Developing and demonstrating innovative solutions for renewable and waste heat-driven cooling technologies in industries: the RE-WITCH project

Christian SCHWEIGLER[1], Felix ZIEGLER[2], Walter MITTELBACH[3], Matteo CALÒ[3,8], Andrea BAELZ[4], Stefan PETERSEN[5], José Luis CORRALES[6], Maider EPELDE[6], Salvatore VASTA[7], Alessio SAPIENZA[7], Andrea FRAZZICA[7]

[1]Hochschule München Munich (Germany)
[2]Technische Universität Berlin Berlin (Germany)
[3]Sorption Technologies GmbH Freiburg, (Germany)
[4]BS Nova Apparatebau GmbH Siegen (Germany)
[5]Factor4Solutions GmbH Berlin (Germany)
[6]Tecnalia Research & Innovation Derio (Spain)
[7]CNR ITAE Messina (Italy)
[8]Politecnico di Torino, Department of Energy Turin (Italy)

Abstract

The present work introduces a research project funded by the European Commission under the Horizon Europe program, focusing on the development and demonstration of innovative cooling technologies for industrial applications, which can be driven by low-grade waste heat and solar thermal collectors. Aiming at increased compactness and reduced cost, an adsorption chiller based on a novel internal cycle configuration will be developed. For simultaneous heating and cooling with increased temperature lift and for supply of cooling at two separate temperature levels, advanced absorption chiller concepts will be applied, based on a hybrid absorption/compression cycle and a twin evaporator/absorber configuration, respectively.

Keywords: absorption, adsorption, industrial cooling, solar thermal, waste heat

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1. Introduction

In 2022, the industrial sector in the EU was responsible for 25.1% of the final energy consumption, which totalled 10,900 TWh. This energy demand was primarily met by electricity (33.3%) and fossil fuels (48.4%), leading to a significant dependence on these resources, most of which are imported from non-EU countries (Eurostat, 2022). Approximately 150 TWh/year of electricity is consumed for process cooling, particularly in industries such as food and beverage, tobacco, and light chemicals, where cooling can account for up to 50% of a company’s total electricity consumption (Rehfeldt, 2016). The market is largely dominated by electricity-powered vapour compression chillers due to their commercial availability and reliability, which restricts the adoption of thermally driven technologies to a niche segment. However, there is about 300 TWh/year of technically available waste heat from industrial processes in the EU, with roughly 35% classified as low-grade waste heat (below 200°C). Additionally, direct solar heating (SHIP) is becoming more attractive for its sustainability, technical, and economic benefits, although it is not yet widely implemented (Kumar, 2019).
Under the “Climate, Energy and Mobility” component of the Horizon Europe programme, a consortium of 27 partners is collaborating on the RE-WITCH project (“Renewable and Waste Heat Valorisation in Industries via Technologies for Cooling Production and Energy Harvesting”) to develop and demonstrate innovative thermally-driven cooling and heating technologies for industrial processes. This includes introducing a next-generation adsorption chiller based on a novel internal cycle and component design. Advanced absorption chiller concepts, which use a hybrid absorption/compression cycle and a twin evaporator/absorber configuration, will be applied for simultaneous heating and cooling with increased temperature lift and cooling supply at two separate temperature levels. These thermally activated cooling systems will be powered by low-

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grade (<100°C) waste heat from industrial processes or high-efficiency solar thermal collectors, providing both process cooling and useful heat for industrial operations.
The project involves analyzing typical applications in key industrial sectors such as food and beverage or pharmaceuticals and conducting detailed modelling of industrial processes with integrated thermal cooling systems for optimized techno-economic integration. The performance of these thermally driven cooling systems will be evaluated and demonstrated in four real installations across Europe in the following settings:

- A brewery located in Poland. In this case, the cooling demand is related to the need to cool down the wort from 98 °C to 8 °C, for the fermentation process. This is accomplished through two two-stage cooling process, using an ammonia vapour compression chiller, with a total capacity of 200 kW. The demonstration campaign will be based on the waste heat recovery from wastewater around 80°C, to drive the innovative adsorption chiller with an installed cooling capacity of 200 kW, to provide cooling down to 5°C. Moreover, a solar collector field with a heating capacity in the range of 50-70 kW will be integrated, to provide up to 100°C to the process and to complement the driving heat for the cooling provision. The demonstrative system is expected to work in parallel with the existing cooling facilities in order to provide energy saving service: preliminary estimations foresee an electricity saving of up to 64 MWh with 800 production cycles per year.
- A dairy industry located in Spain. The portion of the plant interested in the RE-WITCH system integration has on average a cooling demand ranging from 700 to 1500 kW, at temperatures between -6 and 0 °C, with a total electric consumption of 24 GWh/y. At the same time, there is a need for heating, for cleaning at 60°C, with a yearly energy demand of 6.8 GWh. The installation will aim to demonstrate the partial replacement of the existing technology with the innovative hybrid absorption cooling and heating device. A solar field of 80-100 m2 solar collectors will be integrated with renewable heat from the biomass plant to provide up to 110°C and 50-160 kW, to drive the hybrid absorption/compression heat pump with a peak cooling capacity of around 100 kW, providing cooling down to 3°C (in parallel to the existing ammonia chillers) and up to 250 kW of process heating at 60°C. The proposed integration shall be able to save up to 90 MWh/y electric and 830 MWh/y natural gas, with associated 225 t/year of CO2 emissions saved.
- A bio-refinery located in Greece. The cooling demand is at two different temperature levels, namely, 10 °C for process cooling and 20 °C to maintain the digester temperature during hot days in summer. For this reason, the demonstration campaign will integrate an absorption chiller being able to provide both temperature levels at the same time. The system will exploit waste heat recovery from CHP around 99°C, to drive a dual evaporator/absorber chiller, 40 kWc at 10°C and up to 400 kWc at 20/25°C in parallel. Around 30 kWth of solar collectors will be integrated to provide up to 99 °C to the process and to complement the driving heat for the cooling provision Moreover, when there is excess cooling production, this will be used in the post-digester to improve its performance. The system implementation aims to provide up to 3.5 GWh/y of cooling and increase plant productivity by 5-10% by maintaining the optimal digester's temperature.
- The integration of an air compressor and adsorption chiller system in a pharmaceutical industry, in Germany, specialized in the development, analytics, and contract manufacturing of medicinal products. The new facility will feature a 225 kW water-cooled air-compression system, providing waste heat to an 80 kW adsorption chiller. This chiller will generate chilled water for production and laboratory use, feeding into the central cooling system designed for 500 kW nominal capacity at 10/15°C. The system is expected to meet 1.5 GWh of annual cooling demand, with an electricity requirement of 375 MWh per year. The adsorption chiller will operate on base-load compressors, achieving 7,500 hours of operation annually and saving 110 MWh of electricity, equivalent to 29% of the cooling system's energy consumption. This translates to a reduction of 50 tons of CO_2 emissions annually. Pre-assembled in a container, the system includes a hybrid cooler with 230 kW nominal capacity, while BIM-based engineering and monitoring tools optimize its operation. The demonstration highlights significant energy and environmental savings, with high replication potential across industries requiring compressed air and heating/cooling solutions.

In each case, solar thermal collector systems will supplement the driving heat input from the industrial environment.

2. RE-WITCH most relevant innovations

The RE-WITCH project will develop and validate innovative cooling technologies to be driven by low-grade heating sources, such as onsite waste heat and renewable heat from solar thermal collectors. Specifically, three different cooling technologies will be designed, tested at laboratory scale, and demonstrated in real industrial plants:

- A novel adsorption chiller technology, based on a patented solution by Sorption Technologies GmbH company (German patent, 2019), aims at overcoming most of the issues of previous adsorption chiller designs, by applying a novel internal cycle concept by switching the refrigerant flow (i.e. water) in liquid phase, thus making use of smaller valves (thanks to the higher density of the liquid compared to vapor) and applying direct evaporation and condensation inside the adsorber module instead of the conventional heat exchanger design. The target of the project will be the improvement of the core components design (i.e. refrigerant pumps, heat exchangers, module architecture), focusing on the increasing of the chiller compactness This will lead to higher thermal efficiency (thermal cooling COP 0.65) and electric efficiency (electric cooling COP >20). allowing to meet an expected compactness >17 kW/m3 and the easiness in stacking adsorption modules to meet the industrial cooling demand, being able to be driven by heat at temperature varying from 75 to 90 °C.
- A hybrid absorption/compression cooling and heating technology. The hybridization concept will be based on the integration of a mechanical vapor compressor, between the evaporator and absorber of a single-stage absorption chiller. The development will start from previous design validated at lab-scale, as reported in **Error! Reference source not found.** (Schweigler, 2019). The mechanical compression serves for an increase of the pressure level of the absorber, allowing for an increase of the temperature level of heat rejection, usually limited by the risk of crystallization of the LiBr/water solution. The developed concept will be able to provide cooling simultaneously, at around 3/5°C, and heating up to 60°C, thus covering two different requirements for industrial cooling and heating. Under these operating conditions, the thermal cooling COP, is expected being around 0.65-0.70, while the thermal heating COP, reaches up to 1.75. At the same time, the electric consumption will be very limited, being the cooling electric COP, up to 9 and the heating electric COP up to 23.
- An absorption chiller able to provide, by means of the same working cycle, two different temperature levels of useful cooling to the consumer. The integration of a second evaporator-absorber pair will start from the existing design of LiBr/water absorption chillers by the company BS-NOVA and will be adapted to allow the chiller to serve two different chilling temperatures. Specifically, in the demonstration campaign of the project, the target cooling temperatures will be 10 °C and 20 °C, with different capacities, namely, 40 kW and 400 kW respectively.

Figure 1: Design of the lab-scale hybrid chiller (Schweigler, 2019).

Regarding the onsite renewables, the project will rely on the integration of the innovative high vacuum flat plate solar thermal collectors, designed, and manufactured by the Swiss company TVP Solar (TVP Solar. 2024). These collectors can provide heating power in a temperature range between 80 °C and 180 C, at the highest conversion efficiency on the market for non-concentrating collectors technology. This technology will be then employed both as the driving source of the sorption cooling devices as well as to provide direct heating to the industrial plant. The optimization of the system operation will be guaranteed by dedicated control and management algorithms developed and implemented in each demonstration site.

3. The “RE-WITCH way”: the innovative aDsorption chiller

In recent decades, adsorption chillers using water as a refrigerant and solid sorbents like Silica Gel or Zeolites have been developed and utilized in commercial applications to provide chilled water. The fundamental operation of these chillers relies on the cyclic loading and unloading of the solid sorbent in the adsorber and desorber, respectively. By alternating the operation of two reactors filled with sorbent material, continuous cooling power is maintained. This process requires an appropriate valve system to switch the refrigerant flow between the reactors and the evaporator/condenser. Previously, various configurations known as “1st and 2nd Generation” adsorption chillers have been developed. This publication introduces a novel 3rd Generation adsorption chiller:

- 1st Generation Adsorption Chillers (Mayekawa, Bry-Air, SorTech): The refrigerant vapor flows from the desorber to the condenser and from the evaporator to the adsorber through valves integrated between the compartments, offering high flexibility but necessitating complex and expensive vacuum systems.
- 2nd Generation Adsorption Chillers (SorTech/Fahrenheit): These feature a simpler vacuum system by combining each adsorber with a heat exchanger that serves as both evaporator and condenser. Vapor exchange between the adsorber and heat exchanger occurs without valves, simplifying the vacuum system but resulting in significant thermal losses during cycling.
- 3rd Generation Adsorption Chillers (Sorption Technologies): This system, based on a patented solution (see the patent by Mittelbach, 2019), distributes the refrigerant in the liquid phase, alternately connecting each adsorber with the evaporator or condenser loop. The refrigerant evaporates/condenses directly inside the adsorber. Using liquid-phase water, with its higher density,

allows for smaller valves and components, and separating the heat exchangers mitigates the thermal losses encountered in the 2nd generation.

As in the previous solutions, the 3rd Generation includes two equal modules which alternate in adsorption/desorption by properly controlling a system of valves in the refrigerant loops and in the external loops, as shown in Figure 2, thus providing a constant cooling effect. The project's objective is to enhance the design of core components, such as refrigerant pumps, heat exchangers, and module architecture, to achieve a more compact chiller. This will result in higher thermal efficiency (thermal cooling COP ≈ 0.65) and greater electric efficiency (electric cooling COP >20).

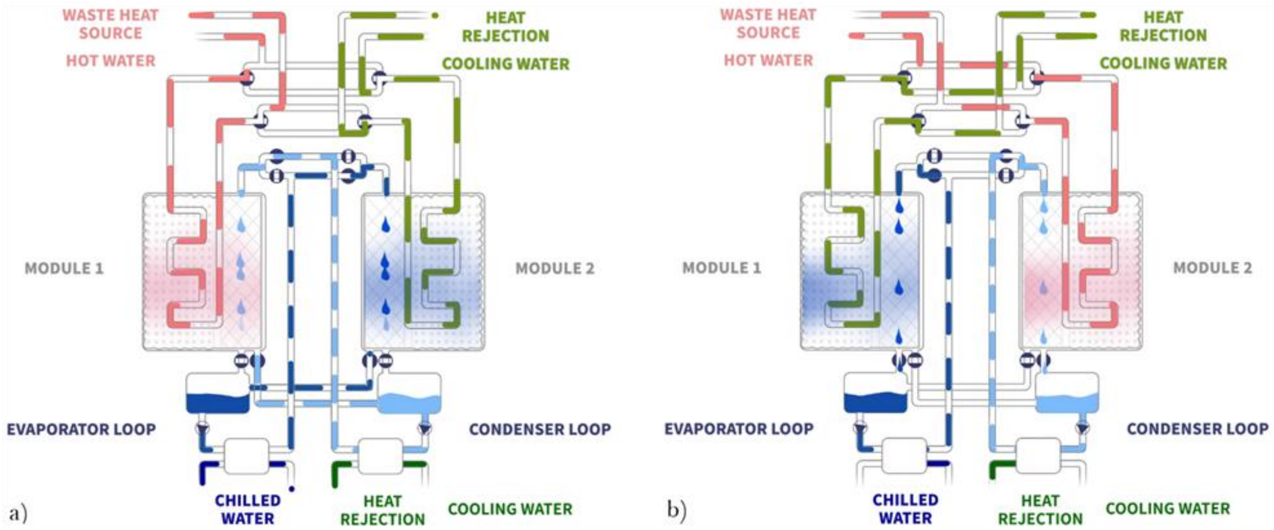

Figure 2: During the first phase, Module 1 is connected to the condenser loop, allowing the solid sorbent to unload, while Module 2 is connected to the evaporator loop, where the solid sorbent absorbs water; the cooling effect is harnessed through the evaporator loop heat exchanger (a). In the second phase, the roles of Module 1 and Module 2 are reversed, with Module 1 connecting to the evaporator loop and Module 2 to the condenser loop, thereby continuing to provide cooling power from the evaporator loop heat exchanger (b).

4. The “RE-WITCH way”: the innovative aBsorption chiller

Absorption chillers utilizing the LiBr-water working pair are well-developed and easily applicable in industrial settings. However, all sorption cooling devices face stringent temperature restrictions: in simple commercially available units, the waste heat temperature and chilling temperature limit the attainable reject heat temperature. This restriction reduces the capability to implement heat pumps that simultaneously provide cooling and useful heat output. For example, if the reject heat is required at around 60°C, standard designs driven by low-temperature waste heat will not suffice. The RE-WITCH project addresses these limitations by implementing advanced absorption cycles that decouple the thermodynamic states of the components. This allows for the provision of cooling at a low temperature (T0), heat output at a medium temperature (T1), and consumption of driving heat at a high temperature (T2) (Figure 3, left). These limitations are due to the equilibrium data of the water/lithium bromide working fluid pair and the potential crystallization of the mixture at states with low water content (Figure 3, right).

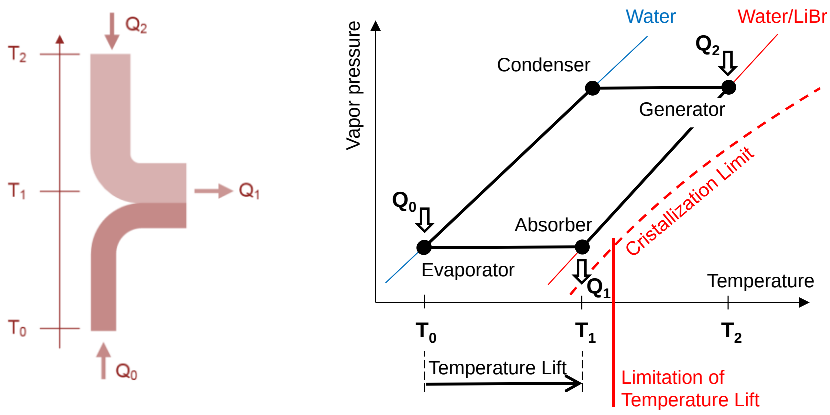

Figure 3: Temperature levels and heat flows of a sorption heat pump (left). Process parameters (internal pressure and temperature) of the standard absorption heat pump cycle (right). Limitation of the operational envelope by the crystallization limit of the sorbent solution.

4.1. Absorption Chiller with dual evaporator design

An absorption chiller featuring two evaporator/absorber pairs will enable the chiller to provide cooling at two different temperatures simultaneously, each with specified capacities (Figure 4). This configuration is distinct from the conventional twin design, which involves two evaporators connected to a single chilled water loop and two absorbers connected to a single cooling water loop. Typically, the solution flows are arranged in series from one absorber to the next to achieve larger temperature glides and avoid crystallization.

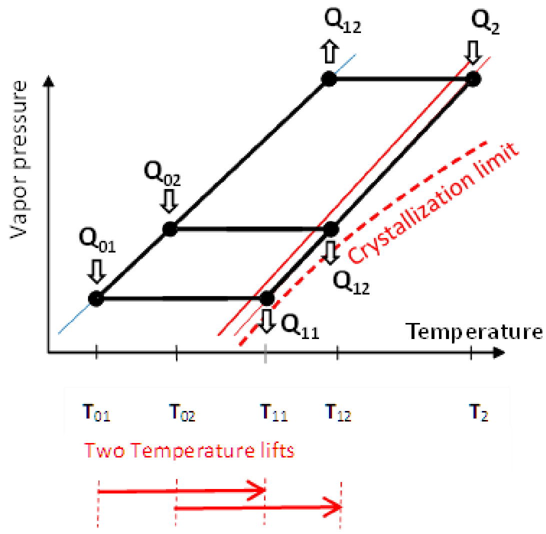

Figure 4: A schematic of the dual-evaporator layout

In the proposed design, each evaporator operates independently to accommodate different temperatures and cooling capacities. The solution flow and cooling water can be arranged either in parallel or in series, based on specific needs and technical constraints, ensuring design flexibility. Beyond the apparatus design, the project will focus on optimizing and controlling the operation.

The dual evaporator chiller will be designed for a demonstration case in Greece, providing cooling for two consumers at 10°C and 20°C, 40 and 400 kW respectively. An alternative to this concept would be installing two chillers operating almost in parallel. However, by directing the absorbing solution to either absorber in varying quantities, the proposed design makes more efficient use of the heat transfer surfaces. It will be demonstrated that cooling capacities and temperatures can be individually adjusted while maintaining cycle efficiency near the nominal COP value.

4.2. Hybrid Absorption/Compression Chiller

Integrating a mechanical vapour compressor between the evaporator and absorber of a single-stage absorption chiller creates a hybrid chiller. This configuration, powered by mechanical energy supplied to the vapour compressor, achieves an increased temperature lift while maintaining the thermal efficiency of the hybrid cycle, as shown in Figure 5.

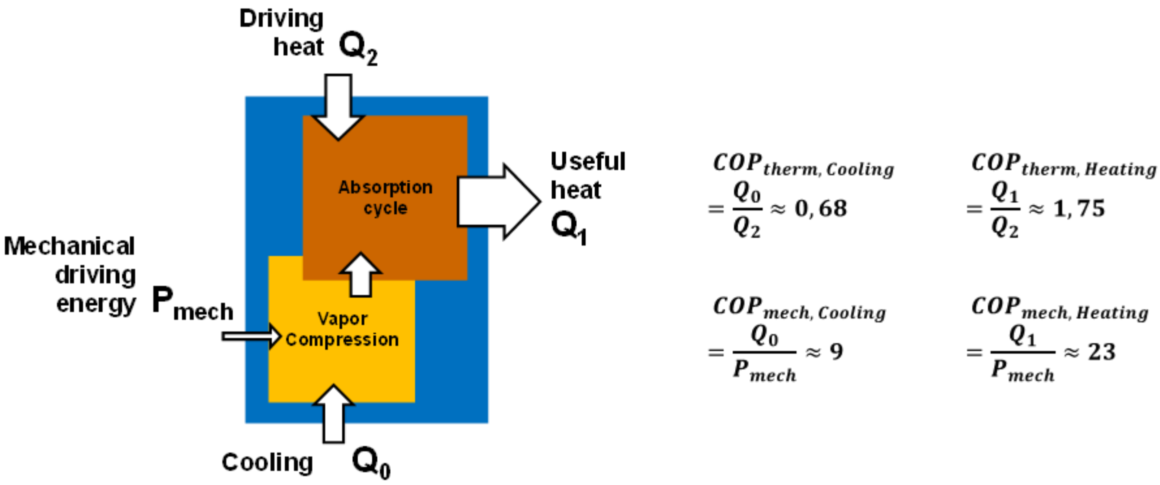

Figure 5: Hybrid absorption/compression chiller/heat pump: Energy flow scheme and COP for thermal and mechanical efficiency

The mechanical compression raises the pressure level of the absorber, which in turn elevates the temperature level of heat rejection within the crystallization limit of the sorbent solution (see Figure 6, left). This hybrid absorption/compression cycle with a high-temperature lift offers significant potential for heat recovery and simultaneous cooling and heating in industrial settings. Compared to a standard absorption chiller, the hybrid absorption/compression chiller provides a substantially higher temperature lift, as illustrated in Figure 6, right.

The development will build on a proof of concept demonstrated by a lab-scale test plant (Schweigler, 2019). For the industrial environment of a dairy plant in Spain, the hybrid cycle will be designed to provide a chilled water outlet temperature at the evaporator of 5°C and heat sanitary hot water from 15°C to 60°C using heat output from the absorber and condenser.

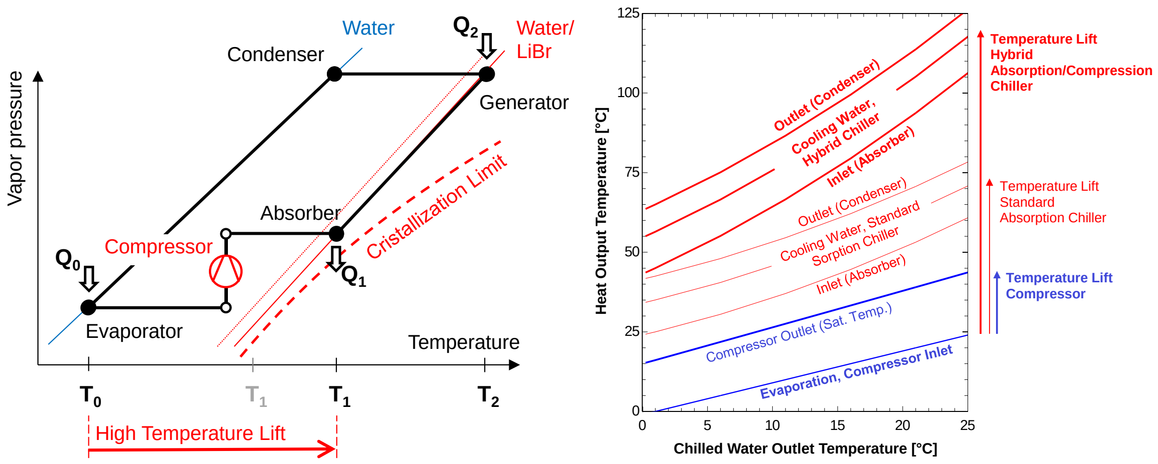

Figure 6: Hybrid absorption/compression chiller/heat pump with vapour compressor between evaporator and absorber (left). Increased temperature lift of the Hybrid chiller/heat pump compared to the standard absorption cycle (right).

5. RE-WITCH's expected impacts

The expected impact of RE-WITCH, with respect to solar energy exploitation, is profound and wide-ranging. Indeed, the integration of solar heat into the proposed systems (see the demos description in Section 1) enables a solar cooling configuration that will lead to significant energy and fuel savings, and improve energy efficiency in the selected industrial processes. By harnessing renewable solar energy to drive cooling systems, the project aims to drastically reduce electric consumption for industrial cooling, thereby cutting down on greenhouse gas emissions and other pollutants. This shift towards solar cooling will lessen the dependency on traditional energy sources, enhancing the integration of renewable energy both at the industrial level and within the EU energy system.

Specific outcomes include the demonstration of solar cooling technologies across four industrial sectors in Europe, proving their viability and efficiency in real-world applications. This will not only validate the technology but also highlight its potential for substantial primary energy savings and CO2 emission reductions. By focusing on solar cooling, the project aligns with the EU's strategic plan for sustainable energy use, promoting clean energy solutions that are "100% Made in the EU."

Further, the project supports the development of a circular and clean economy by leveraging renewable energy for cooling purposes. Long-term projections indicate significant energy savings and GHG emission reductions by 2050, with the potential to cover 25% of the EU's industrial cooling demand through solar cooling technologies. Additionally, this shift is expected to create approximately 1,500 new direct and 4,000 indirect jobs by 2035, accompanied by substantial industrial investments.

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