The Second International Scientific Conference
المؤتمر العلمي الدولي الثاني لتكنولوجيا علوم البحار
For Marine Science Technology
لتكنولوجيا علوم البحار
Sabratha – Libya 09-10/03/2021 ليبيا - صبراتة

Multistage solar photovoltaic membrane distillation system to solve water and energy problems simultaneously (a review article)

Z_Gebrel

Department of physics, Faculty of Science Sabratha , University of Sabratha-Libya,
Corresponding author: zohra Ali Gebrel Tel.: +218944016851.
E-mail address: z_gebrel@yahoo.com or z.gebrel@sabu.edu.ly

Abstract

Clean energy and clean water are among the major challenges for sustainable development .approaches to electricity generation consume huge amounts of water as well distillation of sea water use a lot of energy. Certainly the energy crisis will increase water scarcity, water scarcity will certainly energy problems. The most potential solution to solve this problem is by using desalination technology powered by renewable energy like solar energy. In recent years, significant efforts have been devoted to developing and testing innovative solar based water treatment technologies .Researchers have found a way to purify water and produce electricity from a single device powered by sunlight. The concept of simultaneous production of clean water and electricity by solar energy has been recently investigated by researches group. The objective of this study is to present an overview of current and future technologies applied to the desalination of seawater to produce freshwater Also, In this review study , we exhibit configuration and process of photovoltaics-membrane distillation (PV-MD) device that can stably produce clean water from seawater while simultaneously having uncompromised electricity generation performance by renewable energy.

Keywords: Desalination water, fresh water , Renewable energy, Solar collectors ,Photovoltaics; PV-MD

Introduction

Water is the basis of life on this earth. which covers about 75% of the Earth's surface Water is a widely available natural resource,. However, about 97% of the earth's water is salt water like sea water , and a only 3% is fresh water surface water like rivers and lakes, which are readily to use [1-3]. The only nearly inexhaustible sources of water is (sea &oceans), which, however, are of high salinity. Therefore, one of the best methods to solve this freshwater scarcity problem is by using desalination technology [4].It would be feasible to address the water-shortage problem with seawater desalination; however, separating salts from seawater requires large amounts of energy which, when produced from fossil fuels, can cause environmental damage. Therefore, there is a need to use environmentally friendly energy sources for seawater desalinate.

Water and energy are two key factors in human life that always control the growth and development of human societies. Climate changes, increasing the population in urban areas and industrialization, have increased the demands for freshwater around the world. Using seawater as a source of fresh water supply could be a solution to the increasing globalwater stress. Nonetheless, intensive energy requirements and prohibitive costs of desalination technologies restrain their massive use in many communities affected by water scarcity, even though having unlimited access to seawater. Desalination is one option for producing clean water from seawater in many parts of the world, but most water desalination technologies are energy and capital intensive. The main desalination technologies currently used are reverse osmosis, electro dialysis, and distillation. Continual improvements in desalination processes, particularly in the past decade, have made these systems more reliable and have reduced capital costs, but high energy requirements remain[5-6].

Recently, Increasing attention is being placed on developing desalination processes powered byrenewable energy, such as solar power. Global scarcity of fresh water has driven intensive research in solar desalination to provide clean water directly using processes with minimum environmental impact.Converting solar energy to electricity by photovoltaics (PV) is the most accepted way to produce solar power owing to its low barrier of entry and thus low and flexible capital investment, making it suitable at any scale.

In recent years, the concept of the simultaneous production of electricity and clean water via sunlight has attracted tremendous attention due to its potential to balance the relationship between the water and energy supply, but met with very limited success[7-8].There are several types of conventional desalination processes, e.g. Multi-Effect Distillation (MED), Multi-Stage Flash (MSF)، Reverse Osmosis (RO), and Vapor Compression Distillation (VCD), etc [3] Thermally driven MD is a new process that is being studied as alow-cost, energy-saving alternative compared to conventional separation processes like distillation and RO. Membrane distillation (MD) is a thermally driven separation process that involves phase conversion from liquid to vapor on one side of the membrane and condensation of vapor to liquid on the other side. The exploitation of waste heat energy sources such as solar energy enables MD more promising separation technique for industrial scale[9]..

All desalination systems of seawater, require heat sources or electrical energy input. In this article we report an overview of current and future technologies applied to the desalination of seawater to produce freshwater . Also we report about photovoltaics-membrane distillation (PV-MD) device which remove. salts from the seawater and in the same time produce additional energy[10].

A photovoltaic-membrane distillation (PV-MD) device was designed in 2019 to effectively generate clean water and electricity simultaneously[10]. In this review paper it is described a modified photovoltaics-membrane distillation (PV-MD) system, which simultaneously remove both salts from the sea water and produce additional electricity .

The idea of simultaneous production of clean water and electricity by solar energy has been recently studied and investigated by several groups. A device that can produce electricity from sunlight while simultaneously purifying water from sea/polluted water has been invented by researchers. This development can solve two problems in one stroke the device is not only a source of green energy but also offers a cheaper alternative to current technologies for clean water.

A photovoltaic-membrane distillation (PV-MD) device was designed in 2019 to effectively generate clean water and electricity simultaneously] [10].

DESALINATION TECHNOLOGIES OVERVIEW

Desalination is one selection for producing clean water from seawater international, but most water desalination technologies are energy and principal intensive [3,11].There is a large number of different desalination technologies available and applied in many parts of the world . Some of them are totally developed and applied on a large scale, while others are still used in small units for research and development or for demonstration purposes..

Desalination technology processes can be divided into two broad categories thermal evaporation and membrane separation as shown in table (1).Thermal desalination processes employ heat to evaporate, and the water vapor is then condensed and recovered[12].

Table(1) Display Desalination Technologies and processe

Membrane Technology	Thermal Technology
Electrodialysis (ED)	Multi-Effect Distillation(MED)
Electrodialysis reversal (EDR	Multi-Stage Flash Distillation (MSF))
Reverse Osmosis (RO)	Vapor Compression Distillation (VCD)

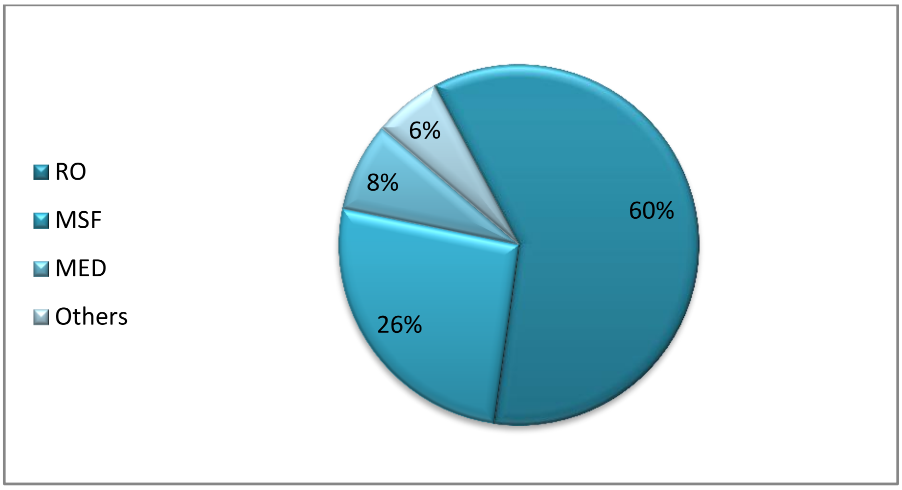

Figure 1: presents the proportions of global freshwater production by the main desalination technologies

Thermal technologies were the only options available for seawater desalination until 1960s were reverse osmosis (RO) membranes developed . Since that, RO membrane processes have steadily been improved, and the efficiency has increased to the point that they are now the technology of choice for most seawater desalination applications[13]. Figure 1 presents the proportions of global freshwater production by the main desalination technologies As a heat-driven membrane separation process, membrane distillation (MD) has a wide range of applications in industry, such as seawater desalination . Compared with other separation technologies as shown in table 2, MD has lower requirements for heat source quality, so it can be combined with abundant solar energy and industrial waste heat resources in mining areas. Besides, the content of organic content in the mine water is low, reducing the risk of membrane wetting. Therefore, MD can be used for the secondary treatment of reverse osmosis (RO)concentrated mine water to achieve higher recovery [13-14]. An exception to MD, where low energy costs allow for thermal desalination to remain relatively competitive. RO and MD are commonly used for desalination of sea water, brackish water, groundwater and other salty surface water resources. The most accepted among the existing commercial membrane technologies for the desalination of sea water is RO. The disadvantages of RO are high operating pressure, high energy consumption, brine disposal problems and environmental hazards. This has led to the introduction of new technologies like MD[15]. The advantages of MD are low operating temperature (below the boiling point of water), no salt water disposal problems, stability of membrane (hydrophobic), and being possible for small-scale processes in rural communities. Renewable energy like solar energy is abundant in arid and semi-arid regions. Hence to make the desalination method more viable for low production requirement and environment-friendly, application of renewable energy integrated with thermaldriven MD is found to be more attractive[13-14].

Table 2. Typical total electrical energy consumptions in different desalination technologies.Source: Reproduced from Ref. [15, 16]

Desalination Technology	Specific Energy Requirements
Multi-Effect Distillation (MED)	4-6kWh/m^3
Multi-Stage Flash (MSF)	20 – 27 kWh/m^3
Mechanical Vapor Compression (MVC)	7 – 12 kWh/m^3
Thermal Vapor Compression (TVC)	16.26 kWh/m^3
Seawater Reverse Osmosis (RO)	14 – 21 kWh/m^3

Use of Renewable Energy in Water Desalination

Desalination technology is one of the best methods can be using to solve freshwater scarcity problem [3]. in the countries with very limited resource of surface freshwater, Like North Africa and Middle East, desalination process might become the only solution to solve the freshwater scarcity problem in their countries [17]. But this method required high value of energy as shown in Table 3. shows the energy required to produce 1 m3 of fresh water from distinct types of water sources.

Conventional fossil fuel-powered desalination techniques consume substantial amounts of energy to produce fresh water and have a very damaging impact on the environment [17-18]. By increasing attention to the environmental problems of fossil fuels, and grow developing of renewable energy technology. providing a wide variety of conventional desalination methods driven by various types of renewable energy. Table 3 shows the specific energy requirements to produce one cubic meter of fresh water from currently available technologies for commercial seawater desalination . use of renewable energy for seawater desalination has increased from 3% in 1999 to 21% in 2017 [9]. The main conventional renewable energy sources of interest for water desalination is solar energy.

Table 3. Energy requirements for different water sources. Source: Reproduced from Ref. [19, 20, 21]

Water source	Energy (kWh/m3)
Surface water (lake or river)	0.37
Groundwater	0.48
Wastewater treatment	0.62 – 0.87
Wastewater reuse	1.0 – 2.5
Seawater	2.58 – 8.5

As a substitute or replacement for electrical energy, desalination systems power-driven by renewable energy represent a real option to reduce operating costs in conventional desalination systems . Studies have shown that low cost makes the solar PV driven desalination process a technically cost viable system for freshwater production in remote areas over a period of five years due to an increase of fossil fuel prices.

Solar power thermal Membrane Distillation:

conservative technologies often use large amounts of electricity and require infrastructure beyond the reach of many communities that lack basic access to safe drinking water. Solar energy can be used very simple to convert seawater into freshwater, low cost and cost-effectivetechnology . Recent developments have verified that solar powered desalination processes MDis better than thealternatives membrane desalination technology like RO. There are two types of solar power MD:

1- direct systems are those where the heat gaining and desalination processes take place naturally in the same device,(Solar still) . in this approach employing direct solar desalination, large-scale deployment is limited by expensive cost and losses in system efficiency, for example, estimated production rate 3–12 kg m^{-2} per day,[11,13] where the low efficiency created from the heat and mass transfer occurring during evaporation and condensation.

2- In indirect method, the plant is separated into two subsystems, a solar collector and a desalination unit.indirect solar desalination using photovoltaic (PV) panels and other traditional desalinationtechnologies, for example, MD distillation, MSF and reverse osmosis (RO) . Typical total electrical energy consumptions in different desalination technologies .

Table 4 provides an overview of the specific energy consumption of different desalination technologies

Table 4: Specific Energy Consumption of Conventional Desalination Plants

Process	Electricity (kWh/m3)	Heat (MJ/m3
RO	4.35-9.72	0
MSF	2.84-5.67	Ca.231
EMD	2.03-4.05	Ca197

Simultaneous production of clean water and electricity

Clean energy and clean water are among the key challenges for property development approaches to electricity generation consume lots amounts of water likewise distillation of sea water use plenty of energy. definitely the energy crisis can increase water insufficiency, water insufficiency will definitely energy issues. the foremost potential resolution to unravel this downside is by mistreatment chemical process technology battery-powered by renewable energy like alternative energy. In recent years, vital efforts are dedicated to developing and testing innovative renewable energy based mostly water treatment technologies .Researchers have found some way to purify water and turn out electricity from one device battery-powered by daylight. The thought of concurrent production of fresh water and electricity by alternative energy has been recently investigated by researches bunch. the target of this study is to gift an summary of current and future technologies applied to the MD process of water to supply fresh additionally, during this review study , we tend to exhibit configuration and method of photovoltaics-membrane distillation (PV-MD) device that may stably turn out clean water from water whereas at the same time having uncompromised electricity generation performance by renewable energy

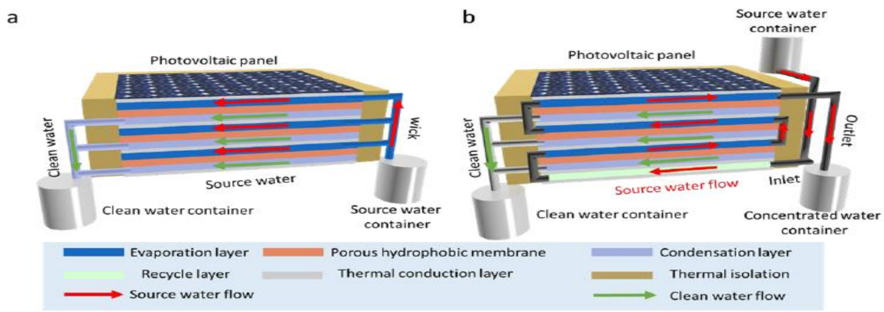

Figure 3. Schematic illustration of the integrated photovoltaic panel-membrane distillation (PV-MD) devices with three stages MSMD devices operated at a dead-end mode and b cross-flow mode

The PV-MD process

The idea of simultaneous production of clean water and electricity by solar energy has been recently investigated by several of scientists groups.Its high clean water production rate is realized by constructing a multistage membrane distillation (MD) device at the back of the solar cell to recycle the latent heat of water vapour condensation at each distillation stage. In most of these challenges , solar distillation was utilized for clean water production and some side effects of the solar distillation were utilized for electricity generation, which led to low solar-to-electricity energy efficiency (<1.2%).

In 2019, Wang's research team developed) strategyof photovoltaic membrane distillation (PV-MD), which exchanges the excess heat generated by the photovoltaic panels into a power source to multi-stage membrane (MD) distillation system to produce fresh water from seawater. Figure 1 shows PV-MD lab-made MD device by Wang's recharges group , a commercial polycrystalline silicon solar cell was adopted both as electricity generation component and photothermal component.

In order to decrease heat loss into the ambient environment, the sides of the PV-MD device were sealed by polyurethane (PU) foam with low thermal conductivity (0.022~0.033Wm−1 K^{-1}) [10]. Each stage of the MD device was composed of four separate layers: a top thermal conduction layer, a hydrophilic porous layer of water evaporation layer, a hydrophobic porous layer of MD membrane for vapor permeation, and a water vapor condensation layer. Aluminum nitride (AlN) plate was used as the thermal conduction layer because of its extremely high thermal conductivity (>160Wm−1 K−1) and its anti-corrosion property in salty water. The water evaporation layer and condensation layer were of the same material, a commercial hydrophilic quartz glass fibrous membrane with non-woven fabric structure.In a PV-MD system, the MD component is attached directly to the back of the commercial PV panels and the heat generated by the PV panels flows into the MD component naturally. As the heat flows through the multi-stage MD, the latent heat from the condensation of the steam is collected and reused to drive multiple cycles of water evaporation, resulting in an increase rate of fresh water production[10].

Part of the captured solar energy is converted to electricity (q_e) for PV-MD, depending of the efficiency of the solar cell (η), the rest of the absorbed solar energy is converted to heat (q_h).

Their relation can be described as follows by equation 1,2 and 3

$$q_E = \alpha \times q_s \ldots\ldots\ldots\ldots(1)$$

$$q_r = \eta \times q_E \ldots\ldots\ldots\ldots..(2)$$

$$q_h = q_s - q_r \ldots\ldots\ldots\ldots..(3)$$

where $q_h$solar energy is converted to heat q_S is sunlight intensity and (η)isefficiency of the solar cell .

which is generally in the range of 10–20% scientists Some of the heat energy is directly lost from the top surface of the solar cell by thermal radiation, thermal conduction, and air convection. Because of the extremely low thermal conductivity of air (0.01~0.04 W m^{-1} K^{-1}), thermal radiation is the main pathway, which can be calculated by Stefan–Bolzmann equation:

$$E = \varepsilon\sigma(T_{cell}^4 - T_0^4) \ldots\ldots\ldots\ldots\ldots(4)$$

Where ε is the emissivity of the material, σ is the Stefan–Bolzmann constant, T_{Cell} is the temperature of the material, and T_0 is the temperature of its surroundings

During membrane distillation process the heat loss from the face side slight almost all the heat comes into evaporation layer transfer to condensation layer. Is mainly composed of two pathways. throughthe water evaporation-condensation the heat (Q1) is transferred as covert heat of water vapor in first pathway. The mass transfer proses in this pathway is responsible for clean water production. In the evaporation layer, the rest (Q2)id directly transferred to condensation layer in second pathway without any mass transferee. The heat ultization efficiency (η_{heat}) can be defined as :

$$\eta_{hea} = \frac{Q_1}{Q_2} \quad \ldots\ldots\ldots\ldots.(5)$$

The heat flow of Q1 can be estimated from the clean water production rater for each stage by following equation:

$$Q_1 = m \times L_v$$

Where m is the clean water production rate m and Lv is the latent heat of the water evaporation.

In a typical solar cell, 80–90% of the absorbed solar energy is undesirably converted to heat, and thereafter passively and wastefully dumped into the ambient air32in recent times, scientists have fabricated a PV-MD device that can produce more than 1.60 kgm-2h-1 of clean water ,of PV surface from sea water, while simultaneously generating electricity with an efficiency of more than 11% under Sun irradiation.[10,22]

The global PV installation ability will increase to 887 GW by 2024.Ifall PV panels were retrofitted to be PV-MD by then, there would be 10% more drinking water for the entire world. Also the water quality were produced by PV-MD is generally better than that of conventional drinking water treatment processes[10] .

The beauty of PV-MD is that the water desalination process on the backside of the PV panel does not affect expected electricity generation by PV, achieving simultaneous and efficient generation of electricity and fresh water on the same system. This composite device can significantly reduce costs by sharing the same mounting system and the same land. This strategy provides a potential possibility to convert an electricity generation plant from otherwise a water consumer to clean water producer

CONCLUSION

This review presents the main coupled technologies and the associated key factors for future development for distillation water. Clean energy and clean water are among the major challenges for sustainable development, but producing one of these resources can deplete the other .Desalination is more and more used as a solution to meet the growing water demand in the world, but desalination requires more energy than any other water supply method,6 3.5–8 kWh m^{-3} new technology can solve this challenge by renewable energy (Sunlight). Waste heat generated from photovoltaic solar panels can now be used to generate electricity and purify water simultaneously, according to researchers designed a device which consists of a three-stage membrane distillation unit placed on the back of a panel containing silicon solar cell, the proses of this system , where described in this article.

The process is pretty simple. It includes a stack of water channels separated by porous hydrophobic membranes and heat conduction layers, which are attached to the underside of a commercial PV panel. Waste heat from the panel then vaporizes seawater in the uppermost channel. The device, through the process of evaporation and condensation, purifies seawater into fresh water

The scientists modified a solar panel that not only generated power, but used some of the heat energy to distil and filter sea water. They believe the idea could make a major difference in sunny climates with simultaneous production of electricity and fresh water by photovoltaic-membrane distillation (PV-MD

Reference

1. G. Meerganz von Medeazza, Water desalination as a long-term sustainable solution to alleviate global freshwater scarcity? A North-South approach, Desalination, 169 (2004) 287-301.

2. Y.-D. Kim, K. Thu, S.-H. Choi, Solar-assisted multi-stage vacuum membrane distillation system with heat recovery unit, Desalination, 367 (2015) 161-171.

3. E. Guillén-Burrieza, J. Blanco, G. Zaragoza, D.-C. Alarcón, P. Palenzuela, M. Ibarra, W. Gernjak, Experimental analysis of an air gap membrane distillation solar desalination pilot system, J. Membr. Sci., 379 (2011) 386-396.

4. A. Chafidz, E.D. Kerme, I. Wazeer, Y. Khalid, A. Ajbar, S.M. Al-Zahrani, Design and fabrication of a portable and hybrid solar-powered membrane distillation system, Journal of Cleaner Production, 133 (2016) 631-647.

5. El-Dessouki HT, Ettouney HM. Fundamentals of salt water desalination. Elsevier Science B.V.; 2002.

6. Eltawil MA, Zhengming Z, Yuan L. A review of renewable energy technologies integrated with desalination systems. Renewable and Sustainable Energy Review 2009;13:2245–62.

7. James E. Miller. Review of Water Resources and Desalination Technologies SAND Unlimited Release,2003-0800

8. TamimYounos, Kimberly E. Tulou, Overview of Desalination Techniques, JOURNAL OF CONTEMPORARY WATER

RESEARCH & EDUCATION, ISSUE 132, DECEMBER 2005, PAGES 3-10.

9. Jhon Feria-Díaz, , MaríaLópez-Méndez, Juan Rodríguez-Miranda, Luis Sandoval-Herazo and Felipe Correa-Mahecha, Commercial Thermal Technologies for Desalination of Water from Renewable Energies, January 2021.

10. Wenbin Wang1, Yusuf Shi, Chenlin Zhang, Seunghyun Hong, Le Shi, Jian Chang, Renyuan Li, Yong Jin, ChisiangOng, SifeiZhuo and Peng Wang, Simultaneous production of fresh water and electricity via multistage solar photovoltaic membrane distillation, Abdullah University of Science and Technology, Thuwal 23955-6900, 2020

11. Chang, H., Lyu, S.-G., Tsai, C.-M., Chen, Y.-H., Cheng, T.-W and Chou, Y.-H., Experimental and simulation study of a solar distillation, 400-411, 286,2012. thermal driven membrane distillation desalination process.

12. Cunha, D.P.S.; Gomes, V.V.; Pontes, K.V. Modeling of multi-effect desalination process operated with thermo solar energy applied to the northeastern Brazil. Comput. Aided Chem. Eng. 2019, 46, 1537–1542,

13. TsegahunMekonnenZewdie, NigusGabbiyeHabtu, AbhishekDutta and Bart Van der Bruggen, Solar-assisted membrane technology for water Purification, Journal of Water Reuse and Desalination 2020, in press Paul.

14. Byrne, Laurence Fournaison , Anthony Delahaye, YacineAïtOuméziane , Laurent Serres , Patrick Loulergue , Anthony Szymczik, , et al, A review on the coupling of cooling ,desalination and solar photovoltaic systems, Elsevier 703-717, 2015.

15. A.M.K. El- Ghonemy ,Future sustainable water desalination technologies for the Saudi Arabia, 6566–6597, Elsevier, 2012

16. W. Teplitz-Sembitzky, The Use of Renewable Energies for Seawater Desalination A Brief Assessment, Technical Information W16e,2000

17. Ali Abbas, M. and Al-Karaghouli (Al-Qaraghuli), Renewable energy applications in water desalination. In 56th Annual New Mexico Water Conference, 2011, pp. 79–87.\

18. Garcia-Rodriguez, L., Sea water desalination driven by renewable energies: a review. *Desalination*, 2002, **143**, 103–l13

19. Nassrullah, H.; Anis, S.F.; Hashaikeh, R.; Hilal, N. Energy for desalination: A state of the art review. Desalination 2020, 491, 114569, 1-44, doi:10.1016/j.desal.2020.114569

20. Walsh, B.P.; Murray, S.N.; O'Sullivan, D.T.J. The water energy nexus, an ISO50001 water case study and the need for a water value system. *Water Resour. Ind.* **2015**, *10*, 15–28.

21. World Business Council on Sustainable Development, WBCSD. *Water, Energy, and Climate Change, A Contribution from the Business Community*; AtarRotoPresse SA: Switzerland, 2009

22. Zhu, L.; Gao, M.; Peh, C. K. N.; Wang, X.; Ho, G. W., Self-Contained Monolithic Carbon Sponges for Solar-Driven Interfacial Water Evaporation Distillation and Electricity Generation. Advanced Energy Materials 2018, 8 (16), 1702149