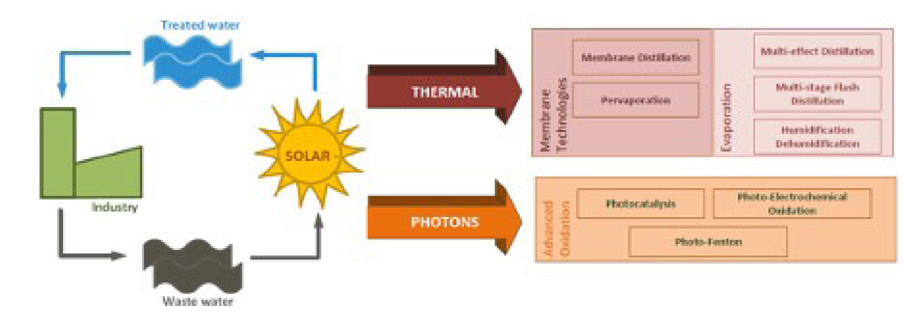
Solar Energy's Potential for Water and Wastewater Treatment

Within the industry's transition to a circular economy, sustainable wastewater treatment and recovery should be reached without excessive strain 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. Experts from 14 countries analyzed the potential for solar heat and photons for wastewater treatment in industry and municipal wastewater treatment. This article highlights the most promising outcomes.

Eighty percent of the world's energy needs are met by fossil fuels. In addition to renewable energy supply, wastewater purification is also a significant issue globally due to regional water shortages and in water-rich industrialized nations due to the explosive nature of microplastics and poorly degradable trace substances. After all, industry accounts for 20% of global water use. The value of water as a resource is made clear by the fact that water represents a closed cycle on Earth. And the potential of solar energy is highlighted by the fact that a thousand times the world's energy requirement hits the earth via solar radiation. Against this backdrop, solar energy represents an enormous but largely untapped potential in industrial wastewater treatment. The efficient interaction – the nexus between solar energy and water – offers new and innovative approaches and was the focus of the work in the IEA SHC Task on Solar Energy in Industrial Water and Wastewater Management (IEA SHC Task 62).

New Technologies and Application Areas: Nexus Energy & Water

Within IEA SHC Task 62, a network of experts addressed the opportunities, challenges, and benefits of integrating solar energy (solar thermal, photons) in the treatment of wastewater in an industrial context. The main objective was to increase the use of solar energy in industry, develop new collector technologies, and demonstrate industrial and municipal water treatment as a new application area with high market potential for solar energy. The nexus between solar energy, water treatment and industry enables the development of innovative technology combinations for a more sustainable, resource and energy-efficient industry.



▲ **Figure 1. Overview of technologies potentially being supplied by solar thermal energy or solar photons.** (Source: AEE INTEC)

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

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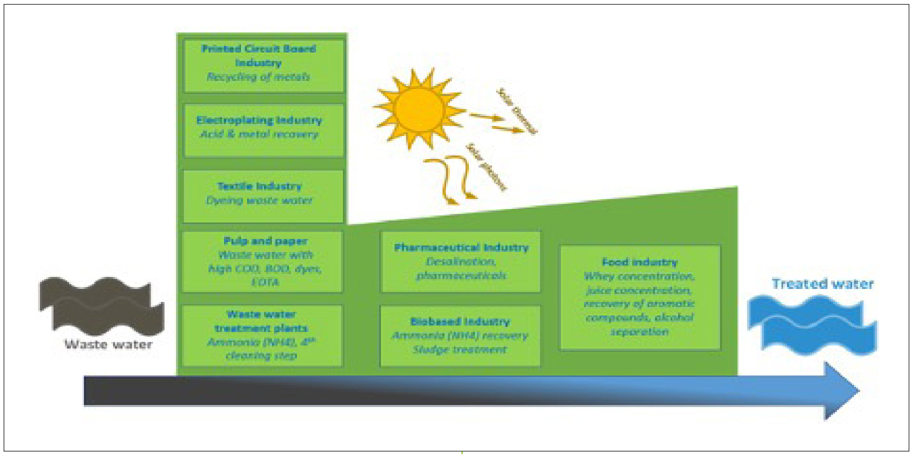
- pressure-driven processes like reverse osmosis (RO) and Ultra-, Nano-, Microfiltration (UF, NF, MF),
- electrically driven processes like electrodialysis (ED),
- concentration-driven processes like diffusion dialysis (DD), pervaporation and
- thermally driven processes like membrane distillation (MD).



▲ **Figure 2. Applications in various industrial sectors for solar water treatment.** (Source: AEE INTEC)

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

Among these technologies, thermally driven membrane and evaporative technologies, in particular, show high solar thermal energy potential, while solar photons are interesting for use in advanced oxidation processes (see Figure 1).

To better understand the current market, the Task participants conducted a market study. The results showed that solar-driven technologies (via solar thermal and photons) are available, but mainly on a low TRL 3 level (tested at laboratory scale), with only a few technologies at a TRL 8 level (available on the market) and even fewer in operation.

Potential of Thermal Water Treatment and Recovery of Valuable Materials

One research focus area of the Task was the combination of solar thermal collectors with technologies for wastewater treatment. This work aimed to create an innovative and, above all, economically attractive solution for industry. Using thermally driven separation technologies, such as membrane distillation in combination with solar process heat, is a promising alternative to conventional electrically driven separation technologies (e.g., micro-, ultra-, nanofiltration, reverse osmosis).

Another project area was solar-powered water treatment. Task experts worked on new applications and defined research and development issues. Figure 2 shows the potential application areas for industrial solar wastewater treatment.

A Task highlight is the work on membrane distillation (MD) for ammonium recovery in wastewater. Along with the research group, Water and Process Technologies, at AEE INTEC in Austria, which has been researching this application for several years, a pilot plant operating 24/7 at a municipal wastewater treatment plant was realized. Because temperatures of 35°C to 40°C are required on the evaporation side of the MD plant, this application is perfectly suitable for solar energy.

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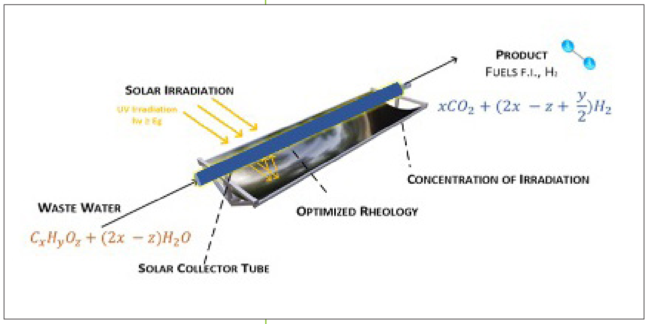
Great Potential for Solar Waster Decontamination and Disinfection via New Solar Concepts

In addition to thermal technologies, SHC Task 62 analyzed technologies that use direct radiation (UV/VIS) in solar water decontamination and disinfection systems. Task experts identified new industrial applications and summarized the technical, economic, and policy barriers to new application areas to facilitate their integration and increase the number of applications. An example of a research project is the Austrian "Solar Reactor," funded by the Climate and Energy Fund under the 7th Call for Proposals for Energy Research in Austria. This solar reactor aims to convert water into hydrogen (H^2) in an efficient photo-electrochemical process while treating wastewater by directly utilizing solar radiation. Through a multidisciplinary approach, the development of the reactor combines competencies from solar collector development, efficient reactor systems, photo-electrochemical material research, wastewater chemistry, and the innovative production of alternative fuels such as H^2. The concept is shown in Figure 3.



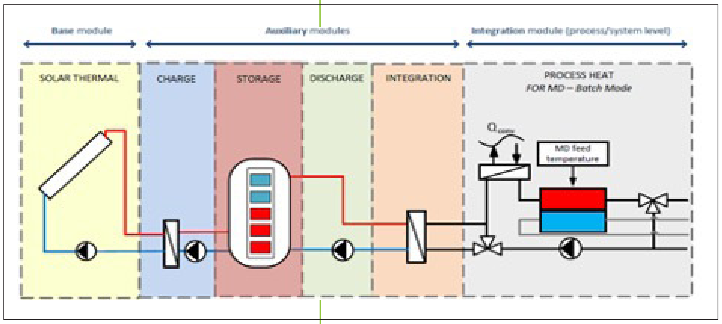
▲ **Figure 3. Concept of the "Solar Reactor." (Source: AEE INTEC)**

Concepts like this are helping to overcome current solar integration obstacles, such as complex systems, numerous components, losses along the supply chain, low efficiencies, and high system costs.

The transition to an intensified and combined unit is a leap in innovation in solar process supply for industrial processes and opens new market potential.

Guidance in System Integration and Decision Making

To deliver system integration and decision support for end-user needs within the Nexus of Energy & Water, SHC Task 62 elaborated on system integration concepts on 1) how solar thermal energy can be integrated in combination with thermal separation technologies like Membrane Distillation (MD) and 2) can provide the thermal energy demand in a renewable way. The integration concepts are modular. Each concept has at least one base module for the renewable process heat supply, like solar thermal (illustrated in Figure 4) or a heat pump. Also, the possibility of waste heat integration is available.



▲ **Figure 4. Example of an integration concept combining solar thermal for the process heat supply of Membrane Distillation.**

The developed concepts for the integration of solar energy into wastewater treatment are available for stakeholders (industrial companies, plant planners, technology providers, etc.) in a decision-making tool to support detailed planning of overall systems (further combination with waste heat, combination with other renewable energies such as heat pumps, etc.). This tool helps users to overcome implementation obstacles due to a lack of user know-how and facilitates the market penetration of solar separation technologies.

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Conclusion

The work within SHC Task 62 shows solar energy's great potential in wastewater treatment. Nevertheless, there is still the need to take further action.

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 use in rural areas (e.g., Africa) for applications like drinking water production. With an overview of the identified potentials and research and development needs, follow-up projects for the demonstration of solar supply and separation technologies for wastewater are required to increase awareness and experiences.

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) represents a leap forward in innovation compared to the state-of-the-art.

An important application area for solar reactors is the production of new energy vectors (e.g., hydrogen from wastewater, reducing carbon dioxide to methanol and other fuels). Sunlight-based photo reforming (e.g., photocatalysis) shows great 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.

The good news is that the SHC Programme is starting a new Task on energy sources from solar-powered reactors. To learn more, see the sidebar "New Task Under Development."

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