SOLAR HEATING & COOLING PROGRAMME
INTERNATIONAL ENERGY AGENCY

Technology Position Paper

Solar Energy for Industrial Water and Wastewater Management

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Technology Collaboration Programme by iea

Contents

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This position paper provides an overview of the solar energy market for industrial water and wastewater management, outlining its importance, potential, and development of this new application area. It addresses issues for policy and decision makers and influencers and presents high-level information as a basis for the uptake and further development of these applications. It concludes by highlighting existing challenges and the actions needed to best exploit environmentally friendly technologies for water management and recovery of valuable substances.

1 Introduction and Relevance

Water resources are finite, and sustainably managing them is a critical challenge for industry and the worldwide economy. Massive amounts of complex wastewater streams are generated. For example, in EU member states, industrial wastewater is reported to be 29 liters per capita[1], with only 18 liters per capita[1] being treated. Efforts to minimize wastewater flows through legislation and regulation of wastewater volumes and concentrations are intended to counteract this trend. To meet volume and concentration targets, the need to install new technologies for wastewater treatment is naturally also increasing the energy requirements for wastewater treatment, creating tension and interdependence within the Energy-Water-Nexus.

Within industry's transition to a circular economy, sustainable wastewater treatment and recovery should be reached without excessive pressure on limited energy supplies and by decreasing fossil energy consumption. The efficient supply of energy, the best possible integration of renewable energy sources, and the recovery of resources in a circular economy must go hand in hand. Within this background, solar process heat represents a vast but largely untapped potential for industry. Innovative and concrete solutions are required for solar energy's long-term and successful introduction. Integrating solar heat and solar photons to supply water treatment and purification technologies represents a new field of application with significant technical and economic potential for solar energy. The efficient interaction, the nexus between solar energy, industry, and water, opens up new and innovative approaches to solutions, which have been elaborated within the framework of the International Energy Agency's Solar Heating and Cooling Task 62 (IEA SHC Task 62).

2 Current Status

In many regions worldwide, water is already a scarce good. Even in central Europe, decreasing water tables and mismatching extraction and refill ratios lead to water shortage during specific periods of the year, severely impacting industry, agriculture, and nature. Ground and surface water pollution through wastewater disposal (households, industry and agriculture) have a severe environmental impact with short- and long-term implications on flora, fauna, and human health. On the other hand, wastewater and process fluids can be considered a source of valuable materials and must become an essential part of sustainable circular economy approaches.

[1] *Alabaster et. Al. (2021): Progress on Wastewater Treatment, UN-Habitat and WHO, ISBN 978-92-1-132878-3.*

Therefore, environmentally friendly technologies for water and recovery of valuable substances in combination with renewable energy supply need to be developed.

Status quo on water treatment technologies

Water treatment technologies are already available on the market for different application targets.

Distillation (evaporation of water) technologies include:

- multi-stage flash distillation (MSF),
- multi-effect distillation (MED), and
- humidification dehumidification (HDH).

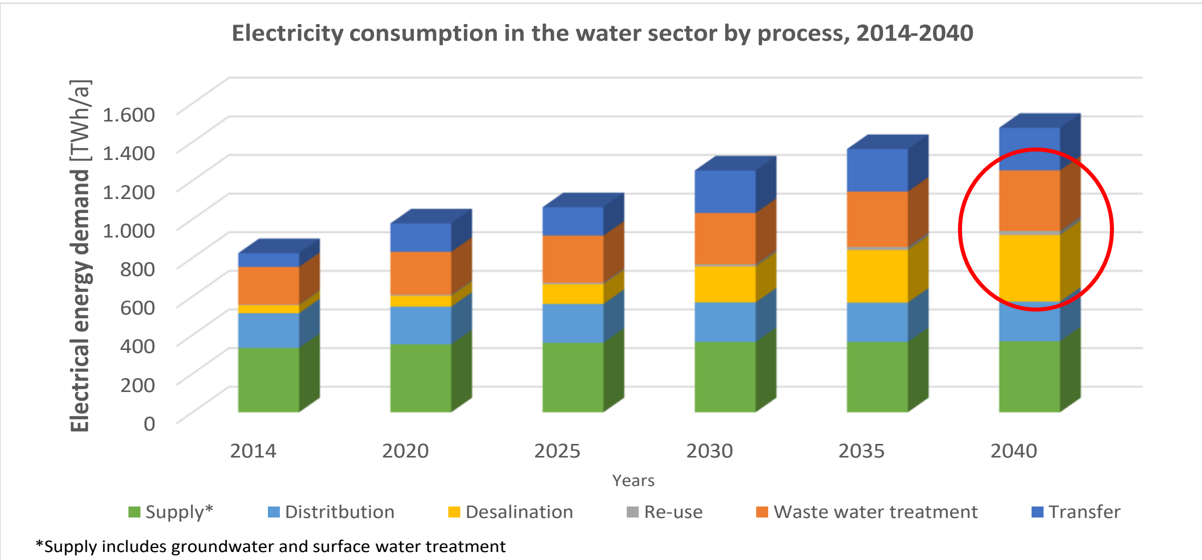
Separation and filtration processes based on membranes include:

- pressure-driven processes like reverse osmosis (RO) and Ultra-, Nano-, Microfiltration (UF, NF, MF),
- electrically driven processes like electrodialysis (ED),
- concentration-driven processes like diffusion dialysis (DD), pervaporation, and
- thermally driven processes like membrane distillation (MD).

Regarding **decontamination and disinfection systems**, advanced oxidation processes (AOPs) for degrading contaminants in wastewater are available. Examples are photocatalysis or Photo-Fenton processes.

Energy demand for water and wastewater treatment - forecast

The forecast for the energy demand of water treatment by 2040 shows that the energy use for the water sector will increase tremendously compared to 2020 and will be ~1,470 TWh[2].



[2] *International Energy Agency (2016: https://www.iea.org/reports/water-energy-nexus)*

Figure 1. Forecast electricity consumption in the water sector (2014-2040).[2]

By comparing this to the world's final energy demand forecast in the industry for 2040, the water sectors make up around 1% of the total demand. A significant part of the energy demand for water treatment will be needed for wastewater treatment (22%, orange)[2] and desalination (24%; yellow) [2] in the form of electricity. Overall, forecasts show that the global electricity consumption for wastewater collection and treatment requires over 40% more energy in 2040 compared to 2014[2].

3 Potential

Forecasts show that, especially for wastewater treatment and desalination, electricity will be the predominant energy source, which affects, even more, the already advancing electrification of the energy system and the strain on the electrical energy power supply infrastructure. If only 10% of the electricity demand for treatment and desalination of wastewater forecasted by 2040 will be covered by solar-treated technologies (solar thermal and solar photons), a considerable reduction of around 68 TWh can be realized. As a result, a total reduction of 18.7 MT of CO_2 can be achieved (calculated with the average EU CO_2 emissions of 275 g/kWh [3] in 2021).

Potential technologies for solar supply

Solar thermal energy is currently used in the industrial sector mainly to supply production processes with solar process heat. The thermal utilization of solar energy can be done with active or passive systems. For industrial processes, active systems are mainly used. The basic principle of active solar thermal heat utilization is the conversion of short-wave solar radiation into heat (photo-thermic conversion) by absorbing the solar radiation with a suitable collector. State-of-the-art collector types can be classified according to the heat transfer medium (liquid or air) and how they absorb radiation (concentrating or non-concentrating). Concentrating systems use beam radiation with one or two-axis tracking. Standard collectors are non-concentrating flat plate collectors with a liquid as a heat transfer medium, using an absorber with an anti-reflective cover. They are typically used for temperature levels until 100 °C or slightly above. Evacuated tube collectors achieve higher temperatures than flat plate collectors and are also commonly used in industry. Applications for solar supply offer a high potential for different **technologies**. In terms of solar thermal supply, membrane or evaporation technologies provide great potential for industrial integration. Solar photons could be used mainly for Advanced Oxidation Processes (AOPs). An overview is given in Figure 2.

[3] *Data downloaded at:* *https://de.statista.com/statistik/daten/studie/1009521/umfrage/co2-emissionen-durch-stromerzeugung-in-der-eu/*

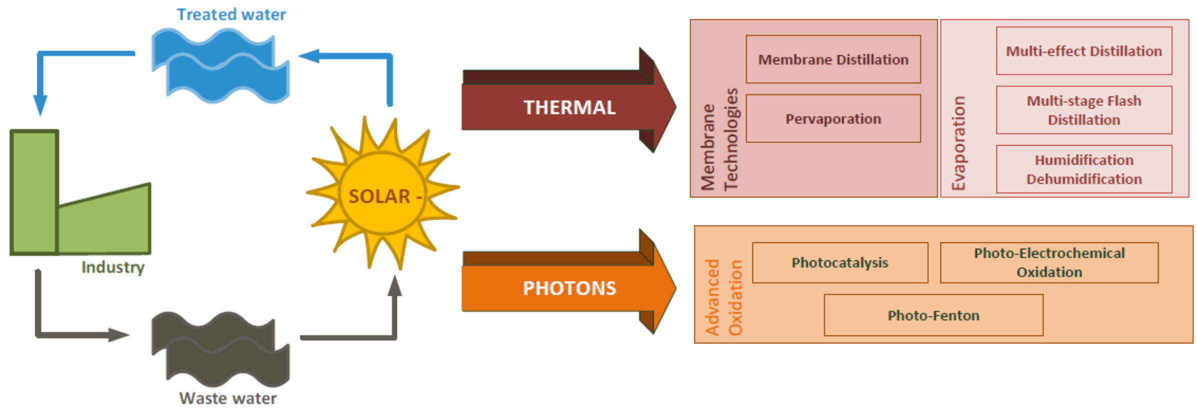


Figure 2. Overview: Technologies potentially being supplied by solar thermal energy or solar photons (AEE INTEC)

Potential applications in industry

Several specific industry sectors have a high demand for integrating wastewater treatment technologies in different application areas. Some general application areas are shown in Figure 3.

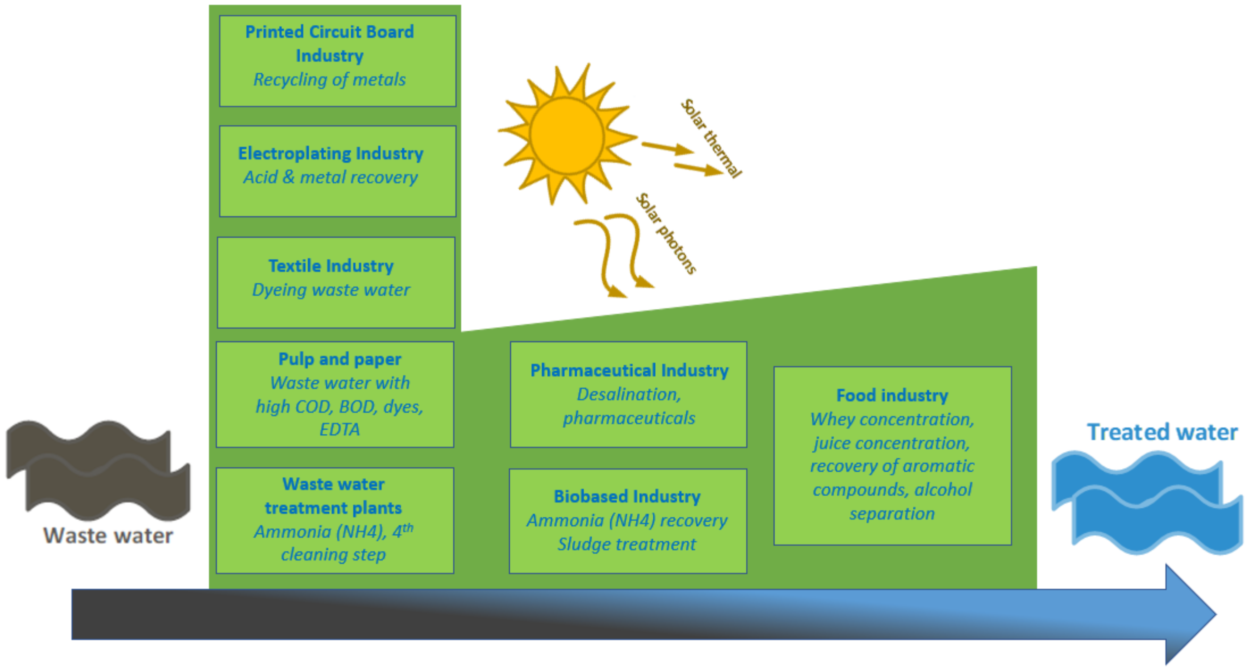


Figure 3. Applications in various industrial sectors for solar water treatment (AEE INTEC)

4 Actions Needed

Demonstration and upscaling of solar-driven water treatment: Using separation technologies such as membrane distillation in combination with solar process heat represents an innovative leap in the industry. The technical and economic potential assessment for using solar-driven water treatment sets the course for further research and development projects in the most significant industrial sectors and municipal wastewater treatment, but also for usage in rural areas (e.g., Africa) for applications like drinking water production. Follow-up projects for the demonstration of solar supply and separation technologies for wastewater are needed to increase awareness experience and expertise to realize the identified potential and support the required research and development.

New materials and coatings: Need for further improvement, especially in terms of long-term stability and efficient use of membrane technologies for industrial applications present. Especially for MD, there is a high need for research in this field, among others, to minimize fouling in organically loaded water streams and increase their selectivity, durability, and chemical stability.

Development of innovative collector concepts: Solar reactor concepts, where solar supply and processes are merged in one collector, must be developed. Current obstacles to solar integration are complex systems, many components, losses along the supply chain, low efficiencies, and high system costs. The transition to an intensified and combined entity represents a leap in innovation in solar process supply for industrial processes. For the solar industry, bringing such new products to the market is possible but requires significant effort.

Increase the demonstration of new decontamination and disinfection system using solar photons: In addition to thermal technologies, decontamination and disinfection processes are paramount in wastewater treatment. Developing new decontamination and disinfection systems using solar photons must gain significant attention and visibility as a promising solution for achieving effective and sustainable disinfection. Further, the simultaneous harnessing of heat and UV light in one technology (solar reactor) would represent a leap forward in innovation compared to the state-of-the-art.

New energy vectors: Producing new energy vectors (hydrogen from wastewater, reducing carbon dioxide to, e.g., methanol) via sunlight-based photo reforming (e.g., photocatalysis) offers an enormous potential to revolutionize the energy sector, providing a clean and sustainable energy source for various applications. However, many challenges remain to overcome, such as improving the efficiency and scalability of the energy conversion processes and reducing the costs associated with producing and distributing solar fuels.

Challenge	Action needed	Action by whom
Lack of awareness and experience of solar-driven water and wastewater systems	Support **solar water treatment in industry**. Increase support for **demonstration projects**.	National & international policy makers, R&D community
Long-term experience, stability, selectivity	Support the development of **components** (like membranes) to increase efficiency.	R&D community, national & international policy makers, technology providers
System integration, high complexity of systems, challenging integration	Combine collector and process in **one unit**. Develop emerging **solar reactor concepts.**	System engineers and technology providers, R&D community
Lack of knowledge of solar disinfection and decontamination systems	Create **tailor-made funding** schemes.	National & international policy makers, R&D community
Technological challenges - efficient technologies for creating new energy vectors	Increase **visibility** for new technologies and create new energy vectors.	R&D community, technology providers