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Previews

Using the sun to co-generate electricity and freshwater

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As an abundant and ubiquitous energy source, solar energy has successfully demonstrated its potential in tackling the water-energy dilemma in an eco-friendly way. In this issue of *Joule*, Wenbin and co-authors creatively propose the co-generation of electricity and freshwater via an integrated PV-membrane distillation system.

The interdependence of water and energy has significant implications for their mutual accessibility and security. However, water and energy technologies are currently independent of each other. Therefore, it is essential to shift the focus toward finding synergistic, integrated solutions that will lead to more efficient outcomes. To reach a sustainable water-energy nexus, solar radiation as an energy source is anticipated to meet the exponentially growing human needs. To put things in perspective, 1 hour of solar energy exceeds the energy consumed on Earth in a year.

In an increasingly water-scarce world, desalination plays a pivotal role in tackling the water crisis because seawater is the dominant water source on the Earth. However, the conventional reverse osmosis (RO) water desalination process is energy intensive and has low seawater recovery because of brine concentration issues and the limited osmotic pressure that can be applied.[1] Membrane distillation (MD), on the other hand, solves the prevalent RO issues, such as low operating pressure and high-concentration brine treatment, and results in a better recovery factor.[2] However, MD is affected by the temperature polarization issue and the high electricity cost needed for heating. The marriage of mature MD technology and the emerging photothermal distillation (PD) technology results in sustainable photothermal membrane distillation (PMD). PMD helps to tackle some of the remaining issues facing desalination because it uses sunlight to achieve localized heating at the membrane feedwater interface and electricity-free means to produce freshwater.[3] Combining the thermally driven processes and mature knowledge makes up for the shortcomings of a single approach.

Besides water, electricity is also the cornerstone of modern society. However, existing electric power production faces a discrepancy between supply and demand. Although fossil-fuel-derived electric power has been used for more than a century, there are growing security and environmental risks associated with consuming nonrenewable fossil fuels and emitting global warming inducing pollution. Photovoltaics (PV) use sunlight as the sole energy source and distinguish themselves from other energy systems with their low carbon footprint, technological maturity, and low barrier of entry.[4] Because of the economic benefit and favorable regulatory policies, PV is predicted to gain an increasing share of the energy market. Although promising, insufficient sunlight-to-electricity conversion efficiencies hamper its progress. When irradiated, short-wavelength (above-bandgap) photons are captured by the semiconductor cell and converted into electricity. Meanwhile, the long-wavelength (below-bandgap) photons are converted into heat, which accounts for more than 70% of the total absorbed solar energy. Inevitably, the PV panel is heated up, and the increased panel temperature is detrimental to the PV performance, causing nearly 0.5% energy efficiency loss for each degree rise in temperature.[5] Worse still, it also accelerates the panel aging rate. Furthermore, the undesired heat consequences are compounded by the possibility of large-scale solar plant installations increasing the local temperatures, resulting in the PV urban heat island effect. The concerns of the temperature influences on PV performance and the environment have motivated industry and academia to explore optimal panel cooling strategies.

Given that semiconducting PV cells waste the long-wavelength photons and that short wavelength photons are overqualified to be converted into heat for photothermal applications, it is rational to tailor spectrum-designated solar capturing system. Notably, integrating PV and PMD is instrumental in bridging these waveband gaps to fully exploit the whole solar spectrum. With a hybrid strategy, high-energy photons are selectively utilized for the PV cell, whereas the other low-energy photons are reclaimed into thermal energy to be used for desalinating process, as shown in Figure 1. It is worth noting that the desalination process not only produces freshwater, but also provides PV panels with much-needed cooling. Thereby, in a simple yet effective way, the dilemma of energy and water demands is tackled with a minimal carbon and land footprint. Although some ingenious prototypes

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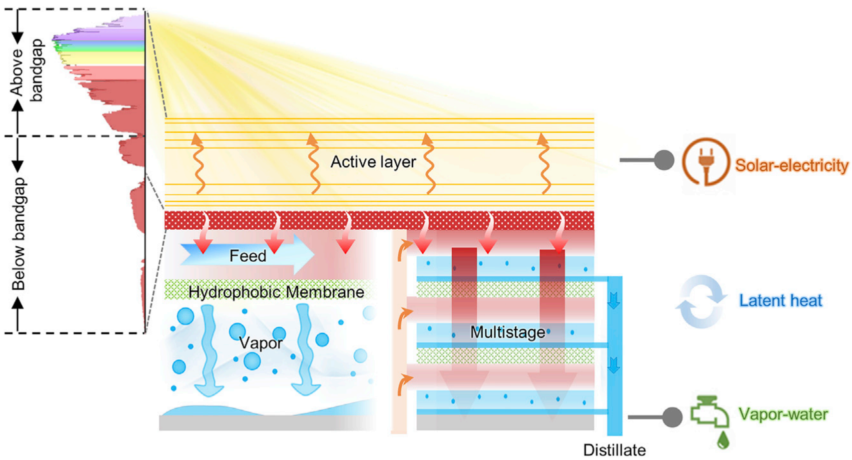

Figure 1. Schematic illustration for selective utilization of the whole solar spectrum

have been proposed,[6,7] higher energy efficiency is still being developed.

To concurrently improve the PV performance and freshwater production, an optimized hybrid system that integrates multi-stage MD and PV cells is proposed by Wang and co-authors.[8] The silicon PV cell is mounted on top of the distiller to capture and filter the high-energy photons, whereas the rest are used to heat the feedwater in the distiller underneath. Compared with previous hybrid PV and distiller systems, an optimized cross-flow multi-stage membrane distiller is used to improve the latent heat recycling. Thus, the waste heat from the solar cell is efficiently removed and conducted downward stage by stage to produce freshwater. Based on the model simulation, hydrophobic membranes with optimized morphology factors (including thickness, porosity, and pore size) are adopted and these factors refine the thermal management in the system. Optimized membranes and number of stages have struck a good balance between the vapor and heat transport, leading to a much higher freshwater yield, even when the PV cell has filtered the light. Moreover, an evaporative crystallizer is installed at the last condensing layer to achieve zero liquid discharge and to serve as a passive heat sink of the system. In addition to the almost doubled freshwater yield, the multi-stage heat recycling efficiently removes the heat of the cell panel, lowering it by 10°C, which results in higher electricity output. The work has also been verified at real-world conditions, undoubtedly proving the practical significance of this integrated water-energy technology.

Benefitting from the low barrier to entry, both in cost and technique, integrated solar-driven PV and PMD will have extensive and far-reaching effect in the water-energy nexus. There is a tremendous potential for bypassing the traditional stages of development straight into emerging technologies with untapped opportunities such as water coupled solar driven ionvoltaic, thermogalvanic, pyroelectric, etc.[9] For example, a promising reverse electrodialysis membrane technology is shown to capture a huge unexploited salinity-gradient energy of 980 GW at river mouths where seawater and freshwater intersect.[10] The bottleneck lies in the high-cost ion-exchange membranes. However, it is believed that if integrated with the newly developed photothermal interfacial evaporation and widely deployed MD, the cost will be reduced sharply because of the technology innovation and economies of scale. This will have a significant potential to synergistically produce water and electricity cost-effectively. Most of these novel water energy sustainable systems are at the research and development stage. Nevertheless, we should continuously innovate to keep pace with ever rising demand and deteriorating climate.

Looking ahead to the near future, the water energy co-generation concept will likely become widespread. It is opportune to identify the remaining challenges and to move toward widespread water energy systems distributed in either off-grid or built environment. A decentralized system can help municipalities adapt with greater flexibility to meet local needs so as to foster self-sufficient and resilient communities. That said, adoption requires not only efficient use of all vital resources but also coordinated policy and government efforts to maximize gain and minimize negative effects.

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1. Lee, K.P., Arnot, T.C., and Mattia, D. (2011). A review of reverse osmosis membrane materials for desalination—Development to date and future potential. J. Membr. Sci. *370*, 1–22.
2. Abu-Zeid, M.A.E.-R., Zhang, Y., Dong, H., Zhang, L., Chen, H.-L., and Hou, L. (2015). A comprehensive review of vacuum membrane distillation technique. Desalination *356*, 1–14.
3. Gao, M., Peh, C.K., Meng, F.L., and Ho, G.W. (2021). Photothermal Membrane Distillation toward Solar Water Production. Small Methods *5*, 2001200.
4. Nugent, D., and Sovacool, B.K. (2014). Assessing the lifecycle greenhouse gas emissions from solar PV and wind energy: A critical meta-survey. Energy Policy *65*, 229–244.
5. Hasanuzzaman, M., Malek, A.B.M.A., Islam, M.M., Pandey, A.K., and Rahim, N.A. (2016). Global advancement of cooling technologies for PV systems: A review. Sol. Energy *137*, 25–45.

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6. Xu, N., Zhu, P., Sheng, Y., Zhou, L., Li, X., Tan, H., Zhu, S., and Zhu, J. (2020). Synergistic Tandem Solar Electricity-Water Generators. Joule 4, 347–358.

7. Li, R., Shi, Y., Wu, M., Hong, S., and Wang, P. (2020). Photovoltaic panel cooling by atmospheric water sorption–evaporation cycle. Nat. Sustain. 3, 636–643.

8. Wang, W., Aleid, S., Shi, Y., Zhang, C., Li, R., Wu, M., Zhuo, S., and Wang, P. (2021). Integrated solar-driven PV cooling and seawater desalination with zero liquid discharge. Joule 7, 1873–1877. https://doi.org/10.1016/j.joule.2021.05.010.

9. Ding, T., Zhou, Y., Ong, W.L., and Ho, G.W. (2021). Hybrid solar-driven interfacial evaporation systems: Beyond water production towards high solar energy utilization. Mater. Today 42, 178–191.

10. Logan, B.E., and Elimelech, M. (2012). Membrane-based processes for sustainable power generation using water. Nature 488, 313–319.

Global 100% energy transition by 2050: A fiction in developing economies?

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Recently, Bogdanov et al. provided a global 100% energy transition pathway by 2050. Although this pathway seems feasible judging by the appreciable progress in renewable energy generation in most developed economies each year, one wonders how realistic this pathway is for developing economies given the capital investment needed.

The substantial growth in renewable energy (RE) development in recent years coupled with advances in battery energy storage systems (BESS) has led to several analysis and projections of 100% global energy transition scenarios. Recently Bogdanov et al.,[1] and others such as Hansen et al.,[2] have provided excellent projections on the possibility of the world achieving a 100% RE system by 2050. These projections seem feasible judging by the appreciable progress in RE generation, especially from solar and wind technologies by countries such as the US, China, and several EU countries each year.[3] However, juxtaposing these projections with RE installation capacity in developing economies, one wonders how realistic these projections are for developing economies. For instance, Africa accounted for only 1.27% of the global installed solar capacity of 586,434 MW in 2019, and of this, 4 (i.e., South Africa, Egypt, Morocco, and Algeria) out of the 54 countries in Africa accounted for 80%. In Asia, out of the total of 330,786 MW, 4 out of 23 countries accounted for 94.6% of the installed capacity.[3] In the case of the 622,704 MW of global installed wind capacity in 2019, Africa accounted for only 0.93%, with 3 countries (South Africa, Egypt, and Morocco) alone accounting for more than 81% of the figure. In Asia, out of the total of 258,323 MW, 4 countries alone accounted for 98% of the installed capacity.[3] Given that in the case of climate change, one person's action affects all, this lack of progress in energy transition in most developing economies is worrisome, and therefore a global solution that can help bridge the gap must be found.

There is a lack of research on the issues and challenges facing developing economies and the realistic energy transition options for them. It should be understood that the behavior of developing economies in relation to energy planning is rooted in the theory of scarcity, which proposes that lack of financial resources induces a scarcity mindset, which in turn forces the less privileged into suboptimal decisions and behaviors.[4] Of greater importance, yet hardly given attention in most energy transition pathways, is a country's ability to raise the needed finances to acquire its energy generation capacity. This financial figure is different from the financial assumptions on energy technologies as presented, for instance, in Bogdanov et al.[1] Rather, and as presented in Afful-Dadzie et al.,[5] it is an explicit constraint that places a limit on how much generation capacity a country can acquire. Developed economies largely ignore this financial constraint in their energy planning analysis on the implicit assumption that the investment capital needed can be sourced no matter the scale and size of the project. This allows developed economies to make energy planning decisions based on the so-called Levelized Cost of Electricity (LCOE), an economic measure used to compare the lifetime costs of electricity generation across various technologies.

On the other hand, most developing economies face increasing energy demand and struggle to raise investment capital. As a result, they perform energy planning with emphasis on acquiring as

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