital and, with increasing confidence in the maturity of the technology, from institutional investors. Although backed originally by tax incentives and attractive power-purchase contracts, these have since been withdrawn, whilst a fall in fuel prices in the late 1980s led to a 40% reduction in electricity sales revenue. Nonetheless, significant cost reductions were achieved during the construction period through increased size, performance and efficiency. All nine SEGS plants are still in profitable commercial operation. Therefore, parabolic trough systems represent the most mature solar thermal power technology, supplying an annual production of 924 million kWh. In terms of efficiency, the SEGS plants have achieved daily solar-to-net electric efficiencies close to 20%, and peak efficiencies up to 21.5% [20]. The annual plant availability constantly exceeds 98% and the collector field availability more than 99%. The five plants at Kramer Junction have achieved 30% reduction in operation and maintenance costs between 1995 and 2000.

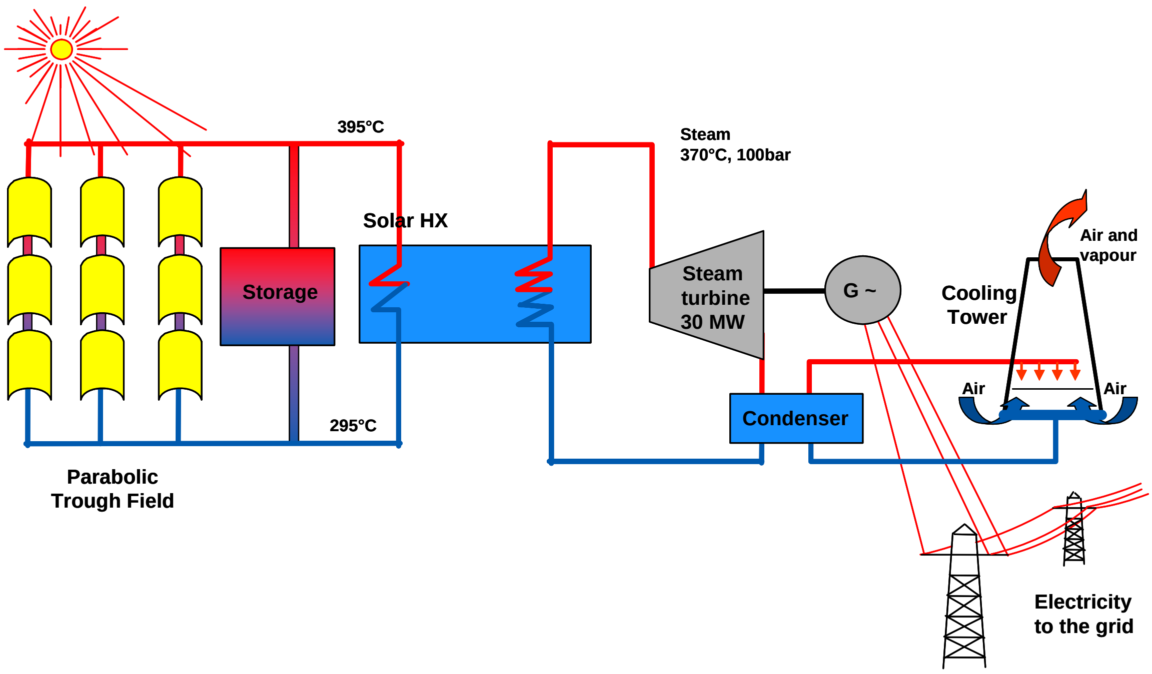

Fig. 3. Example of 30 MW Solar Rankine Cycle Power Plant

The 30 MWe SEGS plants at Kramer Junction, with an annual insolation over 2,700 kWh/m², have generating costs of about 17 US cents/kWh (expressed in 2005 US$) and operate predominantly during high-priced summer daytime peak demand hours (mainly to cover California peak load caused by air-conditioning). They have an allowance to generate up to 25% of the annual thermal output by supplementary natural gas firing. The equivalent pure solar costs would be 20 US cents/ kWh. The two 80 MWe SEGS plants at Harper Lake, with the same annual insolation, have generation costs of 15 US cents/kWh (in 2005 US$). The equivalent “solar-only” costs would be 17 US cents/ kWh [21].

Similar costs are expected at Nevada Solar One (Nevada, USA), latest parabolic trough solar power plant in operation since June 2007 with 64 MW capacity, contracted to supply 129 million kWh annually. However, plant design increased collector field size to produce heat for storage, enabling the plant to continue to produce power after the sun set; this is also expected to enable the Nevada Solar One to yearly produce another 25 million kWh [22].

With greater efficiencies and economies of scale, costs can be expected to fall in coming years. The improvements gained in the performance of the Kramer Junction SEGS and Nevada plants have been the result of successful adaptations to the design of the solar collectors, absorber tubes and system integration. Ongoing development work continues in Europe and the USA to further reduce costs in a number of areas, including improvements in the collector field, receiver tubes, mirrors and thermal storage. Although successful, by no means this represents the end of the learning curve. Advanced structural design will improve optical accuracy and, at the same time, reduce weight and costs, thus resulting in higher thermal output. By increasing the length of the collector units, investment savings can be achieved in drive systems and connection piping. Next-generation receiver tubes will also further reduce thermal losses while, at the same time, improving reliability. Improvements to the heat transfer medium will increase operating temperature and performance. Low-cost thermal bulk storage will increase annual operating hours and thereby reduce generation costs. Most important for further significant cost reductions, however, it is automated mass production in order to steadily increase market implementation.

Solar thermal power plants can be operated with fossil fuel as well as with solar energy. With the addition of thermal storages, extended hours of operation (based on solar energy) may be achieved, combined with better utilization of large trough fields and extended generation hours at nominal loads. Both solar and fossil fuels and also biomass can be used for co-firing the plant, thus providing power capacity whenever required. To generate one Megawatt-hour of solar electricity per year, a land area of only 4 to 12 m² is required. Therefore one km² of arid land can continuously and indefinitely generate as much electricity as any conventional 50 MW fossil fuel fired power station. Their thermal storage capability and hybrid operation with other fuels allows CSP plants to provide power on demand. Their availability and capacity credit is considered to be about 90 percent [23]. The inherent advantage of CSP technologies is their unique adaptability to conventional thermal plants, as it can be integrated as "a solar burner" in parallel to a fossil burner into conventional thermal cycles [24]. Also, with thermal storage or fossil fuel backup, solar thermal plants can provide firm capacity without the need of separate backup power plants and without stochastic perturbations of the grid [25].

3. SOLAR ENERGY DESALINATION TECHNOLOGIES

Conventional desalination technologies. Basically only two technologies are implemented on a commercial scale, membrane processes (reverse osmosis, electrodialysis) and thermal distillation processes (multi-stage flash distillation, multi-effect distillation, mechanical vapour compression) [26]. The sphere of application of the first is both in brackish water and seawater, while the second are only economically feasible if employed in desalting seawater. In reality, only two processes, reverse osmosis (RO) and multi-stage flash distillation (MSF) take up 80% of the market, one or the other leading this classification depending on used feed water. If only seawater desalination is considered, then the MSF process takes up 47.2% of the global production capacity compared to 36.5% for RO. However, if both desalination of brackish water and seawater are considered, then osmosis processes constitute 47.2% of the worldwide production capacity compared to 36.5% for multi-stage flash distillation. Retrospectively, a decade ago these proportions were 32.7% and 51.3%, respectively, which clearly indicates the current market tendencies of the two technologies. MSF plants, due to factors such as cost and apparently high efficiency, pushed out multi-effect distillation (MED) systems in the sixties, and only small-sized MED plants were built [27, 28]. However, in the last decade, interest in multi-effect distillation has been significantly renewed and the MED process is currently competing technically and economically with the MSF technology [29, 30]. Recent construction in Abu Dhabi of an MED plant with a 240.000 m^3/day capacity shows a breakthrough in large-scale MED plants [31].

If the progress of the energy efficiency of the two technologies in the last three decades is considered, thermal distillation systems, which in the last thirty years have hardly undergone any appreciable reduction in the desalination process energy requirement, are found to have stagnated. In fact, today, thermal distillation of seawater can only compete economically in large seawater-electricity cogeneration plant layouts or when the conditions of raw feedwater (temperature, salinity) are not appropriate for membrane technologies. However, in the case of seawater desalination with reverse osmosis, consumption has gone from 30.84 kWh/m^3 (1970) to a consumption of 2 kWh/m^3 (2006), that is, the energy efficiency has multiplied by fifteen [32].

Nevertheless, in spite of all these improvements, the seawater desalination process continues to be an intensive fossil energy consumer. In the current global framework, with growing oil price instability and the environmental requirements derived from compliance with the Kyoto Protocol, the sustainability of this technological solution inevitably passes through continued improvement of energy efficiency of the physical processes involved [33], as well as the use of renewable energy resources [34].

<u>Renewable enegy based desalination technologies</u>. Beside the described conventional desalination plant concepts there are some renewable desalination technologies under development, mostly designed for low outputs of freshwater [35]. Here it can be also distinguished between thermally driven desalination systems (working with humid air [36] or membranes [37]) and RO-systems driven by

photovoltaic panels [38] or by wind generators [39]. Especially the small systems usually exhibit a higher specific energy requirement and therefore much larger water production costs in comparison with conventional operated large-scale installations and therefore they are not comparable to midsized and large-scale solar desalination techniques. An ongoing study on autonomous solar desalination systems *ADU-RES*, which is financed by the EU, also focuses on small-scale systems [40]. Studies on large-scale solar desalination systems, such as the Solar Thermal Desalination Project in Spain [41] are rare. The Spanish CIEMAT worked in the *SOLARDESAL* Project [42] and the EU-financed *AQUASOL*-Project [43] on solar distillation via MED. One important study of coupling concentrating solar power plants with thermal desalination units was done lately (for plant sizes of 1.000, 10.000 and 100.000 m^3/day) [44]. Only one study that investigates a solar thermal driven reverse osmosis system is known [45]; that study mainly focuses on the heat engine [46], not on the solar desalination process. None of the identified studies does investigate large scale solar desalination systems without being free to include all suitable technologies to find the most feasible system.

4. POLYGENERATION OF POWER AND WATER: CSP+D TECHNOLOGY

As there is a clear coincidence, all over the world, in the existence of water problems (arid and semi-arid zones) and the availability of abundant solar radiation, in the current context of progressive increase of energy cost, it makes full sense to seriously consider the use of solar energy to simultaneously solve or palliate the energy and water problems: polygeneration of power and water using solar energy as primary energy source. In many areas, like the Mediterranean, this approach can provide a substantial impulse to the implementation of both CSP and Desalination technologies, fostering the employment and the economy and solving the local needs of power and water with the existent local energy resources. To support this fact, some realized studies demonstrate that CSP can be used to fulfil the total electricity demand in Middle East and North African countries of about 1700 TWh/year by 2025, rising to 3600 TWh/year in 2050 [47].

Conventional Power and water co-generation plants. There are different possible basic conventional configurations of co-generation power desalting plants (CPDP) that generate electricity and also produce fresh water through the desalination of seawater [48]:

- MSF units operating by: a) steam extracted from steam turbines, using extracting/condensing steam turbines; b) steam supplied directly from boilers
- Low temperature multi effect boiling (MED), by steam extracted from turbine
- Seawater RO desalting units supplied with: a) electric energy from steam power plant; b) electricity from combined gas/steam power cycle

In Gulf countries, most power plants are co-generation power desalting plants, which integrate, at different levels, the three conventional (MSF, MED and RO) desalination technologies [49]. The preference of one scheme over another would depend mainly on many factors, such as the required power to water ratio, cost of fuel energy charged to the desalting process, electricity sales, capital costs, and local requirements [50]. As it was stated before, multi-stage flash (MSF) and reverse osmosis (RO) are the most common techniques for seawater desalination [51]. However, the significant recent improvements of MED, makes this technology to be very attractive to future co-generation power desalination plants [52, 53]. It is well known that electrical demand shows daily and seasonal variations whereas water demand is constant. The optimization of water production cost requires that the power output of the steam turbine can follow the demand with a step by step increase or decrease of its outlet pressure. MED units with adaptative thermocompressors allow the transference of the efficiency from power to water production. Also, it has been shown that co-generation power desalting plants are more profitable than stand alone RO plants because the profit margin of the first remains positive within a substantial range for fuel price and investment costs [54].

Since a few years ago, hybrid desalination systems combining both thermal and membrane desalination processes with power generation systems are being considered a good economic alternative to traditional dual-purpose evaporation plants. Hybrid (membrane/thermal/power) configurations are characterized by flexibility in operation, low construction cost, lower specific energy consumption, high plant availability and better power and water matching [55]. In any case, it has also been shown that most of existing dual-purpose power and desalination plants are far from been optimized from the energetic point of view with still many possibilities and opportunities to improve its overall efficiency [56].

<u>Solar Power and water co-generation plants</u>. In the form of seawater and solar radiation, water and energy are available in abundance and, to human time scale, forever. Apart from the idea of using waste heat of large solar thermal power plants for powering thermal distillation systems, at the present time, there are no solutions discussed for cost effective solar powered desalination units in the size of 500 – 50.000 m^3/day for desalination purposes only.

As previously indicated, combined gas and steam turbine cycles are the most efficient to power production, and MED systems can be the most efficient thermal technology, when dual-purpose power and water plant are considered. Therefore, the combination of a solar field and a combined cycle power plant to form an Integrated Solar Combined Cycle Power Plant (ISCC, Figure 4) is an interesting application to reduce the solar generation cost by making better use of the common infrastructure and due to the economics of scale of the steam turbine. In an ISCC, the ratio of solar to fossil generation is low; however the absolute amount of solar generated electricity (in kWh) for a given incremental investment is larger in an ISCC Power Plant, than in a Solar Rankine Cycle Power Plant. This configuration, integrating a MED unit to water production to replace the conventional water cooling system to exhaust steam condensation from the steam turbine, could be one of the most interesting approach to CSP+D plants design but not the only one.

The potential of CSP+D power plants is very high. Power produced by CSP technology is already a reality in countries such as Spain and it could cover the 14 percent of the electricity demand of MENA (Middle East and North African) countries by 2025; by 2050 it could become the dominating power source in the region with a share of 57% and an estimated energy cost in the range of 8 c€/kWh to 15 c€/kWh [47]. Strong effort in R&D and Demonstration projects would be needed but the strong rise of oil prices, already pressuring to reduce the cost of conventional power and energy intensive desalination systems, is already a major force to the promotion of such initiatives as CSP technology is a very promising alternative to the problem [57]. With regard to the amount of land required by these technologies, when desalination is considered, the concentrating solar thermal collector array required for desalinating 1 billion m^3/year would cover a total land area of approximately 10×10 km, corresponding to about 10 m^3 of desalinated water per m^2 of collector area [47].

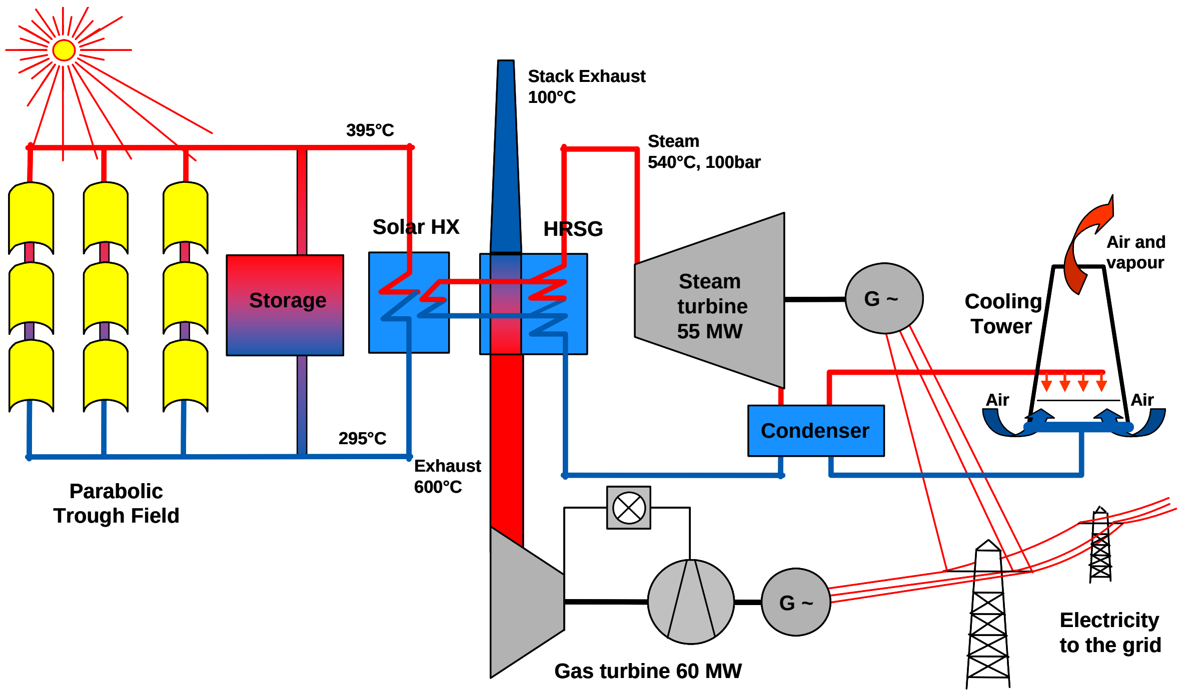

Fig. 4. Example of 100 MW Integrated Solar Combined Cycle Power Plant, where the condenser system can be effectively replaced by a MED desalination system

Another reason to support the installation of cogeneration plants is to provide water to the own power plant for the cooling system [57]. It is known that CSP plants need large amounts of water for their own operation, being this a problem which could limit its potential installation in many locations where the water scarcity is already a problem [58]. Therefore, the integration of CSP+D is also a way to make fully sustainable the solar power concept.

5. SOLAR ENERGY AND SUSTAINABLE DEVELOPMENT. CONCLUSIONS

The 20th century brought an unprecedented development in mankind history with major breakthrough in all scientific and technical fields. However, those breakthroughs have not been free, being possible to consider excessive, under certain point of view, the price paid. During the last 100 years, human population has multiplied by fourfold (going from 1,6 billion people in 1.900 to 6,6 billion at present). However water consumption has multiplied by nine fold in the same period and energy consumption by sixteen fold, with the result of a very important associated degradation of the environment and pressure over the natural resources. Water and energy, together with the air as element permitting breathing, are the 3 essential elements our life and civilization depend on. It is clear that water and energy are specially linked each other, so it makes no real sense to address the solution of one of these problems without take into consideration the other one.

At present there is a clear consensus on the impact that this over-exploitation of resources is having on the fragile ecosystem of our planet stretching to the limit (if not already surpassed) the possibilities for sustainability that the planet can offer. Therefore, it is a must to change this development, which has been and is being clearly unsustainable, by an environmentally friendly and sustainable one which would be able to fulfil our needs without endangering the needs of future generations.

To break the current vicious circle of necessary development and limited resources, the following three essential ingredients are considered necessary: a) new ideas which could be assumed by the majority of people; b) more effective and environmentally friendly innovative technologies; c) political will and policies to effectively implement them.

It is in this context where renewable energies in general and solar energy in particular are called to play a key roll to achieve the objective of sustainable development. Therefore, CSP+D technologies could both provide economic development, employment and guaranty power and water provision at many sunny areas of the world. Costs are still higher than other conventional technologies but a global strong effort in research, development and demonstration is rapidly reducing the existing gap. Growing oil price instability and the environmental requirements derived from compliance with the Kyoto Protocol are other factors which are strongly helping the development of all these solar energy technologies.

6. REFERENCES

1. International Energy Agency. (2006). Key World Energy Statistics.
2. International Energy Agency. (2003). Energy to 2050, Scenarios for a sustainable future. ISBN 92-64-01904-9.
3. International Energy Agency. (2005).Resources to Reserves - Oil and Gas Technologies for the Energy Markets of the Future.
4. Petit, J.R.; Jouzel, J. et al. (1999). Climate and atmospheric history of the past 420.000 years from the Vostok ice core in Antartica, Nature 399 (3June), pp 429-436.
5. Swenson, R. (2005). The production peaks in petroleum and natural gas: information, misinformation, awareness, and implications. Proceedings of the ISES 2005 Solar World Congress, August 6-12, 2005, Orlando, FL, USA.
6. International Energy Agency. (2004). Renewable in Global Energy Supply.
7. Hoffer et al., Nature 395, 883, 1998.
8. United Nations Development Program (UNDP), (2006). Human Development Report 2006. Beyond scarcity: power, poverty ad the global water crisis.
9. Kofi Annan, (2000). We The Peoples. Millennium Report of the Secretary-General, United Nations.
10. El-Dessouky H.T. and Ettouney H.M. (2002) Fundamentals of Salt Water Desalination. Ed. Elsevier, Amsterdam.
11. Wangnick K. (2004) 2004 IDA Worldwide Desalting Plants Inventory. Report No. 18. Wangnick Consulting, Gnarrenburg, Germany

12. Izaguirre Etxeberria, J.K. (2004). Gestión de Recursos Alternativos. Ósmosis inversa: Desalación de agua. Tecnología del Agua, special number, pp. 4-11. Barcelona

13. Blanco, J.; Alarcón, D. The Aquasol system: opening the door to suitable large scale solar desalination. Water at Middle East Electricity. Dubai (UAE), 12th February, 2007.

14. Zarza, E; Valenzuela, L.; León, J. (2004) Solar thermal power plants with parabolic-trough collectors. European Space Agency (Special Publication) ESA SP (567), pp. 91-98.

15. Osuna, R. et al. (2006) PS10, 11 MW solar thermal tower plant in Seville, Spain. Proceedings of the 13th International Symposium on Concentrated Solar Power and Chemical Energy Technologies. June 20-23, 2006. Seville, Spain

16. Keck, T. et al. (2006) Eurodish – Continuous operation, system improvement and reference units. Proceedings of the 13th International Symposium on Concentrated Solar Power and Chemical Energy Technologies. June 20-23, 2006. Seville, Spain

17. Häberle, A. et al. (2002) The Solarmundo line focusing Fresnel collector: optical performance and cost. SolarPACES Conference, Zurich, Switzerland.

18. Sargent & Lundy (2003) Assessment of parabolic trough and power tower solar technology cost and performance forecasts. National Renewable Energy Lab. Report: NREL/SR-550-34440. October 2003. Golden (Colorado), USA

19. Manuel Collares Pereira. Solar Thermal Electricity in Portugal, the Tavira Project Plenary lecture at the 13th International Symposium on Concentrated Solar Power and Chemical Energy Technologies. June 20-23, 2006. Seville, Spain

20. Cohen, G.E. et al. (1996) Recent improvements and performance experience at the Kramer Junction SEGS plants. International Solar Energy Conference, pp. 479-485.
21. Cable, R.G. et al. (1998) SEGS plant performance 1989-1997. International Solar Energy Conference, pp. 445-452.
22. Jackie Jones. CSP Lifts off. Nevada Solar One comes to life. Renewable Energy World. Vol. 10, No. 3, pp. 36-43. 2007.
23. Pitz-Paal, R. et al. (2005) European Concentrated Solar Thermal Road-Mapping – Roadmap Document (SES-CT-2003-502578) ECOSTAR.
24. Geyer, M.; Mancini, T. From Research to CSP Market Introduction Progress and Advances of Concentrating Solar Power Technologies. Solar Power Conference 2006, October 16-19, 2006. San Jose (Ca), USA.
25. Price, H. et al. (2002) Advances in parabolic trough solar power technology. Journal of Solar Energy Engineering, Transactions of the ASME 124, pp. 109-125.
26. Wiseman, R. (2004) Desalination business “stabilised on a high level” – IDA report. Desalination & Water Reuse 14(2), pp. 14-17.
27. Al-Shammiri M.; Safar, M. (1999) Multi-effect distillation plants: state of the art. Desalination 126, pp. 45-49.
28. Alawadhi, A.A. (2002) Desalination – where are we now? GCC Countries. Desalination & Water Reuse 12(1), pp. 12-21.Canton, G. (2006)
29. The recent progress and next generation of MED plants. IDA International Water Forum, March 5-6, 2006. Dubai, UAE.
30. Desportes C. (2006) Sea Water Desalination for the Bo-Hai Gulf: case studies of MED desalination plants installed in Tianjin and Huanghua. IDA Desalination and Water Reuse International Forum & Exhibition, September 6-8, 2006. Tianjin, China.

31. Vermey, J.W. (2003) Taweelah-A1 makes breakthrough in large-scale MED plants. Desalination & Water Reuse 12(4), pp. 10-13.
32. DHV Water BV et al. (2004) Seawater and brackish water desalination in the Middle East, North Africa and Central Asia. World Bank Report.
33. Awerbuch, L. (2006) Impact of high energy and materials cost on desalination and power technology. IDA Desalination and Water Reuse International Forum & Exhibition, September 6-8, 2006. Tianjin, China.
34. Van der Bruggen, B.; Vandecasteele, C. (2002) Distillation vs. Membrane filtration: overview of process evolutions in seawater desalination. Desalination 143, pp. 207-218.
35. L. García-Rodríguez: Seawater desalination driven by renewable energies: a review, Desalination, 103-113, 143 (2002).
36. E. Chafik: A new type of seawater desal. plants using solar energy, Desalination, 333-348, 156 (2003).
37. J. Koschikowski, M. Wieghaus, M. Rommel: Solar thermal-driven desalination plants based on membrane distillation, Desalination, 295-304, 156 (2003).
38. S. Abdallah, M. Abu-Hilal, M.S. Mohsen: Performance of a photovoltaic powered reverse osmosis system under local climatic conditions, Desalination, 611-620, 183 (2005).
39. K. Paulsen, F. Hensel: Introduction of a new Energy Recovery System – optimized for the combination with renewable energy, Desalination, 1191-1195, 184 (2005).
40. C. Epp, M. Papapetrou: Co-ordination action for autonomous desalination units based on renewable energy systems – ADU-RES, http://www.adu-res.org, Desalination, 89-93, 168 (2004).
41. E. Zarza: Solar Thermal Desalination Proj., Phase II Results, Final Report, Ciemat, ISBN 84-7834-285-0, Aug. 1994.

42. García-Rodríguez, L.; Blanco, J.; Alarcón, D.; Vincent M. (2007) Tecnología Híbrida de Desalinazación Avanzada Solar-Gas Basada en Captadores Solares Estáticos. Ed. CIEMAT, Madrid, Spain.
43. Alarcón et al. (2005) Design and setup of a hybrid solar seawater desalination system: the AQUASOL Project. Proceedings of the ISES 2005 Solar World Congress, August 6-12, 2005, Orlando, FL, USA.
44. D. Sagie, E. Feinermann, E. Aharoni: Potential of solar desalination in Israel and in its close vicinity, Desalination, 21-33, 139 (2001).
45. W.C. Childs, A.E. Dabiri: VARI-RO solar-powered desalting study, MEDRC, 97-AS-005a, March 2000.
46. W.C. Childs, A.E. Dabiri: VARI-RO direct drive energy study, Assistance Agreement No. 1425-97-FC-81-30006C, U.S. Dep. of Interior, Bureau of Recl., ISN 7540-01-280-5500, Desalination Research and Development Program Report No. 33, Sept. 1998.
47. Uche, J.; Serra, L.; Valero, A. (2006) Exergy costs and inefficiency diagnosis of a dual-purpose power and desalination plant. Journal of Energy Resources Technology, Transactions of the ASME 128, pp. 186-192.
48. Darwish, M.A. (2007) Desalting fuel energy cost in Kuwait in view of $75/barrel oil price. Desalination 208, pp. 306-320.
49. Almulla, A. et al., 2005/4/10. Integrating hybrid systems with existing thermal desalinationplants. Desalination 174, 171-192.
50. Mussati, S. et al., 2003/2/10. Dual-purpose desalination plants. Part II. Optimal configuration, Desalination 153, 185-189.
51. Cardona, E., Piacentino, A., 2004/8/15. Optimal design of cogeneration plants for seawater desalination. Desalination 166, 411-426.
52. Ophir, A., Lokiec, F., 2005/11/1. Advanced MED process for most economical sea water desalination. Desalination 182, 187-198.

53. Hamed, O.A. (2005) Overview of hybrid desalination systems - current status and future prospects. Desalination 186, pp. 207-214

54. Rensonnet, T. et al., 2007/6. Simulation and thermoeconomic analysis of different configurations of gas turbine (GT)-based dual-purpose power and desalination plants (DPPDP) and hybrid plants (HP). Energy 32, 1012-1023.

55. El-Nashar, A.M., 2001/4/20. Cogeneration for power and desalination — state of the art review. Desalination 134, 7-28.

56. Alnaser, W.E.; Trieb, F.; Knies, G. (2007) Solar energy technology in the Middle East and North Africa (MENA) for sustainable energy, water and environment. Advances in Solar Energy 17, pp. 261-304.

57. Aybar, H.S., 2004/8/15. Desalination system using waste heat of power plant. Desalination 166, 167-170. Cardona, E., Piacentino, A., 2004/8/15. Optimal design of cogeneration plants for seawater desalination. Desalination 166, 411-426

58. Khalil, I.; Sahm, A.; Boehm, R. (2006) Wet or dry cooling?. International Solar Energy Conference, Volume 2006.