Feasibility of Renewable Energies for Sea Water Desalination Plant

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Abstract

Renewable energies, such as solar, wind and biomass, are considered to become new energy resources in Saudi Arabia and other Middle East countries in the near future, if the Clean Development Mechanism (CDM) will be established. There is a high possibility to reduce CO2 emission volume from seawater desalination plants by alternating the conventional fossil fuel energy into renewable energies.

We examined some practical system of desalination by renewable energies, especially solar and biomass energy. Based on the actual operation results, we introduce some new ideas combining multi-type power generating systems in order to increase the capacity operating rate and to reduce the cost of power generation.

Keyword: Desalination, Solar Energy, Reverse Osmosis, Multi Effect Distillation.

Introduction

In 21st century, it is estimated that a short of water resources become a serious problem in arid area, due to the rapid increase of population and global warming effect. Now, most of water resources are secured from ground water and seawater and brackish water desalination system operated by fossil energy in these arid countries. However, both of them are not sustainable and rechargeable.

In arid countries, there are a plenty of solar energy, as shown in Fig. 1. Especially, Middle East and Africa are one of the best countries blessed with solar energy in the world More than 20 years ago, King Abdulaziz City for Science and Technology (KACST) in Saudi Arabia conducted SOLERS project with USA, and examined an availability of solar desalination system with freezing method of sea water in Yanbu near the Red Sea.

After that, many countries constructed test plants of solar power generation, as shown in Table 1. [1)] SEGS (Solar Energy Generation System) power plant in USA has the longest operating history and greatest generating capacity in the world. Cost of electric power generation in SEGS decreases to a comparable one of 4 – 6 cents /kWh with conventional power generation in USA, as shown in Fig. 3.

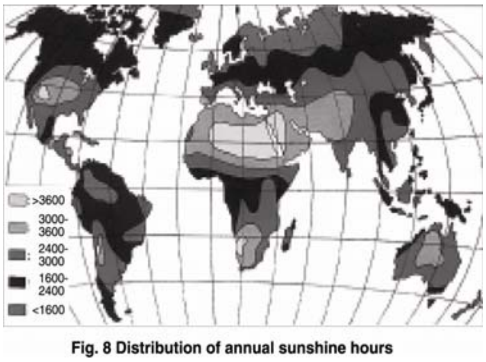


Fig. 1 Solar energy map in the world

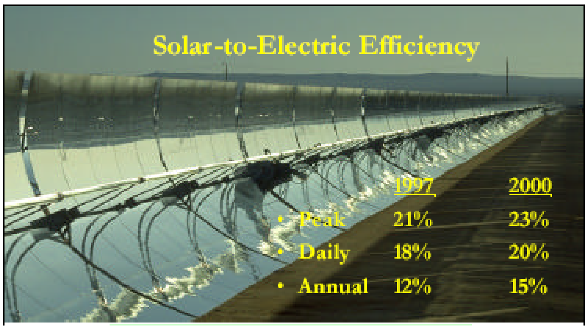


Fig. 2 SEGS power station in California, USA

Table 1 Review of solar power station in the world

Nation	Place	Electric capacity(MW)	Solar collector type	Operation period
USA	California (Solar 1)	10	Tower	1982 - 88
	California (Solar 2)	10	Tower	1996 - 99
	California (SEGS)	354	Trough	1982 – now
	Nevada(SolarOne)	64	Trough	2007-
France		2.5	Tower	1982
Spain	Almeria(PS10)	10	Tower	2005
	Andalusia(Andasol)	50	Trough	2008-
Italy	Sicili	1	Tower	1982
	Specchia	12	Trough	Under planning
Egypt	Cairo (Kurayamat)	40	Trough	Under planning
Morocco	Beni Mathar	30	-	Under planning
Japan	Nio	1	Tower	1981 - 1985

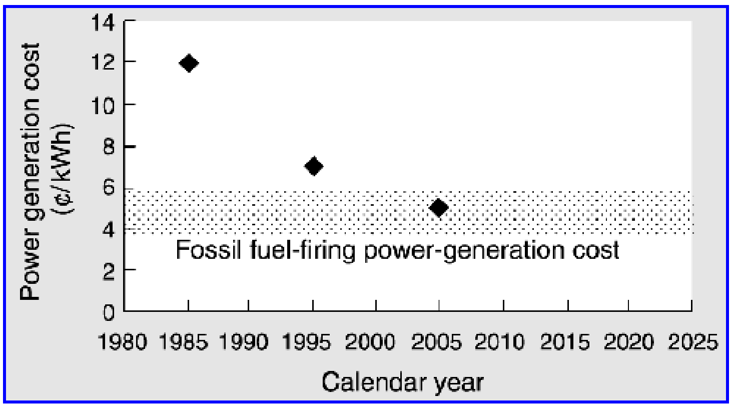


Fig.3 Cost of electric power generation at SEGS power plant in California, USA

Mitsubishi Heavy Industries (MHI) constructed the solar power test plant in Nio, Japan under the sponsorship by Japanese government, as shown in Fig.4. It was a tower type with 1MWe of power generation.

Now, Tokyo Institute of Technology (TIT) is constructing the tower type of solar power test station in Abu Dhabi, UAE, under the sponsorship by MASDAR project. It is a new tower type called a Beam Down type, which reflect a collected solar beam into a heat receiver placed on the ground, as shown in Fig. 5.(Tamaura,2006) [2)] It has a merit of cost reduction for construction and maintenance.

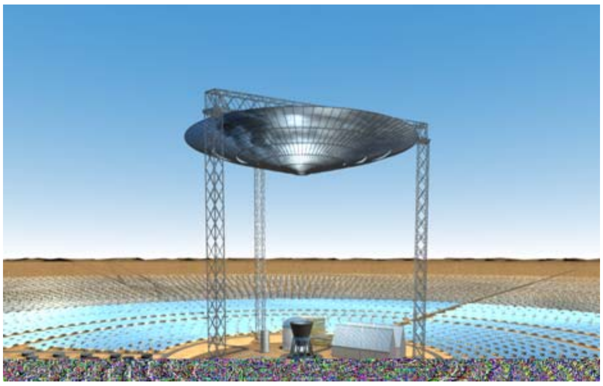


Fig. 4 Solar power test plant in Nio, Japan

Fig. 5 Solar power plant of beam-down type

1. Technologies for Solar Power and Desalination plants

1.1 Solar power plant

In the SEGS solar power generation system, Mineral oil is heated up by solar heat energy collected with solar collector of trough type, and supplied to steam generator, as shown in Figs. 6. Outlet temperature of mineral oil is about 400 degC, and maximum thermal efficiency of heat collector is 73% and average efficiency is 43% in daytime. Steam energy is transformed into electric power by steam turbine and electric generator. Steam temperature is heated up with supplementary boiler using natural gas purchased from commercial gas pine line, in order to increase the electric conversion efficiency of steam turbine up to 40%.

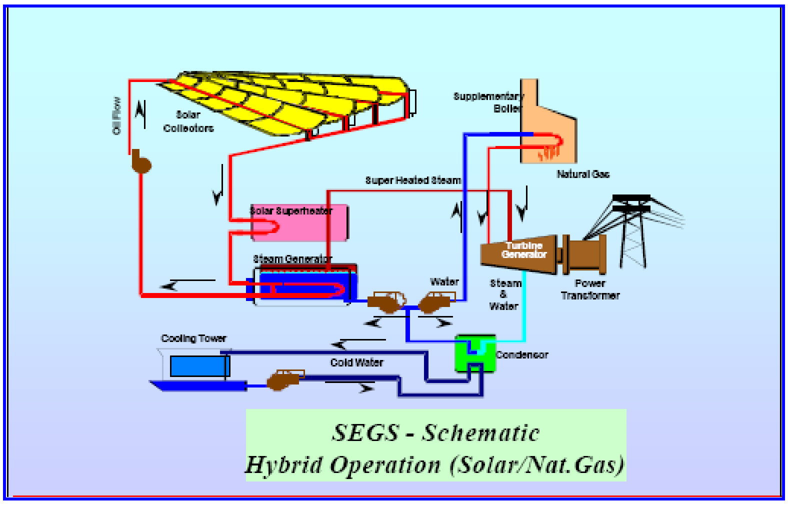


Fig. 6 Total system of SEGS plant in California

Steam outlet from steam turbine is condensed by steam condenser and its cooling water is cooled down by wet type cooling tower with mechanical draft. Cooling water is supplied from water pipeline. Although SEGS plant is now operated only during daytime for 8 hours, it can be operated during nighttime if natural gas will be used as a fuel to heat up a steam. Briefly speaking, there are three kinds of solar collectors used for solar power station; one is a trough type, second a tower one and third a parabola one. Each type has merit and demerit. (Table 2)

Table 2 Comparison of specification for each solar collector type

Items	Trough	Tower	Parabola
Area of total collectors	Almost same	Almost same	Almost same
Thermal efficiency	Almost same	Almost same	Almost same
Temperature of heated liquid	Low (Around 350 degC)	High (Around 400 degC)	High (Around 400 degC)
Heated liquid	Mineral oil	Molten salt	Molten salt
Heat absorber	Steal pipe with or without insulator	Special unit with insulator	Special unit with insulator
Operation of optical angle for solar	1 direction (Simple)	3 directions (Complex)	3 directions (Complex)
Past record	More than 10	Less than 10	Few

1.2 Solar desalination plant

Solar desalination test plant of MED was constructed in Abu Dhabi under the joint sponsorship by Japan and UAE, 1983, as shown in Fig.7. Water production rate was $80m^3$/day and collector area was $1,862m^2$. It had a big storage tank of heated water used for leveling the water production rate of desalination plant in the night time. However, the total construction cost increased due to this storage tank of heated water.

Fig. 7 Flat plate type solar collector and heated water storage tanks for MED desalination system ($80m^3$/day) in Abu Dhabi, UAE

2. Cost performance of solar desalination plant

2.1 Cost of water production

Thermal energy for water production is compared for Reverse Osmosis (RO), Vapor Compression (VC), Multi Effective Distillation (MED) and Multi Stage Flush (MSF) systems in Table 3. In this table, thermal power of MED and MSF can be converted to electric power by assuming an efficiency of power generation of 30%.

Table 3 Comparison of thermal energy for each desalination system

Item	Method / Unit	RO	VC	MED	MSF	
Electricl Energy	kWh-e/t	4.0	12.0	1.5	2.5	
Thermal Energy Demand for Electricity	kWh-t/t	13.3	40.0	5.0	8.3	Efficiency= 30% (300℃)
Performance Ratio	-	-	-	12.0	8.0	
Stem Temperature	℃	-	-	80	120	
Thermal Energy Demand for Evaporation	kWh-t/t	-	-	52.2	78.4	
Total Energy	kWh-t/t	13.3	40.0	57.2	86.7	

It is found from this table that RO is the best system for energy reduction and the ratio between RO and MED is about 1:6.5. Therefore, it can be concluded that solar heat energy should be used for RO system as much as possible, and the remaining of them should be used for MED or MSF. Hybrid desalination system of Fig. 8 is based on this concept. Main desalination part of this hybrid system is RO and MSF is a supplementary part.

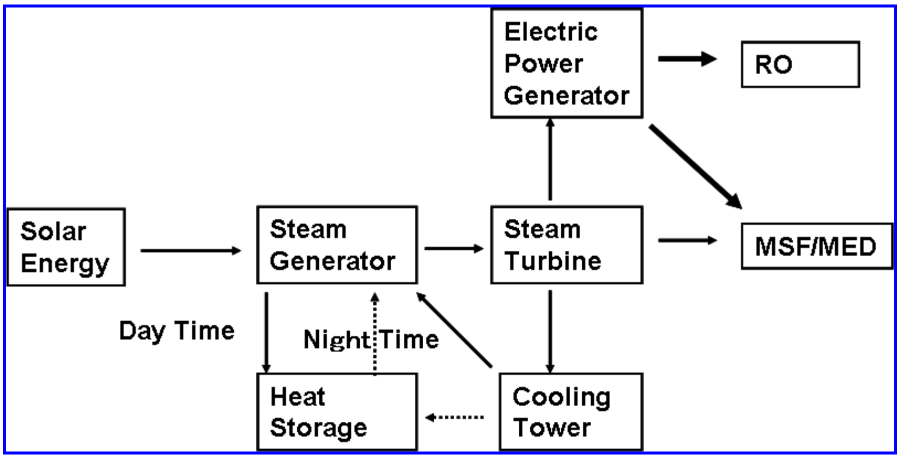
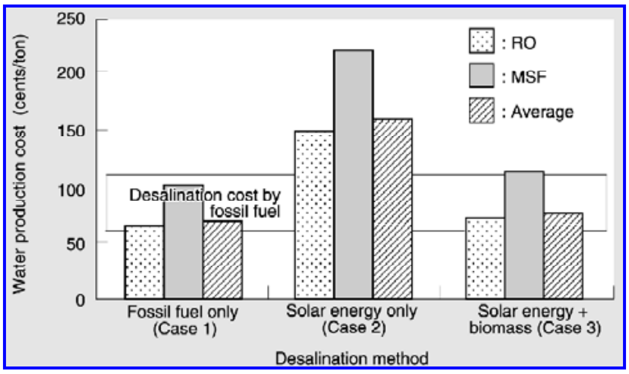


Fig. 8 Flowchart of hybrid system with RO and MSF/MED

We estimated the cost of water production for this hybrid system in consideration with daily change of solar heat supply and depression rate of capital cost, and compared it with the conventional desalination system using a fossil fuel, as shown in Fig.9.

It is found from Fig. 9 that cost performance of solar desalination system is more expensive than the conventional one for 8 hours operation, but it becomes comparable with the conventional one for 24 hours operation, and it has a possibility to become cheaper if considering the credit of CO_2 emission right or CO_2 tax.



Case 1: Conventional plant by fossil power for 24 hrs

Case 2：RO+MSF by solar power for 8 hrs

Case 3：RO+MSF by solar power & other heat source for 24 hrs

Fig. 9 Cost performance of conventional and solar desalinations systems

Another way of the cost reduction is to use solar energy in the day time and renewable energies in night time, as shown in Fig. 10.

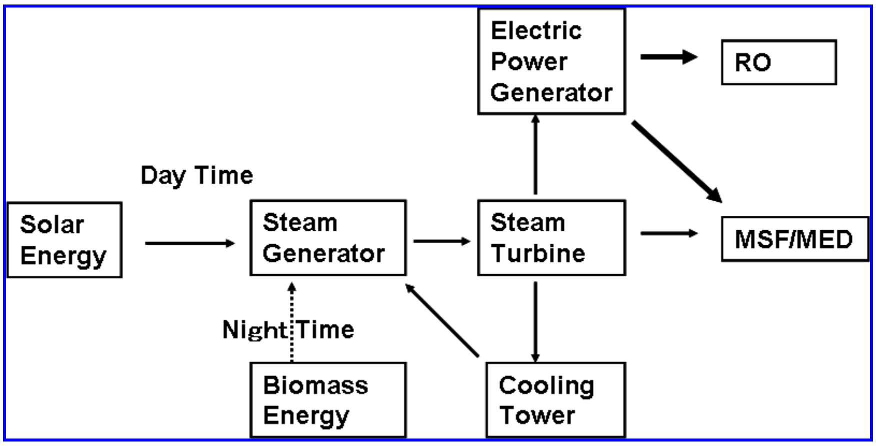


Fig. 10 Flowchart of hybrid desalination system combining solar and biomass energies

Biomass energy in arid areas is scarce, but the waste material of date palm trees and fruits is widely available. It is estimated that there are more than 30 million date palm trees in the Kingdom of Saudi Arabia (KSA). The waste materials of these trees can be used for solid fuels in electric power production, while waste fruits can be used for liquid biofuels such as bio-ethanol. There are several opportunities to obtain date palm tree and fruit waste material, as follows:

1) Cyclic planting of old trees every 25 years
2) Cutting old leaves annually
3) Trees damaged by diseases and pests
4) Removal of date farms to residential area
5) Replacing old species with new ones

Assuming a large date farm with 1 million trees like Al-Hufu in the KSA, it is estimated that we can generate 2.5 MW of electric power from the farm's solid waste materials, thus producing 10 thousand tons of water per day.

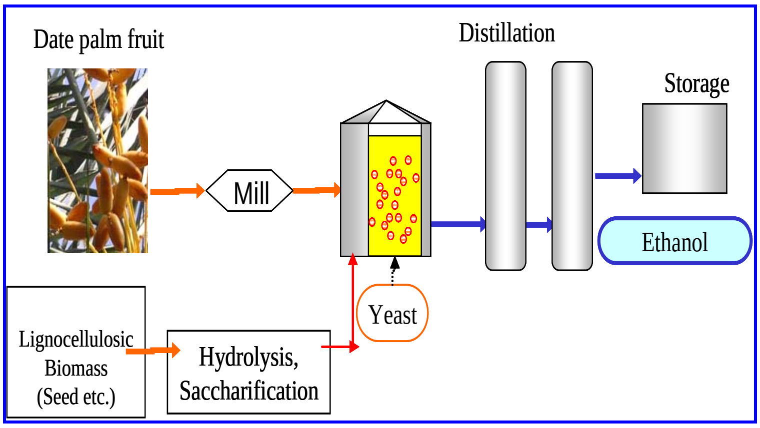


Fig. 11 Process to produce bio-ethanol from date

Fig. 12 Burning and disposing of waste date trees with garbage

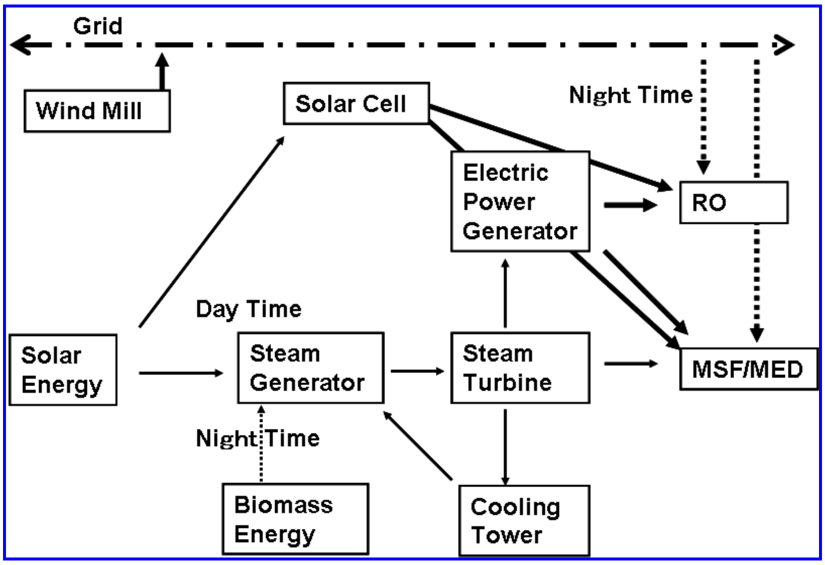


Fig.13 Flowchart of hybrid solar desalination system with electric power from grid

In addition, to operate the plant with stability, and to use renewable energy effectively, the system that showed in Fig 13 was designed. The photovoltaic and wind power generations are added to the system of Fig 12 for the use of renewable energy. Because the fluctuation of the photovoltaic generation is large, an insufficient electric power is supplied from the power grid. This system is effective when a steady power grid by conventional power generation etc. is possessed.

2.2 Availability of Clean Development Mechanism (CDM) [3)]

In 2006, the total carbon transaction (including non-CDM carbon initiative) has become a US$ 30 billion market (up from US$11 billion in year 2005). As the carbon market grows, the Carbon Emittion Rights (CERs) have increased its liquidity. As a result, the CERs have become a financial commodity, where various financial tools are being developed while major financial institutions are entering the market seeking for business opportunities. These already registered CDM projects are expected to generate over 1 billion CERs by 2012.

Although CDM was designed to encourage any types of Green House Gas (GHG) reduction project development, it has a strict procedure as well as monitoring to accurately measure the reduction. In addition, every project requires a technical document called Project Design Document (PDD), which must meet both quality and accuracy standards set by United Nation's committee named UNFCCC. This must also be reviewed by a third party organization called a Validator. Finally, the PDD must apply baseline and monitoring methodologies that have been approved by the CDM Executive Board. The methodologies determine the methods for the calculation of GHG reductions and for the monitoring of the project to ensure that the project results in real reduction.

If there are no approved methodologies applicable to a project, the project proponents or their consultants are required to submit a new methodology application. This add significant time and cost. At present, there are over 60 approved methodologies, covering various types of projects including renewable, landfill and HFC projects.

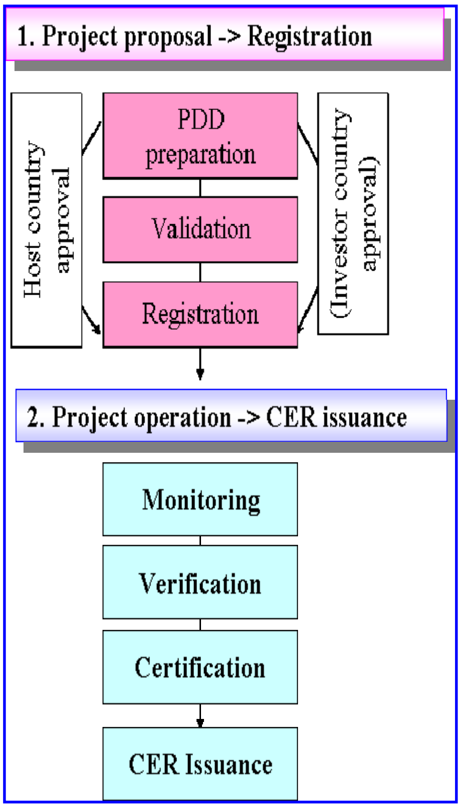


Fig. 14 CDM Process

The CDM can be utilized for eligible projects which reduce GHG emissions and are non-Annex 1 countries. In order for a potential CDM project to register, a Project Design Document must be prepared based on an accepted methodology applicable to the project type. If there is no accepted methodology for a particular project type, a new application must be proposed. This will be accessed by the CDM Methodology Panel who will recommend to the CDM Executive Board, a governing body of CDM under the UNFCCC, whether it should be accepted, considered again after making appropriate changes, or rejected.

Currently there are over 100 approved methodologies available for various types of CDM project.

Discussions

We found that costs for all renewable energy options are higher than for the conventional energy option. However, if the fossil fuel saved through the consumption of renewable energies could be used in the future, or exported to foreign countries at a high market price, the exporting country could partially recover the high cost of renewable energy electric power, as shown in Figs. 15. In addition, if registered as CDM projects, such projects could potentially bring in extra income from the sale of Certified Emission Reduction (CER) credits. Considering the partial cost recovery from the additional export of fossil fuels and revenue from CER credits, the total balance of national expense and income may be in the black.

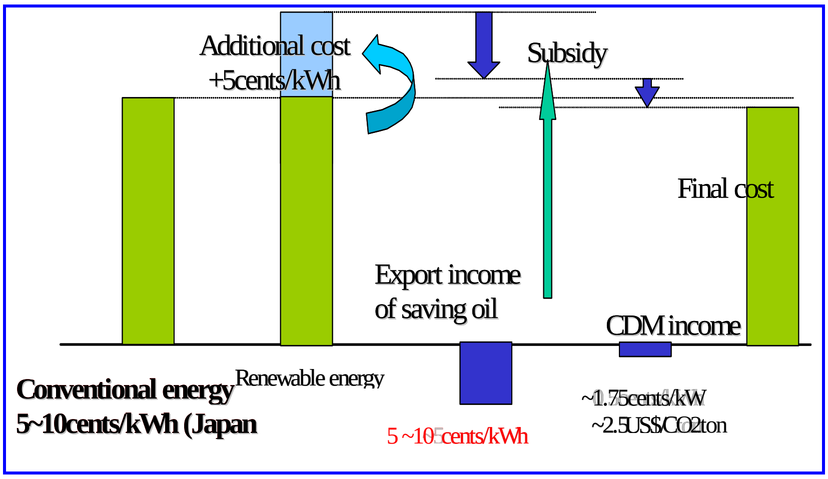


Fig. 15 Total balance of national expense and income for CDM project including additional income of saving oil, where market price of oil is assumed to be US$70/BBL

It is concluded that a CDM project can provide mutual benefits to both Middle East and industrial countries in term of economy, environment, energy, and technology, as shown in Table 4.

Table 4 Mutual benefits for Middle East and industrial countries

Subject	Middle East countries	Industrial countries
Economy	Investor promotion	Investor profits
Environment	Use of clean energy Waste treatment	Certified Emission Reduction (CER) credits
Energy	Reduced oil consumption	Importing oil
Technology	New energy development	Exporting technology

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References

1) R. Ohba et al., New technologies for sustainable desalination system, Second Oman-Japan Symposium: Preservation of Environmental and Water Resources amid Economic Development.6-8/02/2005

2) Y. Tamaura et al., A Novel Beam-Down System for Solar Powergeneration with Multi-Ring Central Reflectors and Molten Salt Thermal Storage, 13th International symposium on concentrated solar power and chemical energy technologies, June 20, 2006, Seville, Spain

3) R. Ohba et al., Feasibility of CDM Projects in Middle East Countries, Proceedings of JPCC Conference, January 28 and 29, 2008, Dhahran, Kingdom of Saudi Arabia