Strategic Energy Technology Plan

Solar Thermal Technologies IWG

Implementation Plan on Non-Concentrated Solar Thermal (NCST)

12 September 2025

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1. An implementation plan for Non-Concentrated Solar Thermal (NCST)

1.1. The relevance of solar thermal

Heating and cooling account for almost 50% of Europe's final energy consumption and are responsible for 40% of energy-related CO2 emissions. Non-concentrated solar thermal (NCST) is a crucial technology for decarbonizing this sector. With over 10 million systems already installed across Europe, NCST is a mature and proven solution that significantly reduces energy costs and emissions.

Non-concentrating solar thermal is a highly efficient, no-regret solution that produces no emissions during operation and integrates easily with other energy systems. Its components are largely reusable or recyclable, making these systems nearly completely sustainable. The technology combines a low Levelised Cost of Heat (LCoH) with a high degree of versatility, providing solutions for domestic hot water at 60°C and industrial process heat at temperatures up to 200°C. Its ability to generate heat on-site with high efficiency makes it a key contributor to Europe's energy independence and security.

This is why NCST's inclusion in the Strategic Energy Technologies Plan (SET-Plan) is so important. The SET-Plan is a key instrument for coordinating research and innovation efforts across Europe. Its recognition of NCST highlights the technology's strategic importance as a building block for the EU's transition to a net-zero economy. By being part of the SET-Plan, NCST is positioned as a priority technology for achieving Europe’s ambitious climate and energy goals. The European Commission has also called on SET-Plan countries and relevant stakeholders to strengthen their collaboration to support solar energy research, innovation, development, and deployment, further cementing its role in a more resilient European energy supply chain.

1.2. Concentrating and Non-concentrating Solar Thermal

There are different approaches to distinguish between solar thermal technologies, based on technology use or final energy output (electricity and/or heat). The approach used in this implementation plan is to divide into two main categories based on their technical approach to collecting solar radiation: non-concentrating and concentrating systems.

Non-concentrating solar thermal (NCST) collectors, such as flat-plate (including evacuated), evacuated tube collectors or hybrid PVT (photovoltaic-thermal) pannels, are designed to absorb solar radiation directly over a wide area without focusing it. This allows them to effectively capture both direct and diffuse solar radiation. Because of this, NCST systems can operate efficiently even on cloudy days or in regions with lower direct sunlight. These collectors are technically simpler than concentrating ones and are primarily used for low-to-medium temperature applications, typically ranging from 60°C up to 200°C. Their key technical characteristics include a high optical efficiency for diffuse light and a robust design that is easy to install and maintain, making them ideal for residential, commercial, and large-scale district heating applications.

Concentrating solar thermal (CST) systems, on the other hand, employ an optical system—such as mirrors or lenses—to focus direct sunlight onto a much smaller receiver area. This concentration of energy allows them to generate much higher temperatures, typically ranging from 250°C to over 1000ºC. The most common types of CST technologies are parabolic troughs, solar towers, and Fresnel reflectors. A key technical requirement for CST systems is a high amount of Direct Normal Irradiance (DNI), which is why they are most effective in regions with consistently clear skies, like Southern Europe.

These technologies are primarily used for generating electricity (solar thermal electricity or STE) and for medium-high (above 200ºC) and high-temperature industrial processes, often incorporating large-scale thermal energy storage to provide power even when the sun is not shining.

In essence, the primary technical differentiator is the use of an optical concentrator and the resulting operating temperature range. NCST is a versatile heat-generation technology suitable for a wide range of common heating needs, while CST is a high-temperature technology focused on power generation and specific medium- and high-heat industrial applications.

Both technologies can also be combined in practice. For instance, in solar process heat, heat supply at 90oC from non-concentrated collectors can be used as flow temperature for concentrating collectors for higher temperatures in the next step.

These two approaches are therefore complementary, with NCST addressing widespread, decentralized thermal demands and CST serving more specialized, centralized, and high-temperature needs. Together, they form a comprehensive solar thermal portfolio capable of supporting the full spectrum of decarbonisation goals across sectors. The table below provides an example of this complementarity; namely how different solar thermal technologies can address different temperature ranges.

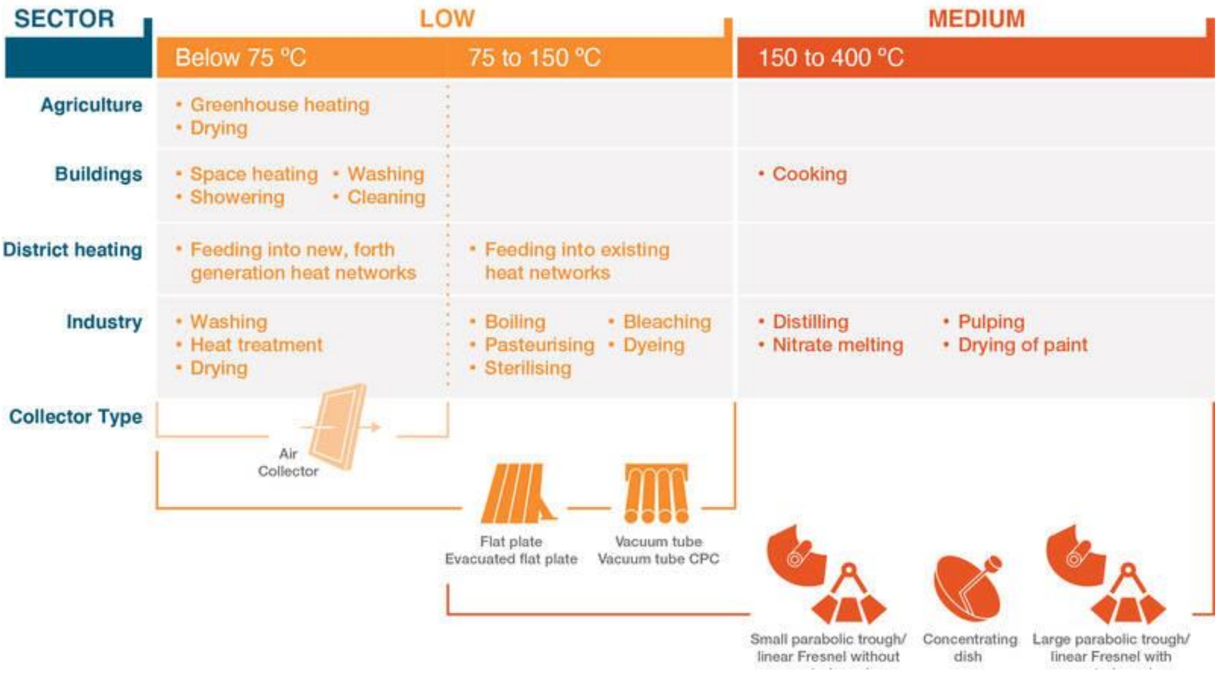

Figure 1: Solar thermal technologies: temperature ranges and sectoral requirements.

Source: Solrico

This implementation plan focuses specifically on Non-Concentrated Solar Thermal (NCST), addressing its crucial role in decarbonizing a broad range of heating and cooling applications that are vital to Europe's energy transition.

1.3. State-of-the-art

Solar thermal systems convert solar radiation into heat through an absorber and then exchange this heat via a transfer medium. This transfer can be done in air, water or a mixture of water and glycol and, for higher temperature needs, with pressurised water or oil. The thermal energy produced is transferred to a storage tank, which is always a built-in feature of solar heating and cooling systems, regardless of their size and geographical location.

Indeed, solar thermal technologies are extremely flexible and can be used to warm up swimming pools and sanitary hot water, for space heating of both residential and non- residential buildings, or even for higher temperatures to decarbonise industrial heat processes with temperatures up to 400°C. These solutions range from small domestic systems (1.4 kWth or 2m2) to medium-large large industrial plants (over 30 MWth already existing), up to very large district heating installations (largest in Europe reaching 110 MWth).

Furthermore, components of solar thermal collectors are of EU origin, and can almost entirely be reused or recycled. Considering that heat production through solar thermal does not produce emissions nor hazardous substances and consequently does not represent a risk for health or environment and since solar thermal can be combined with a myriad of other solutions (power or heat), solar thermal heat is clearly a no regret option.

Solar thermal is the most efficient renewable energy sources. It converts the inexhaustible solar resource with an efficiency up to 70% (40-60% in most collectors), meaning that it is able to convert into thermal energy 70% of the solar energy received in the surface of the collector. As a reference, solar PV panels have an efficiency between 15 and 20%. The comparison with other heating solutions, such as heat pumps, presenting a COP from 1 to 5 (for ground-source heat pumps), would show an even larger difference, as a solar thermal system primary energy consumption (electricity for running the water pump) would lead to COPs of 60 and above.

Worldwide, most solar thermal systems are used for domestic hot water (DHW) production. However, the market has experienced a constant and robust increase of solar heat for industrial process (SHIP) plants and solar-assisted district heating (SDH) networks. Additionally, solar thermal at individual and large-scale level is easily compatible with other solutions, for both heat and power production.

Currently, typical applications of solar thermal technologies are:

- Domestic hot water preparation for single- and multi- family houses: these applications are usually done with thermosyphon or forced circulation systems, with t typical solar fractions between 40-90% (meaning that solar energy covers these shares of the total heat demand). Temperature levels are between 40-60°C
- Space heating for single and multi-family houses with typical solar fractions between 15-40%, and for non- residential buildings and temperature level around 40°C
- Combi systems: combining DHW and space heating for single or multifamily houses
- District heating, with solar fractions going up to 50%, depending on the type of storage (seasonal to cope with summer-winter fluctuations, or storage for shorter periods) temperatures are usually between 40-100°C
- Low, medium, and high temperature heat for industrial process applications (through both solar heat and concentrated solar heat). Temperature can range from 40°C up to 400°C depending on the process
- Other applications, as Solar Thermal for swimming pools, Solar Active House, and Solar cooling applications.

The fact that solar thermal solutions do not produce polluting emissions contributes clearly to the reduction of greenhouse gas emissions and the improvement of air quality. For example, thermosyphon systems (e.g. individual solar collectors at building level) in Greece can save up to 1.5 tons of CO_2 per year which in Europe is the equivalent of the annual emissions of a combustion engine car.

Large-scale solar thermal applications have experienced a strong growth over the years:

- **Solar heat for industrial processes (SHIP)** continues to be an expanding niche market with significant potential for cost reductions in manufacturing and decarbonization of industrial heat. In 2024, the global SHIP market reached a five-year high, with 106 new systems commissioned totalling 120 MW of thermal capacity, and an additional 125 MW under construction1 This marked a notable increase from the 94 MW installed in 2023. The food and beverage industry remains the leading sector for SHIP installations, followed by the textile and pharmaceutical industries. The diversification of applications and growing interest across 20 countries underscore the increasing relevance of SHIP in the global energy transition.

[1] Solar Heat Worldwide, IEA SHC, 2025

- **Solar district heating (SDH)** systems, both with and without large-scale seasonal thermal energy storage, continue to expand steadily across Europe and globally. As of 2024, 346 towns and cities worldwide have integrated solar energy into their district heating networks. That year alone, ten new SDH systems were commissioned, adding a total of 74 MW of thermal capacity.2 The market is also geographically diversifying, with new large-scale collector fields under development in Central and South-East Europe. Notable projects include a 44 MW installation in Pristina, Kosovo, and a 27 MW system in Novi Sad, Serbia—both paired with seasonal thermal energy storage These developments highlight the growing recognition of SDH as a cost-effective and scalable solution for decarbonizing urban heat supply.

- **Large commercial and residential systems**, ranging from collective systems used in multi-family homes, and applications in key segments such as hospitals, schools, and hotels.

The use of direct solar energy for heating individual buildings has a long-standing tradition, often integrated into architectural design. Today, this practice has evolved significantly, with solar energy being widely captured through dedicated solar thermal collectors for various heating applications. These systems are now the most common form of solar-based heating, particularly for domestic hot water and space heating. In addition, solar thermal technologies are increasingly being applied to thermally driven cooling solutions, offering a sustainable alternative for climate control in buildings. This dual capability—providing both heating and cooling—enhances the versatility and year-round utility of solar thermal systems.

Combining photovoltaic (PV) and solar thermal technologies in PVT (photovoltaic thermal) collectors has become an increasingly attractive option for maximizing solar energy utilization. PVT collectors simultaneously convert solar radiation into usable thermal and electrical energy, offering higher overall efficiency compared to standalone PV or solar thermal systems. In 2024, the global market saw a resurgence, with 72,544 m² of PVT collectors newly installed equivalent to 37.5 MWth of thermal and 18.6 MWp of electrical capacity 3. Europe remains the leading region, accounting for 64% of the global installed PVT collector area, with France, Germany, and the Netherlands as the top contributors. PVT technologies vary significantly in design and application, ranging from uncovered collectors used with heat pumps to glazed systems suitable for higher temperature uses, making them adaptable to diverse building and industrial needs.

Solar thermal technologies offer a wide range of advantages that make them a cornerstone of the renewable heating and cooling transition. They integrate seamlessly with other renewable energy systems—both thermal and electrical—as well as with existing fossil-based infrastructure, enabling sector coupling and facilitating building renovation strategies. As a direct energy-saving solution, solar thermal can be considered an energy efficiency measure, facing similar challenges such as upfront investment and delivering long-term cost savings rather than immediate financial returns.

As a clean and inexhaustible energy source, solar thermal produces no emissions and can be easily combined with other technologies, making it a “no-regret” option for sustainable heat generation. Its deployment supports local economies by creating jobs across the value chain, including manufacturing, distribution, system design, installation, and maintenance. The technology is highly scalable and has been successfully implemented in all EU Member States, proving effective across diverse climates and applications.

Solar thermal systems are not subject to the volatility of fossil fuel or electricity prices and contribute to reducing peak electricity demand, thereby enhancing grid stability. They also enable genuine self-consumption, strengthening energy security and independence at both household and community levels. By providing direct renewable heat, solar thermal reduces the need to use high-exergy energy sources—such as electricity or gas—for low-exergy applications like space and water heating. This helps avoid unnecessary infrastructure investments and supports a more efficient and resilient energy system.

Solar heat provides clear benefits for local economies. In the European internal market, 90% of available solar thermal products are manufactured in Europe with European components. This

[2] Solarthermalworld, 2025
[3] idem

solution not only produces clean energy locally, but it also creates new business and new jobs (including job-reconversion) at local and regional level. Furthermore, the European solar industry is an exporting sector, with annual net exports surpassing at times 1 billion Euros.

1.4. Market trends & potential

The European Union has set a legally binding objective to become climate-neutral by 2050, as outlined in the European Commission's long-term strategy and enshrined in the European Climate Law. The plan of the EC, EU binding renewable energy target for 2030 raised to 42.5%, aiming for 45% is to reach 124 Mtoe by 2030 with an annual average increase of about 2.3%. Combined with a reduction in consumption due to efficiency measures in the building sector, this moderate rate will decarbonise 50% of H&C by 2040 and produce 155 Mtoe annually. This is clearly too little to achieve the above- mentioned goal of a net-zero greenhouse gas emissions economy by 2050.

This goal aligns with the EU's commitments under the Paris Agreement and is central to the European Green Deal. While renewable energy has made significant progress—particularly in electricity generation—the heating and cooling (RHC) sector remains a critical challenge. Heating and cooling account for nearly half of the EU's total energy consumption, yet the transition to renewables in this sector has been slower than in others.

In 2023, renewable energy sources—including biomass, solar thermal, geothermal, and ambient heat via heat pumps—accounted for 26.2% of total energy use for heating and cooling in the EU, up from 11.7% in 2004[4]. This growth has been driven by developments across the industrial, services, and residential sectors. However, to meet the EU's 2030 and 2050 climate targets, this share must continue to rise significantly, requiring accelerated deployment of renewable heating and cooling technologies and supportive policy frameworks.

The revised Renewable Energy Directive (EU/2023/2413) now requires each Member State to raise the share of renewables in heating and cooling by 1.1 percentage points annually, with additional provisions to support district heating and cooling. These measures are designed to accelerate the deployment of renewable heating technologies and ensure their integration into the broader energy system.

As of the end of 2024, Europe hosts approximately 40 GWth of installed solar thermal capacity, generating an estimated 27 TWhth of renewable heat annually. This capacity is distributed across more than 11 million systems, ranging from small-scale residential installations to larger commercial applications. The majority of these systems operate within a temperature range of 40–70°C, making them ideally suited for domestic hot water production and space heating in both residential and commercial buildings. This widespread deployment underscores the maturity and reliability of solar thermal technologies in meeting everyday heating needs while contributing to climate and energy goals.

The main market segment for solar thermal in Europe is the residential sector, where this technology is mainly used in domestic hot water (DHW) systems. This market segment is experiencing challenging times, and this is especially evident in countries where the traditional mass markets for small- scale solar water heating systems for single-family houses and apartment buildings are under market pressure from heat pumps and photovoltaic systems. However, even in this market segment there are resilient countries, especially in Southern Europe, with countries such as Greece, Portugal or Cyprus showing a growth trend in recent years.

In addition to domestic hot water (DHW) production, space heating remains a key application of solar thermal technologies, particularly in Central European countries. In Germany, approximately 50% of the total installed collector area is dedicated to "combi systems," which simultaneously provide thermal energy for both DHW and space heating. In this segment, competition from heat pumps and

[4] Renewable energy statistics, Eurostat, 2024

photovoltaic (PV) systems is less pronounced, as peak heating demand occurs during winter months when solar irradiation is limited and PV systems are primarily used for electricity generation.

While small-scale systems still dominate the market, large-scale solar thermal installations are gaining momentum. By the end of 2023, 598 large-scale solar heating systems (each >350 kWth or 500 m²) were in operation globally, with a combined capacity of 2,285 MWth, equivalent to 3.3 million m² of collector area. Of these, 336 systems were dedicated to solar district heating, accounting for 1,908 MWth (2.73 million m²). In 2023 alone, 28 new large-scale systems were commissioned, adding 139 MWth of capacity[5].

These figures reflect the growing role of solar thermal in decarbonizing both district heating networks and large-scale building applications across Europe and beyond. Interest is also increasing throughout Europe in solar heat for industrial process (SHIP) systems. Several promising projects implemented range from small-scale demonstration plants to large systems in the MWth scale. In 2021 a new record has been achieved for the largest SHIP plant in Europe in operation: a malting plant in France, with a capacity of 10 MWth. The same year, also in France, started the construction of a 15 MWth plant for a whey powder factory, while a 20 MWth SHIP plant for a malting factory in Croatia has been contractualized.

In addition to the more traditional industrial sectors like food, beverage, textile, chemistry, and mining industry, in which solar thermal systems are commonly used, there are two new applications which are attracting more and more interest. One of these more recent applications, is the production of solar heat for flower and vegetable cultivation in greenhouses. The second application relates to the heating of gas pressure control systems, an interesting application which is already implemented in several systems in Germany.

Finally, the Photovoltaic Thermal (PVT) collector market developed very well in in recent years in Europe and saw in 2019 37.5 MWth thermal and 18.6 MWp electrical capacity installed in 2024, a 13% increase over 2023 [IEA SHC, 2025]. By the end of 2019, the worldwide installed PVT collector area was 1.166.888 m2 (606 MW_{th}, 208 MW_{peak}), and 58% of this collector area was in Europe.

By effectively addressing the challenges and proposals include in this Implementation Plan, solar thermal technologies will have a strong impact on the adoption of solar thermal technologies across different applications and a total solar energy supply equivalent to 31 000 toe will be reached by 2040. An electric car can avoid approximately 1400kg CO2/y compared to a single solar collector of 2.5m^2 size that can save up to 1700kg CO2/y. Such great impact will be reached if enough research and demonstration efforts will be directed to this technology, which is strongly acknowledged by the public as one of the 100% renewable heating technologies and is predominantly manufactured in Europe.

Nevertheless, solar heat can be used for a variety of applications: for example, solar-assisted district heating systems are commercially available, can reach sizes over 100 MWth, and are particularly developed in Central and Northern Europe. The largest solar assisted district heating in the world is in the Danish city of Silkeborg where the solar thermal plant covers 100% of the summer heat demand of the city and 20% of the winter load, thanks to large seasonal thermal energy storage capacity.

As mentioned before, solar district heating (SDH) networks are an innovative and promising solutions which is more cost- effective than gas-based systems. However, the potential for this application is still underestimated and limited mostly to areas supplied with natural gas networks. In this context, the integration of solar heating and cooling with other renewable sources (be it for electricity or heat production) can also be an effective solution for peak shaving, especially when coupled with seasonal thermal storage.

Solar heat for industrial processes (SHIP) is rapidly emerging as a key solution for decarbonising European industry. It has already demonstrated strong performance in sectors with consistent thermal demand, such as the food and beverage industry—including breweries and dairies—as well as in textile manufacturing and mining operations. These industries are particularly well-suited for SHIP

[5] Solarthermalworld, 2025

applications due to their reliance on low to medium temperature heat, which solar thermal systems can efficiently supply.

The European Union has recognised the strategic importance of solar thermal technologies in its broader industrial policy framework. Under the Net-Zero Industry Act (NZIA), solar thermal is listed among the key technologies essential for achieving climate neutrality by 2050. The Act aims to scale up the EU's manufacturing capacity for clean technologies to meet at least 40% of annual deployment needs by 2030, while simplifying permitting and improving market access. This is complemented by the Clean Industrial Deal, which outlines concrete measures to turn industrial decarbonisation into a driver of competitiveness, including targeted support for clean manufacturing, public procurement incentives, and investment mobilisation. Together, these initiatives create a favourable policy environment for accelerating the deployment of SHIP systems, enhancing the competitiveness of European industry, and supporting the transition to a low-carbon economy.

In a carbon-neutral energy mix by 2050, renewable heating solutions are expected to play a central role. The decarbonisation of the heating and cooling sector—responsible for nearly half of the EU's final energy consumption—cannot be achieved without a significant contribution from solar thermal technologies. According to the European Commission, solar thermal is expected to cover at least 50% of the final energy demand for heating and cooling in Europe by mid-century. This ambition aligns with the EU Solar Energy Strategy, adopted in 2022 as part of the REPowerEU plan, which calls for a tripling of solar thermal capacity by 2030 to accelerate the transition away from fossil fuels and strengthen energy security. Achieving this target will require coordinated efforts across policy, industry, and research to scale up deployment, improve system integration, and ensure affordability for all users

2. Strategic Targets on Non-Concentrated Solar Thermal (NCST)

2.1. Introduction

Solar thermal technologies are a key component of the EU's strategy for achieving climate neutrality. The Strategic Research and Innovation Agenda for Climate-Neutral Heating and Cooling in Europe identifies solar thermal as a vital technology for decarbonizing the heating and cooling sectors, which account for over half of the EU's final energy consumption. As the EU seeks to reduce its reliance on fossil fuel imports, particularly from sources like natural gas, solar thermal provides a domestic, renewable solution. Its ability to generate heat directly aligns with the goals of energy independence and security. The Solar Thermal SRIA provides more details on the technological challenges for solar thermal, which was an important basis in the analysis of priorities.

The following strategic targets for Non-Concentrated Solar Thermal (NCST) are designed to address the current market barriers and technological challenges. They focus on accelerating the large-scale deployment of solar heat for both residential, district heating and industrial applications, building on the foundation laid by previous research and the ongoing efforts of the NCST Implementation Working Group. These priorities are crucial for moving the technology from a niche application to a mainstream solution for a sustainable energy future.

2.2. Key Challenges

The solar thermal sector faces both technical and non-technical barriers to widespread adoption. This is a crucial moment for the technology, as the twin pressures of climate change and the urgent need for energy security have made the decarbonization of heating and cooling a top priority. As outlined in the Solar energy joint research and innovation agenda, the EU has identified solar thermal (and solar PV) as "net-zero technologies" under the Net-Zero Industry Act, which aims to increase the EU's manufacturing capacity to at least 40% of annual deployment needs by 2030. This highlights the strategic importance of building a strong, competitive, and secure domestic supply chain. The competitiveness of solar thermal and its capacity to deliver new solutions to a fast-evolving market is of paramount importance.

Addressing these challenges is essential for ensuring solar thermal can play its full role in the EU’s energy transition and contribute to a resilient, decarbonized energy system.

- **Technological Challenges:** The sector faces competitiveness challenges that require additional developments in terms of cost reduction and efficiency gains. It also requires more efficient and proven hybridisation with other technologies, either at small (residential) or at large (district/industry) scale. This means an improvement in integration protocols for hybrid systems, facilitating a seamless combination of solar thermal with other renewable heat sources like heat pumps and biomass. In parallel, continued innovation in combining solar thermal with thermal energy storage is essential to enhance system flexibility, reliability, and year-round performance.

- **Non-Technological Challenges:**

    - **General:** There is a significant skills gap across the solar thermal supply chain. The lack of qualified installers is a common concern, particularly for small-scale systems. For large-scale applications, the sector faces shortages of engineers and project developers with specialized expertise. In addition, limited awareness among key stakeholders—including policy makers, building professionals, and end-users—hinders uptake and slows down project development.

    - **Large-Scale:** There is a significant skills gap in the supply chain, which includes a shortage of engineers, installers, and project developers with the specialized knowledge for large-scale solar thermal systems. Furthermore, current business models are not optimized for large-scale heat delivery. The absence of a recognized, EU-wide certification scheme for large-scale systems creates market uncertainty, hindering investor confidence and project scalability.

- **Building Sector:** Market uptake is hindered by a lack of integrated solutions for domestic hot water and space heating/cooling. The complex and often fragmented regulatory landscape for buildings, along with a limited awareness among building owners and designers, poses a significant barrier to widespread adoption.

Overcoming these multifaceted barriers requires a coordinated and comprehensive approach. The priorities that follow are designed to address these challenges head-on, from developing advanced components and new business models to building a skilled workforce and establishing trusted market frameworks. By focusing on these key areas, the solar thermal sector can accelerate its growth and become a cornerstone of Europe's sustainable energy future.

The NCST Implementation Working Group, in collaboration with experts from the solar thermal sector, in particular from the European Solar Thermal Technology Panel (ESTTP) and Solar Heat Europe (SHE), has defined the following priorities:

- **Advanced Collector and System Performance:** Develop next-generation solar thermal collectors, including hybrid systems, to improve performance in terms of higher overall output, lower production costs, and better environmental performance. This includes advancing circular design principles—such as recyclable components and sustainable materials—to reduce environmental impact and support resource efficiency. These improvements are essential to lower the cost of solar heat and make it more competitive with fossil fuels and other renewable energy sources.
- **Integration in Buildings:** Improve the integration of solar thermal systems for domestic hot water and space heating/cooling in residential and commercial buildings, aiming for high solar fractions and reduced LCoH. This is a critical step to decarbonize the building sector, which is a major energy consumer.
- **Solar Heat for Industrial Processes (SHIP):** Optimize solar thermal systems for industrial processes, specifically for temperatures up to 200∘C. The industrial sector is a significant consumer of heat, and this priority is key to reducing its carbon footprint and reliance on fossil fuels.
- **Large-Scale District Heating:** Expand the use of large solar thermal systems for district heating and cooling applications in various geographical locations. District heating networks are essential for providing heat to urban areas, and integrating solar thermal can significantly reduce the use of fossil fuels and improve energy efficiency.
- **Hybrid Systems:** Develop systems that combine solar thermal with other renewable heat technologies, such as heat pumps and biomass. This is relevant to ensure a consistent and reliable heat supply, as solar thermal output can be intermittent.
- **Technological and Market Innovation:** Explore novel applications for solar thermal, implement new business models, and enhance digitalization in the design, construction, and operation of solar thermal systems. This is necessary to accelerate market deployment, overcome non-technical barriers, and attract private investment.

In conclusion, these strategic targets represent a decisive roadmap for the Non-Concentrated Solar Thermal sector to become a central pillar of the EU's energy transition. By proactively addressing both technological and non-technical barriers, the industry can unlock its full potential, reduce Europe's energy dependency, and deliver a cleaner, more resilient, and more affordable energy future.

3. Overcoming Non-technological Barriers to Solar Thermal Deployment

3.1. Main barriers for deployment

The widespread adoption of Non-Concentrated Solar Thermal (NCST) technologies is essential for achieving Europe's climate and energy goals. However, a number of significant non-technical, economic, and regulatory barriers must be addressed to accelerate deployment and unlock the full potential of solar heat.

Addressing non-technological barriers is crucial because technical innovation alone isn't enough to drive widespread adoption. Even if the technology is highly efficient and cost-effective, it will fail to reach its potential if the market, regulatory, and workforce conditions are not supportive.

The following points summarize the key non-technical, economic, and regulatory obstacles that hinder the widespread deployment of solar thermal technologies. These barriers range from a general lack of market awareness and underdeveloped business models to specific challenges in financing, permitting, and regulatory frameworks.

Awareness and Communication

A primary barrier to market uptake is limited awareness of solar thermal's benefits among policymakers, investors, and end-users remains a key barrier. Strengthening communication and outreach is essential to build trust and support informed decision-making.

Market and Business Model Gaps

Existing business models are often misaligned with the characteristics of solar thermal systems, especially for large-scale projects. New financing and contractual approaches are needed to improve bankability and attract investment.

Skills Deficit

The sector faces a shortage of qualified professionals across the value chain—from installers to engineers and project developers. Targeted training and capacity-building are critical to support deployment and ensure quality.

Fragmented Regulatory Landscape

Complex and inconsistent permitting and regulatory frameworks slow down project development. Streamlining procedures and harmonizing standards across Member States is vital to enable faster and broader adoption.

Financing and Bankability Issues

High upfront costs and perceived risks hinder access to financing, particularly for first-of-a-kind demonstration projects. Improved risk mitigation and tailored financial instruments are needed to unlock investment.

In short, a strong focus on non-technological barriers is necessary to create a fertile ground where technological advancements can flourish. It is about building a robust ecosystem that includes the right business models, a skilled workforce, streamlined regulations, and reliable financing to accelerate the transition from development to commercial deployment.

3.2. Non-Technical, Economic, and Regulatory Barriers

3.2.1. Awareness and Market Communication

A persistent lack of awareness and effective communication remains one of the most significant obstacles to the wider adoption of solar thermal technologies[6]. Information and concrete performance data are not disseminated widely enough, and the added value of solar thermal is often poorly understood by policymakers, investors, and end-users across all market segments. This means that crucial benefits—such as direct contributions to climate action, cleaner air, job creation in Europe, enhanced energy security, and stable long-term prices that shield consumers from fossil fuel volatility—are frequently overlooked. The sector would benefit from a standardised communication framework that moves beyond the Levelised Cost of Heat (LCoH) to also capture the technology's role in grid stability, peak-shaving, and energy independence. Awareness gaps are particularly acute among building owners, designers, and industrial decision-makers, where solar thermal is often not considered despite being technically and economically viable.

3.2.2. Financing

Securing investment remains a challenge despite the existence of European funding programmes such as the Innovation Fund and InvestEU[7]. First-of-a-kind (FOAK) demonstration projects, whether in industrial processes or new applications, face high perceived technical risk and significant upfront capital expenditure (CAPEX). Without a track record of proven, commercial-scale examples, private investors are often reluctant to commit funds. This is compounded by the mismatch between the long lifespan of solar thermal assets and the short-term return profiles preferred by many financiers. In large-scale heat supply projects, the long-term nature of Heat Purchase Agreements (HPAs) — often necessary to secure financing — can conflict with industrial clients' preference for shorter contractual commitments, creating an additional barrier to closing deals. The recent launch of the European Commission's Decarbonisation Bank offers a promising opportunity to de-risk and finance such projects, but stronger connections between financial institutions and project developers are needed to create a more favourable lending environment.

3.2.3. Skills and Workforce Capacity

A shortage of skilled professionals is a barrier across the sector. Engineers, EPC contractors, installers, and operators with specialised knowledge of solar thermal system design, integration, and operation are in short supply. This skills gap slows project development, increases costs, and can undermine system performance. he limited offer of specialised training programmes and certification schemes for solar thermal—covering both building-scale and large-scale applications—constrains the sector's ability to scale up deployment rapidly. There is a pressing need for modular training and qualification pathways, including micro-certificates, that enable installers to progressively expand the range of technologies they are qualified to work with, thereby strengthening workforce capacity and flexibility.

3.2.4. Regulatory and Policy Frameworks

Fragmented and inconsistent regulations across Member States create uncertainty for investors and developers. In the building sector, complex rules and a lack of harmonisation hinder integration of solar thermal into heating and cooling systems[8]. In some cases, well-intentioned policies such as solar mandates inadvertently favour one technology, such as PV, over solar thermal, even when the latter may be more efficient for the application. For larger projects, the absence of EU-wide standards and certification for large-scale systems reduces bankability and slows market growth. A more coherent,

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[6] The need for improved market communication is also highlighted in the Strategic Research and Innovation Agenda for Solar Thermal Technologies.

[7] These challenges are also identified in the Solar Thermal SRIA

[8] The importance of fair regulatory conditions is also highlighted in the CST Implementation Plan.

technology-neutral regulatory framework would help unlock investment and ensure fair competition between renewable heat solutions.

3.2.5. Permitting and Siting

Permitting processes for solar thermal installations—especially at larger scales—are often complex, lengthy, and fragmented across jurisdictions. Bureaucratic hurdles, environmental impact assessments, and land-use conflicts can significantly extend project timelines, increase costs, and in some cases lead to cancellations[9]. These challenges are not limited to utility-scale projects; even medium-sized installations in industrial or urban contexts can face similar delays. Streamlined, harmonised, and fast-tracked permitting procedures, particularly for non-agricultural or brownfield sites, would reduce development risk and accelerate deployment.

These challenges highlight the fact that a strong technological foundation is a necessary, but not sufficient, condition for success. To pave the way for a stronger deployment of solar thermal technologies, a coordinated and comprehensive roadmap is essential. The following sections will propose specific R&I activities that are not only focused on improving efficiency and reducing costs, but also on building the supportive ecosystem—including business models, workforce skills, and market frameworks—that will truly enable solar thermal to reach its full potential.

[9] This point is also a key recommendation in the Solar energy joint research and innovation agenda.

4. Priority technology actions (R&I Activities)

4.1. Proposed areas of IP activity

The proposed research and innovation (R&I) activities for Non-Concentrated Solar Thermal (NCST) are focused on four key activity areas, which directly support the strategic goals of accelerating the development and deployment of solar thermal technologies.

A. Next-generation solar thermal and hybrid collectors

This R&I area focuses on creating the next generation of solar thermal collectors and hybrid systems. The goal is to enhance overall performance by increasing the output per kilowatt of installed thermal capacity (kWth), reducing production costs through innovative materials and manufacturing processes, and improving environmental performance. By making solar heat more efficient and cost-effective, this work aims to increase its competitiveness against both fossil fuels and other renewable energy sources. This also includes the development of hybrid collectors PV and thermal collectors (PVT) generating both heat and electricity, a promising technology with high R&I demands.

This activity directly addresses the strategic priority to develop advanced solar thermal collectors, including hybrids, improving performance on criteria such as higher overall output per kWth, lower production costs, or improved environmental performance.

B. Advanced solar thermal systems and digital design tools

This activity focuses on enhancing the performance, flexibility, and integration of solar thermal systems through advanced digital tools and innovative applications. It includes the development of AI-based control systems, digital twins, and predictive maintenance solutions to improve system efficiency, reduce operational costs, and support smart energy management. It also explores emerging low-temperature applications—such as solar desalination, drying, and solar-driven chemical processes—targeting new sectors like agriculture and the water-energy-food nexus. The activity supports the creation of open data platforms, standardized performance metrics, and design tools to facilitate replication, improve planning, and accelerate market uptake.

This activity supports the strategic priorities on Technological and Market Innovation and Advanced Collector and System Performance, by advancing digital tools and novel applications to improve efficiency and accelerate deployment.

C. Solar Thermal in Buildings and B.I.S.T.

This priority is dedicated to improving how solar thermal systems are integrated into both residential and commercial buildings. Research will focus on developing seamless, aesthetically pleasing solutions for domestic hot water, space heating, and cooling. The aim is to achieve a high solar fraction, meaning a large percentage of a building's heating and cooling needs are met by solar energy, which in turn will reduce the Levelized Cost of Heat (LCoH) for building owners. This is a critical step for decarbonizing the building sector, which is a major energy consumer in Europe. Within this context, Building-Integrated Solar Thermal (BIST) solutions are an important area of work, ensuring that solar thermal can be incorporated seamlessly into building envelopes in ways that meet both functional and architectural requirements. This priority also includes the development of hybrid systems that combine solar thermal technologies with other renewable heat sources, such as heat pumps and biomass, to ensure a consistent and reliable heat supply. Furthermore, it also includes the enhancement of digitalization in the design, construction, and operation of these systems, as part of the broader effort to accelerate market deployment and overcome non-technical barriers.

This activity is directly aligned with the strategic priority on Integration in Buildings, aiming to improve solar thermal uptake through high solar fractions, reduced LCoHC, and better integration in residential and commercial buildings.

D. Advanced system integration – Large scale solar thermal systems

This activity covers the integration of solar thermal systems into large-scale applications, including industrial processes (SHIP), district heating and cooling networks (SDH), and the enabling conditions for market deployment. For SHIP, the focus is on tailored solutions for sectors like food, textiles, and chemicals, with systems operating up to 200°C. For SDH, priorities include expanding solar fractions through advanced storage and hybridization, supported by digital tools for system optimization. Addressing market barriers—such as permitting, financing, and skills gaps—is essential to accelerate deployment and improve bankability across all large-scale applications

This activity directly supports the strategic priorities to expand the use of large solar thermal systems for district heating and cooling across diverse geographical areas, and to develop and optimize solar thermal solutions for industrial processes requiring temperatures up to 200°C.

The strategic priorities related to "Hybrid Systems" and "Technological and Market Innovation" are not listed as separate activity areas. Instead, they are considered cross-cutting themes that are integrated into the four main R&I activity areas. The development of hybrid systems is essential for improving performance and reliability in both the advanced collector and large-scale system integration areas. Similarly, the focus on new business models, digitalization, and market innovation is fundamental to overcoming non-technical barriers in all areas, from building integration to large-scale projects for both district heating and industry

Annex I – R&I Activities

NCST Implementation Plan: R&I Activities

Area of Activity	Activities
A. Next-generation solar thermal and hybrid collectors	*A.1 Next-generation solar collectors*
	A.2. Sustainable and low-cost manufacturing
B. Advanced solar thermal systems and digital design tools	*B.1. Smart systems for solar thermal*
	B.2 Emerging concepts
C. Building Integrated Solar Thermal (BIST) Systems	*C.1. Integration of solar thermal technologies in buildings.*
D. Advanced system integration – Large scale solar thermal systems	*D.1. Advanced systems for SHIP*
	D.2 System-level innovation for solar district heating (SDH) systems
	D.3. Addressing market barriers affecting Large Scale Solar Thermal Systems

AREA OF ACTIVITY A: NEXT-GENERATION SOLAR THERMAL AND HYBRID COLLECTORS

R&I Activity A.1: Next-generation solar collectors

<table>
<tr><td colspan="2">Title:
Next-generation solar thermal and hybrid collectors for enhanced performance, cost-efficiency, and sustainability</td></tr>
<tr><td>Previous related research activities:
• Development of first and second-generation flat-plate and tube collectors
  ○ e.g. ESSteam
• Early-stage development of PVT (Photovoltaic/Thermal) collectors (including recyclability)
  ○ e.g.: PVT4EU, RC-PV/T, ECOMESH, SHE Panel
• Fundamental research into advanced materials for solar thermal applications
  ○ e.g. LifeSolar;
• Development of basic simulation and design tools for solar thermal systems
• Standardization efforts for solar thermal collector testing and certification
  ○ Solar KEYMARK II, QAiST, IEA-SHC-Task73</td>
<td>State-of-the-Art
• Hybrid PVT collectors (glazed) can achieve over 60% combined efficiency (heat + electricity) but face integration challenges and operating temperature limits.
• Solar thermal circular designs achieve ST over 80% recyclability.
• PVT recyclability can improve with designs that improve layer separation, but validation is needed
• Limited standardization for hybrid collector performance and durability testing.
• Advanced coatings (e.g., selective absorber layers) improve thermal performance, though their cost is often driven by deposition processes rather than raw materials.
• Fragmented standardisation and certification protocols for circularity and hybrid collector performance.</td></tr>
<tr><td>Targets:
- Develop hybrid PVT collectors with combined efficiency >60% (heat + electricity) at 40ºC.
- Develop electrical modelling tools for PVT systems by 2028.
- Improve recyclability of collector components (85% ST, 60% PVT)
- Reduce material costs by 25% through advanced material innovations.
- Establish standardized testing protocols for circularity and environmental performance.</td>
<td>Monitoring mechanism:
• Track hybrid PVT combined efficiency and performance
• Measure recyclability rates and material recovery percentages for new collector designs.
• Monitor progress on cost reduction targets through material and manufacturing cost analysis.
• Report on the development and adoption of new standardization and certification protocols by relevant bodies.

Key Performance Indicators:
• Combined PVT Efficiency (%)
• Recyclability Rate (%)
• Material Cost Reduction (%)
• Number of new or updated standards/certification protocols (Number)</td></tr>
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Description:

This activity focuses on advancing Non-Concentrated Solar Thermal (NCST) collector technology to enhance efficiency, sustainability, and versatility, thereby strengthening the EU's energy independence and industrial leadership in the heating and cooling sector. Key priorities include:

Hybrid PVT systems: Integrate photovoltaic and thermal layers for dual energy output, optimizing heat and electricity co-generation. Emphasis will be placed on overcoming current integration challenges, enhancing combined efficiency while expanding nominal operating temperatures up to i) 60ºC for household applications, ii) 100ªC for district heating and iii) 150ºC for industrial applications, and reducing overall system costs for broader market adoption. In addition to improving thermal design, there is a clear need for dedicated electrical modelling of PVT systems. This is key to improving reliability and scalability, as current models often overlook nonlinear behaviour and thermal-induced electrical effects, such as capacitance.

Circular design: Develop recyclable components and resource-efficient manufacturing processes to minimize waste. This includes promoting the use of sustainable, low-carbon, and abundant materials, and establishing comprehensive end-of-life strategies for all collector components to achieve high recyclability rates (e.g., ≥90% by 2030). PVT systems require solutions to improve layer separation (e.g. non-EVA); tools like material passports and disassembly guides should support end-of-life recovery.

Advanced materials and designs: Engineer novel coatings, absorbers, and structural materials for thermal enhancement, improved durability, cost-effectiveness, and reduced environmental impact. This encompasses research into high-performance, non-toxic, and affordable alternatives to critical raw materials, capable of withstanding diverse climatic conditions and operating temperatures (e.g., up to 200°C for specific industrial applications).

Projects aiming to achieve these targets should include:

- **Hybrid PVT prototypes**: Testing modular designs for residential, commercial or industrial applications under varying climatic conditions, coupled with advanced digital twins and control strategies for optimal performance validation. Electrical simulation tools for PVT systems, validated against field data and designed to capture thermal-electrical interactions.
- **Circularity frameworks**: Development of standardized Lifecycle Assessments (LCAs), design-for-disassembly guidelines, and material passporting systems for all collector components, ensuring full material traceability and high recovery rates.
- **Material innovation**: R&D on highly corrosion-resistant and durable coatings, lightweight and high-strength composite materials, and low-carbon footprint manufacturing processes (e.g., additive manufacturing, roll-to-roll processes).
- **Faster installation**: Modularisation, prefabrication and other designs for faster and easier installation of solar thermal and PVT systems in urban and industrial settings, including integration with prefabricated façades.
- **Standardization and Certification**: Collaborative efforts with relevant European and international bodies (e.g., ISO, CEN, Solar Heat Europe) to define robust performance, durability, and circularity metrics, leading to harmonized testing protocols and certification schemes to facilitate market acceptance and regulatory alignment.

</td></tr>
<tr><td colspan="2">TRL: From TRL 5 (validation in relevant environment) to TRL 8 (commercial demo)</td></tr>
<tr><td colspan="2">Total budget required: X M€ (to be confirmed)</td></tr>
<tr><td>

Expected deliverables:

- Hybrid PVT collector prototypes with efficiency >70% at 40ºC for residential applications and efficiencies > 50% at 100ºC for tertiary and industrial applications.
- Electrical simulation tools for PVT systems capturing thermal-electrical interactions.
- Recyclability guidelines and certification framework for solar thermal and PVT components, including new designs and disassembly protocols
- Open-access database of advanced materials (cost, performance, environmental impact).

</td><td>

Timeline:
3-5 years (rolling basis, with 2028 and 2030 as key milestone years for targets)

</td></tr>
</table>

• New ISO/CEN standards for circularity and hybrid collector performance.		
Party/Parties: ***Interested countries:*** - IWG members: Spain, Austria, Germany, Italy, Portugal, Turkey, Belgium, Cyprus, France, Greece ***Industrial partners:*** - Solar thermal and PVT manufacturers - Material science companies (e.g., for advanced coatings, polymers, metals) - Manufacturing equipment firms and robotics/AI startups ***Research institutes:*** - Universities and RTOs working on: thermal engineering; optics and photonics; electrical engineering; chemical engineering; nanotechnology; material science and engineering; material durability and corrosion; surface and coating engineering; mechanical and structural engineering; life cycle analysis; eco design; sustainability sciences and circular economy; among others **Other entities potentially interested:** - Solar Heat Europe, RHC ETIP (&ESTTP), National Solar Trade Associations, Solar KEYMARK Network, European Committee for Standardization (CEN), International Organization for Standardization (ISO),	**Implementation instruments:** - Horizon Europe (Cluster 5: Climate, Energy, and Mobility) - LIFE Programme (circular economy and environmental projects) - National grants (e.g., Germany's BMBF, France's ADEME) - Clean Energy Transition Partnership - European Innovation Council (EIC) Pathfinder grants - Private sector	**Indicative financing contribution:** To be defined (Based on individual project proposals and national funding commitments)

R&I Activity A.2. Sustainable and low-cost manufacturing

Title: Automated, scalable, and cost-efficient manufacturing for next-gen sustainable solar collectors	
Previous related research activities: - Early automation and robotics in industrial manufacturing - Initial circular economy concepts for materials and products - Basic digitalization in factory operations - Fundamental Life Cycle Assessment (LCA) development - Early-stage PVT manufacturing concepts; limited certification and standardization frameworks.	**State-of-the-Art:** • Manufacturing still relies on manual labour for critical and complex assembly steps, leading to high costs and limited scalability. • Partial automation (e.g., robotic welding) exists but lacks widespread adoption due to high upfront costs and insufficient flexibility to adapt to diverse product variants or production volumes. • PVT production lines are of limited capacity and require innovative process integration, digital control, certification and market signals to achieve significant economies of scale. • Circular practices (e.g., recycled aluminium frames) achieve ≤20% recyclability rates. • Low automation in sealing/insulation stages. • High reliance on virgin materials (copper, specialty coatings) • Absence of EU-wide circular manufacturing standards.
Targets: • Reduce manufacturing costs by 20% through automation and material optimization by 2030. • Strengthening European supply chains • Scale PVT production capacity to 0,5 million panels in Europe by 2030. • Develop certification and standardization frameworks to support scalable PVT manufacturing. • Increase the circularity of materials (especially photovoltaic ones) involved in the PVT manufacturing process.	**Monitoring mechanism:** • Cost reduction for ST: track specific examples of % cost reduction per unit collector (€/m²) in manufacturing. • Automation: measure automation level across key manufacturing stages using standardized metrics (e.g., Robotic Process Automation index). • Assess PVT production capacity growth, utilization rates, and operational flexibility **Key Performance Indicators:** • Manufacturing Cost Reduction per unit (%). • Automation Level in Assembly (%). • PVT Production Capacity (units/year).

Description:

This activity aims at securing a sustainable and innovative manufacturing value chain in Europe for Non-Concentrated Solar Thermal (NCST) collector manufacturing. As such the activity focuses on scalability, affordability, and sustainability, critical for accelerating the deployment of solar thermal solutions and securing a competitive European manufacturing base.

Key priorities include:

- **New/ improved machinery and production lines, including partial automation**: new concepts for production lines (adapting to new collector designs), incorporating also robotics, advanced sensing, and AI-driven quality control to streamline production, reduce labour costs, and ensure consistent high quality.
- **PVT manufacturing optimization**: Develop modular and flexible manufacturing of PVT collectors for cost-efficient mass production. Scaling PVT production requires not only technical readiness but also clear certification pathways and market signals from public procurement and large integrators.
- **Material circularity:** Incorporate recycled content and design for end-of-life recycling. This includes developing processes for efficient material recovery, integrating secondary raw materials, and exploring new steps toward remanufacturing of components.
- **Digitalization:** Utilize Artificial Intelligence (AI) and Machine Learning (ML) for predictive maintenance, process optimization, and smart factory operations, enabling adaptive and efficient production lines.

Projects aiming to achieve targets should include:

<table>
<tr><td colspan="3">- **Automated production pilots**: Deploy robotic assembly lines for PVT and solar thermal collectors.
- **Material efficiency studies**: Optimize material use (e.g., aluminium, glass) to reduce costs and carbon footprint.
- **PVT scalability trials**: Test high-volume production of standardized designs in partnership with manufacturers.
- **Lifecycle analysis (LCA)**: Assess environmental and economic impacts of new manufacturing methods. Use LCA and the EPD (Environmental Product Declaration) to externally validate lifecycle impacts in comparison with other technologies.</td></tr>
<tr><td colspan="3">**TRL:** From TRL 4 (lab-scale automation) to TRL 7 (industrial demonstration)</td></tr>
<tr><td colspan="3">**Total budget required:** X M€ (to be confirmed)</td></tr>
<tr><td colspan="2">**Expected deliverables:**
- Flexible, partially automated and digitally integrated PVT production lines (≥100,000 units/year capacity).
- Cost-benefit analysis report for off-site vs. traditional manufacturing, including socio-economic impact, job creation potential, and regional benefits.
- Open-access toolkit for circular manufacturing practices, including guidelines for material selection, design-for-disassembly, end-of-life processing, and recycling value chain mapping.
- Life Cycle Assessment (LCA) and Life Cycle Costing (LCC) methodologies adapted for automated and circular solar collector manufacturing, along with a database of material properties for circular design.
- Draft proposals for new or updated EU-wide manufacturing and circularity standards for solar thermal and PVT collectors, enabling future reuse and recycling.</td><td>**Timeline:**
3-5 years (with specific milestones for 2028 and 2030 aligning with targets).</td></tr>
<tr><td>Party/Parties:
Interested countries:

- IWG members: Spain, Austria, Germany, Italy, Portugal, Turkey, Belgium, Cyprus, France, Greece
Industrial partners:
- Manufacturing equipment firms, Solar PVT producers, Robotics/AI startup, Material suppliers, Digitalization solution providers, Automation integrators
Research institutes:
- Universities and RTOs working on: robotics and automation engineering; computer science and artificial intelligence; process and manufacturing engineering; advanced manufacturing technologies; systems engineering and industrial engineering; sustainable manufacturing; mechanical engineering; electrical engineering; material science and engineering; sustainability sciences and circular economy; among others.
Other entities potentially interested:
Solar Heat Europe, RHC ETIP (&ESTTP), National Solar Trade Associations, Solar KEYMARK Network, European Committee for Standardization (CEN), International Organization for Standardization (ISO)</td><td>**Implementation instruments:**
- ***Horizon Europe*** (Cluster 4: Digital, Industry, and Space, Cluster 5: Climate, Energy and Mobility) – specifically calls related to advanced manufacturing, industrial symbiosis, circular economy, and AI/robotics in production processes for renewable energy technologies.
- ***Clean Energy Transition Partnership*** (CETP): Joint calls focusing on industrial decarbonisation, advanced manufacturing for renewables, and integrated energy solutions.
- ***European Regional Development Fund*** (ERDF): Support for regional innovation ecosystems, modernization of industrial facilities, pilot lines, and SME involvement in adopting advanced manufacturing processes.
- National grants (e.g.,…)
- ***EIT Manufacturing*** (European Institute of Innovation & Technology): For innovation in advanced manufacturing processes, skill development, and accelerating industrial scaling of new technologies
- ***Innovation Fund:*** For large-scale demonstration and first-of-a-kind deployment of innovative low-carbon manufacturing technologies.
- ***Private sector investment***: Direct industry funding for R&D, pilot projects, and establishment of new, highly automated, and sustainable production facilities in Europe.</td><td>**Indicative financing contribution:**

N/A</td></tr>
</table>

AREA OF ACTIVITY B: ADVANCED SOLAR THERMAL SYSTEMS AND DIGITAL DESIGN TOOLS

R&I Activity B.1: Smart systems for solar thermal

<table>
<tr><td colspan="2">Title:
Transformative AI-enhanced digital tools for solar thermal (ST) systems and technologies</td></tr>
<tr><td>Previous related research activities:
- Development of initial digital models for solar thermal components
• E.g.: Digital tools for CSP and solar thermal plants (HE call)
- Establishment of fundamental data collection methods for solar thermal performance.
• IEA-SHC Task46</td><td>State-of-the-Art
• Basic AI tools optimize small-scale systems; district heating digital twins lack real-time adaptability and predictive capabilities.
• Limited open, standardised and high-resolution data restricts AI training and benchmarking for diverse solar thermal system configurations and operational scenarios.
• Sparse interoperability standards and robust communication protocols for hybrid systems hinder seamless integration and optimal energy management.
• AI tools for sector-specific solar heat are experimental.</td></tr>
<tr><td>Targets:
• Demonstrate the benefits that AI tools and technologies can have across the lifetime of solar thermal systems (EPC, Operation & Maintenance, end-of-life management)
• Reduce LCoHC (Levelized Cost of Heat and Cooling) of integrated smart solar thermal systems by 10% by 2030, compared to 2020.
• Deploy AI-driven control in district heating networks and large-scale industrial solar thermal plants by 2030, demonstrating at least 15% improvement in operational efficiency.
• Create an open-access solar thermal database with performance and operating data from ≥ 1.000 systems by 2030, enabling robust AI model training.
• Demonstrate complementarity to electrification strategies by reducing the load of local grids at peak hours and increasing supply flexibility through hybrid solutions.
• Control algorithms to improve thermal performance, considering variables like heat transfer fluid flow rate, mirror/collector inclination</td><td>Monitoring Mechanisms:
• Track LCoHC reduction (€/MWh) of ST systems implementing AI tools.
• Measure solar fraction in hybrids (%) and overall renewable energy share.
• Assess AI adoption in large solar thermal plants and its impact in efficiency
• Monitor database growth (number of data points, system types represented) and usage metrics.
Key Performance Indicators:
• LCoHC reduction (%).
• Solar fraction in hybrid systems (%).
• AI-driven operational efficiency improvement (%).
• Database size (number of data points).
• Electricity peak load reduction (%)
• Improve TES utilisation rate (%)</td></tr>
<tr><td colspan="2">Description:

This activity focuses on enhancing solar thermal technologies and systems, and on achieving their deeper integration into the future hybrid energy systems through transformative AI-driven digital solutions and innovative hybrid system configurations.

Innovative AI technologies and models will be applied across the lifecycle of ST systems to substantially enhance existing digital tools and applications (used e.g. in ST system design, modelling, simulation, engineering, operation & maintenance), and/or develop new digital tools and services. The</td></tr>
</table>

overall aim is to take advantage of AI to significantly improve the efficiency, accuracy and reliability of ST systems, reduce cost, facilitate the adoption of new business models, and to accelerate and deepen ST integration into the clean energy system.

Activities may include but are not limited to the following:

- AI-driven optimization of the operation & maintenance of ST systems coupled with Thermal Energy Storage (TES).
- Stimulating ST integration into hybrid energy systems & sector coupling, thereby enabling flexible operation and maximizing renewable energy utilization at high efficiency.
- Application of Digital Twins and data sharing for ST & TES systems and hybrid energy systems for scenario testing, operational optimization, early fault detection, performance benchmarking, and system-level validation, which also includes developing robust, interoperable, and open data platforms.
- AI-driven upgrade of software applications and systems that are used in the design, modelling and engineering of ST and TES systems, monitoring & control, performance verification, and Life Cycle Assessment (LCA).
- Awareness creation and training of ST stakeholders including ST technology providers, energy consultants and engineers, installers, operators, energy service companies, utilities, etc.

Projects aiming to achieve targets should include:

- **Hybrid Energy System Demonstrations:** Implement large-scale demonstration projects integrating solar thermal with various heat sources (e.g. waste heat, geothermal, biomass) and clean energy technologies (e.g. Heat Pumps) using advanced control strategies and showcasing high solar fractions and operational flexibility.
- **Digital Twin and Data Exchange Platform Development:** Create comprehensive digital twin platforms for ST plants and networks, as well as hybrid energy systems, enabling real-time performance monitoring, predictive maintenance, and optimized operation.
- **AI-driven Predictive Control Pilots:** Develop and deploy advanced AI algorithms for dynamic heat generation, distribution, and grid balancing in diverse solar thermal applications (e.g., district heating, industrial process heat, individual buildings), demonstrating optimal dispatch and grid service provision.
- **Development and piloting of open, standardized data frameworks and APIs** for seamless data exchange between different system components and energy management platforms.
- **Market-ready Solutions for grid services:** Develop and demonstrate ST systems capable of providing ancillary services to the grid (e.g. demand-side response, peak shaving via TES), leveraging smart controls and hybrid configurations.

TRL: TRL 4-5 to TRL 6-8

Total budget required: X M€ (to be confirmed)

Expected deliverables:	Timeline:
• Open-source AI tools and validated control algorithms for solar thermal system optimization across different scales and applications. • Hybrid demonstration plants (ST+TES+ other RES and/or clean energy technologies) showcasing high solar fraction, operational flexibility, and grid integration. • Commercial digital twin platform for solar thermal plants and district heating networks. • Solar thermal performance database with standardized data models and open access APIs. • Training modules for professionals (engineers, operators, planners) on smart solar thermal systems and digital tools.	3-5 years (with specific milestones for 2028 and 2030 aligning with targets)

Party/Parties:	**Implementation instruments:**	**Indicative financing contribution:**
Interested countries: - IWG members: Spain, Austria, Germany, Italy, Portugal, Turkey, Belgium, Cyprus, France, Greece ***Industrial partners:*** - Energy utilities, Tech firms, Solar thermal system integrators, Heat pump manufacturers, TES technology providers, Digital solution providers, AI/software developers, District heating operators, Industrial end-users. ***Research institutes:*** Universities and RTOs working on: artificial intelligence and machine learning; control engineering and model predictive control; data science; systems integration and energy informatics; energy systems engineering; thermal engineering; electrical engineering; among others **Other entities potentially interested:** Solar Heat Europe, RHC-ETIP, EUREC, ESTTP, Smart Grids Technology Platform (ETIP SNET), European Energy Research Alliance (EERA), European Heat Pump Association (EHPA), relevant industry associations (e.g., for industrial process heat users)	- Horizon Europe (Cluster 5: Climate, Energy, Mobility – specifically calls related to smart grids, energy system integration, AI in energy, TES, and renewable heating/cooling solutions). - Clean Energy Transition Partnership (CETP): Joint calls focusing on integrated energy systems, smart grids, and industrial decarbonisation. - Digital Europe Programme: Support for AI/data infrastructure, high-performance computing, and cybersecurity relevant to energy systems. - Innovation Fund: For large-scale demonstration and first-of-a-kind deployment of innovative smart energy technologies. - Competitiveness Fund - National grants: (e.g., Germany's BMBF, Spain's MICINN, Austrian FFG, French ADEME, Danish EUDP, Italian PNRR). - Connecting Europe Facility (CEF): Support for cross-border energy infrastructure projects, where smart solar thermal could play a role in integrated grids. - Private sector investment: Direct industry funding for R&D, pilot projects, and deployment of smart solar thermal solutions and associated digital infrastructure.	To be defined based on individual project proposals, national funding commitments, and anticipated private investment leverage

R&I Activity B.2: Emerging concepts for non-concentrated solar thermal innovation

<table>
<tr><td colspan="2">Title:
Emerging concepts for low temperature solar innovation</td></tr>
<tr><td>Previous related research activities:
• Initial pilot projects on solar thermal desalination or brine concentration, often limited in scale and without full integration into water management systems.
    o E.g. : AQUASOL-II IEA-SHC Task 62, Tenerife, WOLL
• Exploratory research into low-temperature solar drying systems for agriculture, demonstrating modest post-harvest loss reduction but lacking large-scale deployment or diverse crop application.
    o E.g.: IEA-SHC Task29
• Fundamental laboratory research on photocatalytic materials for solar fuel production and low TRL photo-reactor development.
    o E.g.: SOL2CHEM, DESIRED, REFINE, MOF2H2, SPECTRUM, IEA-SHC Task72</td>
<td>State-of-the-Art
- Solar desalination pilots produce ≤72 m³/day at 63 kWh/m³.
- Agro-solar drying efficiency gains can reach 50% using forced convection solar dryers.
- Prototypes of photo-reactors demonstrated at laboratorial scale.
- No standardized solutions for water-energy-food nexus integration, not even in the evaluation of the performance metrics of thermal desalination plants (as multi-effect distillation.</td></tr>
<tr><td>Targets:
- Demonstrate scalable solar desalination (≥80 m³/day capacity at <70 kWh/ m³).
- Demonstrate the use of photo-reactors for fuel or chemical commodities production up to TRL 6
- Achieve ≥8% solar-to-fuel efficiency in photo-reactor systems.
- Collect 1000 + sector-specific data points for open-access use.</td>
<td>Monitoring Mechanisms
• Solar-to-fuel efficiency (%) and production rate (e.g., kg H2/day).
• Desalination capacity (m³/day) and specific energy consumption (kWh/m³).
• Database: growth (number of data points, number of data contributors).

Key Performance Indicators:
• Solar-to-fuel efficiency (%).
• TRL of photo-reactors for fuel or chemical commodities.
• Desalination capacity (m³/day & kWh/ m³).
• Sector-specific data points collected (number).</td></tr>
<tr><td colspan="2">Description:

This activity targets disruptive solar applications beyond traditional heating and cooling, leveraging its unique ability to provide nonelectric solar energy for diverse, non-conventional and emerging sectors. Key priorities include developing and demonstrating new applications. It is open to new applications of solar energy, though it already includes some concrete cases of promising disruptive applications. One of these are Water-Energy-Food (WEF) Nexus Solutions, which encompasses low temperature solar applications for sustainable water management (e.g., desalination, wastewater treatment, purification) and food security (e.g., solar drying, sterilization, greenhouse heating), all while focusing on integrated, resource-efficient systems. Furthermore, the activity aims to advance the development of solar photo-reactors for the production of fuels and chemicals for photocatalytic, photo-electrochemical or photothermal processes, opening the pathway towards efficient and cost-effective production of green hydrogen, synthetic fuels, and other solar-derived chemicals, thereby promoting the decarbonization of industrial feedstock and energy carriers. Another crucial aspect is Agro-Industrial and Specialized Process Heat, involving research and piloting solar thermal integration into specific agro-industrial processes (e.g., drying of agricultural products, food processing, textile dyeing, bio-refineries) and other emerging industrial heat demands, demonstrating high solar fractions and process optimization. Finally, the activity emphasizes the development and validation of Advanced Digital Tools for Emerging Sectors, including AI-driven models and digital twins for accurate solar heat potential mapping, feasibility assessment, process integration, and optimal operation within these novel, sector-specific applications.</td></tr>
</table>

Projects aiming to achieve targets should include:

- Solar WEF Nexus Demonstrators: Design, build, and operate scalable solar thermal systems for desalination, wastewater treatment, and/or agricultural applications (e.g., smart greenhouses, solar drying of crops/food).
- Solar photo-reactor development: research, development and demonstration of photocatalytic, photo-electrochemical or photothermal reactor and system designs focusing on increasing efficiency, durability, and scalability. Demonstration in a relevant environment (TRL6) for green hydrogen or other chemical production at a pilot scale (TRL 6), assessing their technical feasibility, economic viability, and scalability.
- Open Data Platforms: Establish and populate open-access databases for diverse sector-specific solar thermal data, developing and promoting interoperability standards to facilitate data exchange and integration across different technologies and applications.

TRL: TRL 4- 6 (prototype validation) to 7 (prototype demo)

Total budget required: X M€ (to be confirmed)

Expected deliverables:

- Solar desalination (WEF, brine concentration) demonstration plants, demonstrating scalable solutions and resource efficiency.
- Photo-reactor systems for production of fuels or chemicals validated at pilot scale and providing a roadmap for industrialization.
- Sector-specific AI tools for solar thermal feasibility assessment and operational optimization, validated in diverse real-world use cases.
- Public database, including standardized data models and open APIs.
- Feasibility studies and techno-economic analyses for promising new solar fuel or WEF nexus applications.

Timeline:
4-5 years

Party/Parties:

Interested countries:
- IWG members: Spain, Austria, Germany, Italy, Portugal, Turkey, Belgium, Cyprus, France, Greece

Industrial partners:
- Water-tech firms, Agri-food companies, Chemical and energy companies (for fuels and chemical commodities), Industrial process heat users (e.g., textile, pulp & paper, mining), Digital solution providers, Solar thermal integrators.

Research institutes:
Universities and RTOs working on: thermal and mechanical engineering; environmental and chemical engineering; water and wastewater treatment science; agricultural engineering; material science and nanotechnology; photocatalysis and photochemistry; chemical and reactor engineering; industrial process engineering; renewable energy engineering; data science; systems integration and control engineering; artificial intelligence and machine learning; among others.

Other entities potentially interested:
Solar Heat Europe, RHC ETIP, Hydrogen Europe, Circular Bio-based Europe Joint Undertaking (CBE JU), Water Europe, relevant industrial sector associations.

Implementation instruments:
- Horizon Europe (Cluster 6: Food, Bioeconomy, Natural Resources), Cluster 5: Climate, Energy, Mobility (specifically for solar fuels, industrial processes, and digital aspects).
- PRIMA Partnership (Mediterranean innovation)
- National grants (e.g., Spain's MICINN, Greece's EYDAP, Germany's BMBF, French ADEME, Italian PNRR).
- Connecting Europe Facility (CEF): For infrastructure related to hydrogen or large-scale industrial projects.
- Innovation Fund: For first-of-a-kind commercial deployment of promising concepts.
- Clean Hydrogen Partnership: For research and demonstration projects specifically on green hydrogen production.
- Private sector investment: Direct industry funding for R&D and pilot projects.

Indicative financing contribution:

N/A (To be defined based on specific project proposals, national commitments, and anticipated private investment leverage

AREA OF ACTIVITY C: SOLAR THERMAL IN BUILDING AND B.I.S.T.

R&I Activity C.1: Integration of solar thermal technologies in buildings

<table>
<tr><td colspan="2">Title: High-solar-fraction and cost-effective systems for Net-Zero Energy and Zero-Emission Buildings in new buildings and in deep retrofit projects.</td></tr>
<tr><td>Previous related research activities:

• Pilots with high-solar fraction buildings (usually labelled as Solar -Active House).
  • IEA SHC Task 66, HeizSolar, SolSys, Excess, SensOpt
• Research on solar thermal solutions regarding building-integrated solar thermal (BIST) solutions (e.g. improving efficiency of coloured collectors).
  • Entranze, Farbkollektor, TABSOLAR II, Active Office
• Pilot projects demonstrating hybrid solar thermal systems (e.g., with heat pumps) primarily at building level with constrained solar fractions and basic control strategies.
  • E.g.: SunHorizon, SolWP-Hybrid,
• Development of early prefabricated solar-integrated façade prototypes, which were often costly, architecturally inflexible, or limited to building typologies.
  • Building of Tomorrow, Sundays, Excess</td>
<td>State-of-the-Art

- Solar thermal integration in buildings is well developed, with conventional rooftop solutions (on-rood and in-roof). Mostly used for domestic hot water in Southern Europe (solar fraction from 60-90%) and used also for combined (Combi) space and water heating in Central and Northern Europe (solar fraction 20-60%).
- Concepts such as Solar Active House (SAH) tested and implemented with over 60% solar fraction for space and water heating.
- Concepts combining ST and PV (including PVT) in Solar Active Houses (labelled SAH+) implemented, reaching over 37% solar fraction.
- Commercial and Industrial buildings benefitting from integrated solar thermal/PVT technologies, including storage.
- Hybrid solar + heat pumps achieve ~20–35% solar fraction; TES solutions offer short -term (≤12-hour) storage capabilities at competitive costs.
- Prefabricated solar thermal façades implemented in pilot cases.
- Business models (e.g., Heat as a Service -HaaS) remain experimental, with few large-scale examples.
- High upfront costs and low adoption of BIST in retrofits/historic buildings.
- Limited data on long-term performance and user acceptance.</td></tr>
<tr><td>Targets:

• Achieve higher solar fraction in NZEB/Zero-Emission Buildings and deep retrofit projects by 2030 (≥80% Mediterranean, ≥65% Continental, ≥50% Nordic).
• Reduce installed system costs by 25% through prefabrication, modular designs or streamlined installation processes.
• Develop scalable BIST solutions adaptable to diverse climates and building types (including historical buildings and high-density urban areas).
• Launch new, validated, and replicable business models for solar thermal in urban retrofits and multi-family dwellings.</td>
<td>Monitoring Mechanisms

• Solar fraction (%) in pilot buildings (new and retrofitted) and overall energy performance.
• Cost reduction progress (€/m² or €/kWth installed)
• Installation time (hours/m² or days/system).
• BIST adoption rate (number of new installations, market penetration)
• Replicability of business models.

Key Performance Indicators:

• Solar fraction in BIST systems (%).
• Installed system cost reduction (%).
• Installation time reduction (%).
• Number of scalable BIST solutions developed.
• Number of new, validated business models.</td></tr>
</table>

Description:

This activity focuses on the seamless, cost-effective, and aesthetic integration of solar thermal into new and existing buildings to maximize energy efficiency and accelerate decarbonization. Such integration should prioritise the easy adoption of the solutions, in terms of costs, technical complexity and permitting (e.g. concealed connections and colour-matched finishes).

Key priorities include developing and optimizing High Solar Fraction Systems for New & Renovated Buildings, which involves advanced solar thermal systems (including integrated storage) designed to achieve very high solar fractions (e.g., >80% for space heating and domestic hot water) in Net-Zero Energy Buildings (NZEB), Zero-Emission Buildings (ZEB), and specifically for deep retrofits of existing building stock. Additionally, the activity prioritizes Prefabricated, Multifunctional, and Aesthetic Façades & Roofs, entailing the design, development, and demonstration of prefabricated and modular solar thermal solutions (including hybrid PVT where appropriate) that combine energy generation with other building functions like aesthetics, insulation, shading, and structural elements, with an emphasis on ease of installation, architectural flexibility, and durability for diverse building types and climates. Furthermore, the creation of Climate-Adaptive and Urban-Friendly Designs is crucial, aiming to develop highly adaptable solar thermal solutions suitable for diverse geographical regions (e.g., cold vs. hot climates, high-density urban areas, historic buildings) and building typologies, ensuring high performance regardless of external conditions while minimizing visual impact. Lastly, the activity focuses on Innovative Business Models & Market Uptake, involving the development and piloting of scalable business models beyond traditional ownership, such as Heat-as-a-Service (HaaS), and community solar thermal schemes, which also includes addressing non-technological barriers like financing, policy frameworks, and user acceptance to accelerate market adoption, especially in urban retrofits.

Projects aiming to achieve targets should include:

- ***Integrated Pilot Projects for NZEB/ZEB & Deep Retrofits:*** Implement demonstration projects of high solar fraction BIST systems in a variety of new NZEB/ZEB and particularly deep retrofit scenarios (e.g., multi-family dwellings, public buildings, historic buildings), showcasing energy performance, comfort, and architectural integration.
- ***R&D and Prototyping of Next-Gen BIST Components:*** Research and develop lightweight, low-profile, and highly aesthetic solar thermal collectors and integrated storage solutions, focusing on ease of manufacturing, circularity, and adaptability to diverse architectural styles and climates. Prioritize innovations that cut install time and simplify permitting.
- **Hybrid solar thermal systems for buildings**: Develop and validate integrated solutions combining solar thermal with complementary technologies (e.g. heat pumps), tailored for residential and commercial buildings, to increase solar fractions and improve overall system performance.
- ***Piloting and Scaling Innovative Business Models:*** Establish partnerships with Energy Service Companies (ESCOs), real estate developers, and local authorities to test, validate, and scale new business models (e.g., Heat-as-a-Service, community financing schemes) for solar thermal deployment in urban and rural contexts, focusing on financial attractiveness and user engagement.
- **Digital tools for smart building integration:** Develop and demonstrate digital twins, predictive control, fault detection and diagnostics, open APIs, and BIM-connected commissioning tools to reduce operational costs and improve reliability of solar thermal systems in buildings.
- ***Standardization and Certification Development***: Drive the development of new, performance-based standardization and certification protocols for BIST systems, covering aspects like energy yield, durability, architectural integration, and installation efficiency, to build market trust and accelerate adoption.

TRL: From TRL 5 (prototype) to TRL 8 (commercial deployment)

Total budget required: X M€ (to be confirmed)

<table>
<tr><td colspan="2">Expected deliverables:

- NZEB/Zero-Emission Buildings with ≥80% solar fraction, including deep retrofit projects

- Prefabricated multifunctional solar façade systems and integrated roof solutions for EU-wide use, with documented cost reduction potential and installation time savings.

- Open-access digital toolkit for BIST design, feasibility assessment, and performance optimization, integrated with BIM software.

- Validated case studies on operational business models (HaaS, community schemes, etc.) for BIST in diverse building types and urban settings, including financial analyses.

- Provide open BIM objects (IFC/Revit families), installation sequences, and LCA/EPD info for the kits, aligned with CPR

- Guidelines and best practices for BIST integration into historic buildings and high-density urban environments.</td><td>Timeline:

3-5 years</td></tr>
<tr><td>Party/Parties:

Interested countries:

IWG members: Spain, Austria, Germany, Italy, Portugal, Turkey, Belgium, Cyprus, France, Greece
Industrial partners:

Construction firms, ESCOs, Solar thermal manufacturers, Building material suppliers, Architects, Real estate developers, Utilities, Financial institutions.

Research institutes:
Universities and RTOs working on: Building-integrated solar thermal (BIST) design and engineering, advanced solar heating and cooling systems, smart control systems for building energy management, PVT collector technology.
Other entities potentially interested:
Solar Heat Europe, RHC ETIP, Efficient Buildings Europe, sectoral associations (construction, architects, builders), ESCO associations, associations representing local and regional authorities.</td><td>Implementation instruments:

- <u>Horizon Europe</u>:
• Cluster 5: Climate, Energy, Mobility – specifically calls related to sustainable built environment, integrated energy systems, and renewable heating/cooling in buildings.
• Horizon Europe (Cluster 4: Digital, Industry, and Space – for industrialization of BIST and digital tools).
- <u>LIFE Programme</u> (circular economy and sustainability in buildings).
- <u>National grants</u> (e.g., France's ADEME, Italy's PNRR, Germany's BMWK, Spain's MITECO, Austrian KPC).
- <u>European City Facility</u> (urban decarbonization projects).
- <u>European Regional Development Fund</u> (ERDF): Support for regional innovation and smart specialization strategies in construction.
- <u>InvestEU Programme</u>: Providing financing, including for sustainable infrastructure and innovation in buildings.
- <u>Private sector investment</u>: Direct industry funding and partnerships for R&D, pilot projects, and market deployment.</td><td>Indicative

financing

contribution:

N/A

(To be defined based on specific project proposals, national funding commitments, and anticipated private investment leverage, with strong potential for private co-funding given the market relevance and building sector focus.)</td></tr>
</table>

AREA OF ACTIVITY D: ADVANCED SYSTEM INTEGRATION – LARGE-SCALE SOLAR THERMAL

R&I Activity D.1: Advanced system for SHIP (Solar Heat for Industrial Processes)

Title: High-efficiency solar industrial heat (SHIP) systems	

Previous related research activities:
- Pilot projects demonstrating solar thermal for industrial processes (SHIP) in different industrial processes, at different temperature levels, often limited to low-to-medium temperature applications and average solar fractions (e.g., 30-40%).
    • E.g.: SHIP2FAIR, INSHIP, IEA-SHC Task64
- Exploratory research on thermal storage, looking into options using phase change materials or chemical storage, aiming at improved flexibility and broader temperature ranges.
    • E.g.: ThermalBattery, IEA-SHC task75, IEA-SHC task74
- Pilot projects on hybrid systems (e.g., solar + heat pumps), aiming at improving exergetic efficiency and improving integration protocols.
    • E.g.: HyCool, SOLINDARITY, AnanaS
	State-of-the-Art
	- Existing SHIP systems achieve 30–40% solar fraction in sectors like food processing, indicating a significant reliance on auxiliary heat sources.
	- Storage costs for phase-change materials aiming at up to 200°C at €30-60/kWh (thermal capacity), which represents a significant economic barrier to widespread adoption.
	- Hybrid solar + heat pump systems under development, but market deployment is limited due to a lack of sufficient proven integrated solutions and standardized protocols for industrial integration.
	- High capital costs for SHIP and thermal storage, combined with the preference of industrial companies for short-term HPA (Heat Purchase Agreements), constitute an important economic barrier, particularly in the absence of carbon pricing.
	- Limited exergetic efficiency in hybrid configurations, indicating a need for more advanced system design and control strategies.
	- No standardized protocols for industrial integration, resulting in costly, bespoke installations and a lack of trust from industrial end-users.
	- Attempts at integrating solar thermal into niche industrial processes, often without comprehensive system optimization or economic viability at scale.

Targets: • Reduce thermal storage costs (up to 200°C) by 10% for SHIP applications. • Achieve steam generation efficiency ≥35% in solar-driven systems (150–250°C). • Demonstrate industrial plants with ≥40% solar heat fraction, sharing and collect the cost for the investments in TES and for the heat delivered. • Develop hybrid systems (solar + heat pumps/renewable gases) with ≥45% exergetic efficiency.	**Monitoring Mechanisms** • Storage cost reduction (€/kWh) and capital expenditure (€/kWth installed). • Steam efficiency (%) and specific steam output (kg/m2). • Solar fraction (%) in demonstration projects. • Exergetic efficiency improvement (%) in hybrid demos. **Key Performance Indicators** • Thermal storage cost reduction (€/kWh). • Steam generation efficiency (%). • Exergetic efficiency improvement (%). • Solar fraction in demonstration plants (%).

Description:

This activity focuses on advancing components critical for SHIP scalability and cost-effectiveness. The key priorities include developing thermal storage with low-cost, high-capacity solutions to meet variable industrial demand and optimising steam generation through advanced solar collectors and heat exchangers for efficient steam production. Furthermore, the activity emphasises hybrid integration, coupling solar heat with heat pumps, biomass, or renewable gases to create robust systems. Finally, it involves the development of digital tools, such as AI-driven control systems for demand-side management and grid flexibility.

Projects aiming to achieve targets should include:

- Solar Thermal for Specialized Industrial Process Heat: Develop and demonstrate innovative solar thermal solutions tailored for specific industrial sectors (e.g., textiles, pulp & paper, bio-refineries, mineral processing), ensuring seamless integration, high solar fractions, and verifiable energy and cost savings, sharing data on costs and performance.
- Pilot solar steam systems in sectors like food & beverages, or chemicals, validating high-efficiency components in real-world operational environments.
- R&D on phase-change materials (PCM),molten salt and novel storage technologies for SHIP, focusing on cost reduction, scalability, and integration into existing industrial systems.
- Hybrid system demonstrations (e.g., solar + heat pumps or solar + biomass) that optimize exergetic efficiency and provide high solar fractions year-round.
- Development of open-source digital twins for SHIP performance optimization, enabling real-time monitoring, predictive maintenance, and seamless integration with factory control systems.
- Standardized interfaces for industrial heat exchanger integration, developed in collaboration with industrial partners and engineering firms to facilitate ‘plug-and-flow’ solutions.

TRL: TRL 7-8 (industrial demonstration)

Total budget required: X M€ (to be confirmed)

Expected deliverables:

- Low-cost thermal storage systems at ≥10 MWh capacity, validated in an industrial environment.
- Solar steam plants with NCST with ≥35% efficiency, operational in diverse industrial sectors.
- Hybrid SHIP systems operational in diverse industries, demonstrating high exergetic efficiency.
- Open-access digital toolkit for SHIP design and integration, including validated performance models and technical specifications.
- New standardized interfaces for SHIP integration, published as open protocols.

Timeline:

3-5 years

Party/Parties:

Interested countries:

- IWG members: Spain, Austria, Germany, Italy, Portugal, Turkey, Belgium, Cyprus, France, Greece

Industrial partners:

- Industrial heat users, Thermal storage firms, Engineering bureaus

Research institutes:

Universities and RTOs working on: Thermal and process engineering, materials science, control systems, and data science.

Other entities potentially interested:

Solar Heat Europe, RHC-ETIP, ESTTP, A.SPIRE (for process industries), national associations for district heating and industrial energy.

Implementation instruments:

- Horizon Europe (Cluster 5: Climate, Energy, Mobility) and Cluster 4 (Digital, Industry and Space).
- Clean Energy Transition Partnership (CETP).
- National grants (e.g., Germany’s BMWK, Spain’s CDTI), and other national R&I programs aligned with industrial decarbonization.
- European Innovation Council (EIC) Accelerator.
- Innovation Fund (for large-scale, first-of-a-kind projects).
- InvestEU Programme (for project financing and de-risking).
- National Recovery and Resilience Plans (RRPs) that support industrial modernization.

Indicative financing contribution:

N/A

R&I Activity D.2: System-level innovation for solar district heating (SDH) systems

<table>
<tr><td colspan="2">Title: New development for next-generation solar district heating networks</td></tr>
<tr><td>Previous related research activities:
• Large-scale SDH projects in Northern and Central Europe implemented.
• e.g.: IEA SHC Task 68, IEA SHC Task 55,
• Validation of seasonal thermal energy storage (STES), including pit and borehole storage.
• E.g.: TREASURE, IEA SHC Task 45, USES4HEAT, PUSH-IT, INTERSTORES
• Early development of digital twin concepts for solar thermal integration.
• E.g.: WarmteStad Groningen, GREEN HEAT LIFE, HeaTwin</td><td>State-of-the-Art
• SDH solar fraction without seasonal storage averages 10–20%.
• SDH solar fraction with seasonal storage can reach above 50%.
• Seasonal thermal energy storage costs remain high at €25–38/m^3.
• Hybrid systems lack standardized integration protocols.
• Major barriers include high capital costs and limited retrofit solutions.
• Digital twins for SDH are still limited and experimental.
• Standardized digital tools for planning are non-existent, leading to custom solutions.</td></tr>
<tr><td>Targets:
• Reduce LCoH (Levelized Cost of Heat) by 15% in SDH systems by 2030.
• Achieve ≥25% solar fraction in new/retrofitted SDH networks without seasonal storage.
• Deploy digital twins in SDH systems for real-time optimization.
• Demonstrate seasonal thermal storage with ≤€1,5/kWh capacity cost.
• Pilot automated cleaning systems for large-scale solar thermal plants</td><td>Monitoring Mechanisms
• LCoH reduction,
• Solar fraction in SDH networks
• Storage cost/kWh,
• Digital twin adoption.

Key Performance Indicators
• LCoH (€/MWh).
• Solar fraction (%).
• Cost of seasonal storage (€/kWh).
• Number of digital twin deployments.
• SDH grid efficiency improvement (%).</td></tr>
<tr><td colspan="2">Description:

This activity focuses on enhancing SDH performance and scalability through the development of advanced thermal storage, which includes low-cost, high-capacity solutions such as seasonal storage technologies. It emphasizes the creation of hybrid systems by integrating solar heat with sources like geothermal, waste heat, or heat pumps. To support effective integration of solar thermal in district heating networks and hybrid systems (e.g. ST-HP, ST-biomass, ST-TES), the activity will also address tools to simplify dimensioning and design, specific hydraulic concepts, and optimized control strategies. Additionally, it includes the development and demonstration of automated and resource-efficient cleaning systems for large-scale solar thermal collector fields. Furthermore, the activity will leverage digital tools, including AI-driven digital twins, for predictive maintenance and demand forecasting.

Finally, a key priority is the creation of retrofit solutions for upgrading existing networks with smart valves, sensors, and solar collectors.

Projects aiming to achieve targets should include:
- Hybrid solar + heat pump DH plants in high-heat-demand regions.
- Retrofit projects integrating solar thermal into solid fuel (e.g. biomass) or fossil-based district heating systems with higher solar fractions.
- AI-driven digital twins for SDH network balancing and failure prediction.
- Automated and resource-efficient cleaning systems for large-scale solar thermal collector fields
- Open-source tools for urban planners to assess solar SDH potential.</td></tr>
<tr><td colspan="2">TRL: TRL 7-8 (commercial demonstration)</td></tr>
<tr><td colspan="2">Total budget required: X M€ (to be confirmed)</td></tr>
</table>

<table>
<tr>
<td colspan="2">Expected deliverables:
• SDH networks with ≥25% solar fraction (without seasonal storage)
• Seasonal thermal storage systems reaching ≤€1,5/kWh.
• Commercial digital twin platform for SDH operators.
• Cleaning system prototypes for large-scale solar thermal collectors
• Retrofit toolkit for fossil-to-solar SDH transitions.</td>
<td>Timeline: 3-5 years</td>
</tr>
<tr>
<td>Party/Parties:

Interested countries:
- IWG members: Spain, Austria, Germany, Italy, Portugal, Turkey, Belgium, Cyprus, France, Greece

Industrial partners:
- District heating utilities, Energy Service Companies, DH component suppliers, Engineering firms.
Research institutes
Universities and RTOs working on: Heat and fluid dynamics, thermal energy storage, systems integration, digitalization, and urban planning.
Other entities potentially interested:
Solar Heat Europe, RHC ETIP, EuroHeat and Power (EHP), DHC+ Platform, IEA-SHC, IEA-DHC.</td>
<td>Implementation instruments:
- Horizon Europe (Cluster 5: Climate, Energy, Mobility)
- Digital Europe Programme (AI and data tools)
- European Regional Development Fund (ERDF)
- European Investment Fund (EIF)
- Clean Energy Transition Partnership (CETP)
- European Innovation Council (EIC) Accelerator.
- InvestEU Programme (for project financing and de-risking).
- National grants (e.g., Denmark's EUDP, Germany's BMWK)</td>
<td>Indicative financing contribution:

N/A</td>
</tr>
</table>

R&I Activity D.3: Addressing market barriers affecting Large Scale Solar Thermal Systems

Title: Overcoming non-technical barriers for accelerated market deployment	
Previous related research activities: • Projects focusing on standardization and certification of small-to-medium-scale solar thermal components. o E.g.: QAiST, IEA-SHC Task57 • Initiatives from industry associations and the European Commission to promote renewable energy business models and financing schemes. o E.g.: SOLARGE • Academic studies on the skills gap in the renewable energy sector and the development of digital training tools. o E.g.: Skills in the Renewable Energy Sector, Green skills gap	**State-of-the-Art** • Projects face long development times. Different causes include complex permitting, a lack of standardized contracts, and a shortage of experienced developers. • A significant skills deficit exists in the supply chain. Engineers, installers (EPCs), and utility operators lack the specialized knowledge needed for designing, installing, and operating large-scale systems. • Additional financing and operational models for large-scale heat delivery are needed. Current models often favour electricity (e.g., PV) or traditional fossil fuels. This hinders bankability and investor confidence. • The sector lacks EU-wide standards and certification. Solar KEYMARK is well-known for products, but not for large-scale systems, nor is it widely recognized by non-solar actors like utilities and financial institutions. This creates market uncertainty.
Targets: • Reduce average project development time for large solar thermal systems by 20% by 2030. • Pilot financial or contractual business models. • Develop certification for large-scale systems. • - Upskill professionals in the supply chain via new digital training platforms.	**Monitoring Mechanisms** • Project development lifecycle (time from concept to operation). • Number and type of new business models launched. • Adoption rate of the new certification scheme. • Number of professionals trained and certified.

Description:

This activity focuses on dismantling the primary non-technical barriers to the widespread deployment of large-scale solar thermal systems. It will achieve this by increasing awareness and training, of actors across the wider value chain—including EPCs, ESCOs, and utilities, as well as financiers and insurers—to confidently and efficiently work with this technology. A second key priority is developing new business models that better align with the characteristics of solar thermal heat, making projects more financially attractive and scalable. Finally, the activity aims to advance standards and certification schemes for large-scale solar thermal systems to build market trust and reduce project risk. This holistic approach will accelerate the transition of solar heat from a niche technology to a mainstream solution for industrial and district heating applications.

Projects aiming to achieve targets should include:

- Studies and implementation of different models of Heat -as-a-Service (HaaS) contracts, selling heat to a utility or industry on a per-MWh basis.
- Development of digital training module for system installers (considering tools such as AI and a virtual reality), a digital twin for operational optimization training, and a collaborative project management platform for large-scale solar thermal deployment.
- Develop a new EU-wide standard for system-level performance and safety, building on the Solar KEYMARK, and pilot its certification on several real-world projects.

<table>
<tr><td colspan="3">TRL: Soft activities / Coordination and Support action</td></tr>
<tr><td colspan="3">Total budget required: X M€ (to be confirmed)</td></tr>
<tr><td colspan="2">Expected deliverables:

- New business models for large-scale solar thermal systems (e.g., EaaS, heat purchase agreements).
- Digital tools for skills development and fast deployment downstream the supply chain (EPCs, ESCOs, utilities, etc.)
- Standards and certification schemes for large-scale solar thermal systems.
- A comprehensive report on financial, legal, and regulatory barriers in key EU markets.</td><td>Timeline: 3-5 years</td></tr>
<tr><td>Party/Parties:
Interested countries:
- IWG members: Spain, Austria, Germany, Italy, Portugal, Turkey, Belgium, Cyprus, France, Greece
Industrial partners:
- Engineering, Procurement, and Construction (EPC) firms; Energy Service Companies (ESCOs); financial institutions; solar thermal manufacturers.
Research institutes
Universities, RTOs and think-tanks working on: Economics and business models, legal and regulatory studies, workforce development, and standardization.
Other entities potentially interested:
Solar Heat Europe, RHC ETIP, IEA-SHC.</td><td>Implementation instruments:
- Horizon Europe (Cluster 5: Climate, Energy, Mobility),
- Digital Europe Programme,
- Innovation Fund for low-carbon technologies,
- EIT InnoEnergy,
- National grants (e.g., German BMWK, Spanish CDTI).</td><td>Indicative financing contribution:

N/A</td></tr>
</table>