SMART INTEGRATION OF WASTE AND RENEWABLE ENERGY FOR SUSTAINABLE HEAT UPGRADE IN THE INDUSTRY (SUSHEAT)

Antonio Rovira[1,*], Rafael Guedez[2], Silvia Trevisan[2], Arne Høeg[3], David Vérez[4], Luisa F. Cabeza[4], Alex Butean[5], Juan Enríquez[6], Richard Law[7], Mikael Muegge[8], Harry Sayannos[9], Katarína Nagyová[10], Michele Santovito[11], Blaž Likozar[12], Vasilis Mandrekas[13], Eirik A. Solberg[14], Rubén Barbero[1].

[1]*Universidad Nacional de Educación a Distancia (UNED), Juan del Rosal 12, 28040, Madrid (Spain)*
[2]*Kungliga Tekniska Hoegskolan (KTH), Brinellvägen, 11428, Stockholm (Sweden)*
[3]*Enerin, Torvveien 1, 1385, Asker (Norway)*
[4]*Universitat de Lleida (UdL), Pere de Cabrera, s/n, 25001, Lleida (Spain)*
[5]*WIZ development & services, Lucian Blaga University of Sibiu, Poiana Nr 5 / 24, 550151, Sibiu (Romania)*
[6]*Dynamic & Security Computations, Camarena 177 Local, 28047, Madrid (Spain)*
[7]*Newcastle University, Kings Gate, NE1 7RU, Newcastle upon Tyne (UK)*
[8]*RTDS Association, Lerchengasse 25/2-3, 1080, Wien (Austria)*
[9]*Industrial Solar, Basler Str. 115, 79115, Freiburg (Germany)*
[10]*LC Innoconsult International (LCIN), Felső-Tisza part 31-34. G. 9/24, 6723, Szeged (Hungary)*
[11]*I-TES, Via G. Quarello, 15/a, 10135, Torino (Italy)*
[12]*Kemijski Institut, Hajdrihova 19, 1000, Ljubljana (Slovenia)*
[13]*Galaktokomika Mandrekas, National Road Athens-Korinth 80, 20100, Corinth (Greece)*
[14]*Pelagia, Bradbenken 1, 5003, Bergen (Norway)*

*Corresponding Author: rovira@ind.uned.es

ABSTRACT

SUSHEAT is an EU-granted project (GA 101103552) that faces the main technological challenges to design key components for a new generation of heat upgrade systems for the industry, fed by Renewable Energy Sources (RES) and waste heat recuperation. With 14 partners from 11 different countries, SUSHEAT develops three novel technologies: an advanced high-temperature heat pump (HT-HP) by Enerin, a Phase Change Material (PCM) bio-inspired Thermal Energy Storage system by University of Lleida, and a Control & Integration Twin system (CIT) by WIZ development & services.
SUSHEAT should attain an efficient heat upgrade up to 150-250 °C thanks to the use of an innovative high-temperature Stirling heat pump working with helium, drastically enlarging the industrial exploitability of waste heat upgrade systems. Enerin’s heat pump technology has been developed based on experience with several previous Stirling engine and heat pump projects, first generating hot water at up to 120 °C, and then also generating steam with a hot-water heated steam generator. The aim for the SUSHEAT is to reach TRL 5 when the heat pump is validated at up to 250 °C in the relevant operating conditions. Besides, the integration of innovative energy storage solutions should ensure a reliable, flexible, and customizable heat delivery with full decoupling from any waste heat recovery and renewables availability. Finally, SUSHEAT will provide user-friendly tools and a digital twin for the control system based on smart decision-making algorithms.
Once designed, the three prototypes (one per key component) will be investigated and tested via experimental lab at KTH’s premises to replicate the operational conditions of a dairy and a fish-oil industries.
Taking into account typical industrial heat requirements, as well as excess heat production, electric market perspectives and regulation aspects, the project will be a keystone towards the promotion of renewable-based hybrid industrial heat upgrade systems for industrial heat decarbonization.

1 INTRODUCTION

Decarbonization of industry requires a new approach for the design of every link of the energy supply chain at the different industries. Moving from fossil fuel-based technologies that use flexible burners able to provide energy at wide temperature ranges, to renewables technologies that are strongly constrained by the availability of the resource and the temperature of the heat, makes it necessary to optimize the resources and the processes, including the excess & waste energy generated by/within them.

Heat upgrade technologies are becoming increasingly relevant as one of the ways to meet the high thermal energy demand required for industry. This involves a double benefit: firstly, by using Renewable Energy Sources (RES), fossil fuel consumption and emission of pollution and greenhouse gases (GHG) into the atmosphere are reduced; secondly, heat for industrial processes becomes a new market where other renewable-based technologies, like solar, are having limitations for deployment.

According to a study by the National Renewable Energy Laboratory (NREL) (Kurup & Turchi, 2015), the EU has been a leader in the development and deployment of solar heat for industrial processes. However, this solar contribution is currently limited to heat below 150 ºC due to the constraints present in the sector, mainly weather at site and land availability within the industry. This temperature threshold coincides with the current limitation of maximum temperatures for heat upgrade technologies based on conventional heat pumps, mainly due to the limitations introduced by the working fluid.

Thus, the next step in wide scale introduction of RES at temperatures above 150 °C is to develop heat pumps and integrated technologies for reliable and intensive heat supply in processes above that temperature, based on energy harvesting regardless the renewable source or waste sink, and even able to enlarge the exploitation possibilities. Nowadays, commercial technologies (heat pumps) can effectively deliver heat up to 120 °C. However, a wide part of the industrial sector requires higher temperatures, 150-250 °C (**Figure 1**) and is currently mostly dependent on fossil fuels.

Industry (TWh)	<60 °C	60-150 °C	150-400 °C	>400 °C	Total
Basic metals (iron and steel and non-ferrous metals)	2	12.2	16.6	343.1	373.8
Chemicals & petrochemical	10.4	63.8	95.5	159.1	328.8
Non-metallic minerals	1.6	9.9	11.5	256.5	279.4
Transport equipment	3.2	19.7	5.7	0	28.7
Machinery	10.1	61.5	23.9	0	95.4
Mining & quarrying	1.1	6.5	6.3	0	13.9
Food & tobacco	17.5	106.8	77.6	0	201.9
Pulp & paper	8.2	50.3	31.9	16	106.3
Textile & leather	0.4	2.7	19	0	22.2
Other process heat	10.9	66.5	49.3	22.9	149.6
Total	65.4	400	337.2	797.5	1600

Figure 1: Potential for SUSHEAT concept (Kosmadakis, 2019).

The integration of different renewable sources as another link of the chain, together with the use of the available waste energy of the plants, and the introduction of thermal storage system, become into a potential path to manage the energy flows, upgrade the heat available in the sinks and optimise the dispatchability of the resources.

2 SUSHEAT PROJECT

SUSHEAT project tackles the problem, proposing an innovative approach enabling a more cost-efficient, flexible, user oriented, and reliable heat upgrade concept with a smart integration of all the available resources and targeting a heat delivery temperature in the range of 150 to 250 ºC. The proposed concept, while leveraging on existing industrial/R&D partners' scientific and commercial know-how, targets a wide spectrum of the industrial sector, where current renewable-based technologies have limitations and there is not enough awareness about the potential economic savings, environmental benefits and experience.

The project has started in May 2023 and, during its four years of duration, it will face the main technological challenges to address the development of the key components for a new generation of

highly efficient industrial heat upgrade systems fed RES and waste heat recuperation. It develops and validates three novel enabling technologies: HT-HP, PCM bio-inspired Thermal Energy Storage (TES) system, and CIT system. Thanks to the use of the HT-HP, the system is able to reach the targeted temperature. The Stirling-based heat pump works with helium -non-toxic, inert, zero ozone depletion potential (ODP) and zero global warming potential-, and it is expected a COP higher than 2.8 for a temperature ratio of 1.2, and a long-term production cost (by 2030) of 100 €/kW. The integration of innovative bio-inspired energy storage solutions will ensure a reliable, flexible, and customizable heat delivery with full decoupling from any waste heat recovery and renewables availability. Moreover, SUSHEAT will provide user-friendly tools and a digital twin for the control system and advising industrial stakeholders, based on smart decision-making algorithms.
Figure 2 shows a simplified layout of the proposed concept. The layout shows how the concept integrates different renewables resources & sinks, namely solar energy, ambient (as a reservoir) and waste industrial excess energy, thanks to the use of two novel TES, an innovative HT-HP and a Fresnel solar thermal collector. The concept is completed with the smart CIT system based on AI.

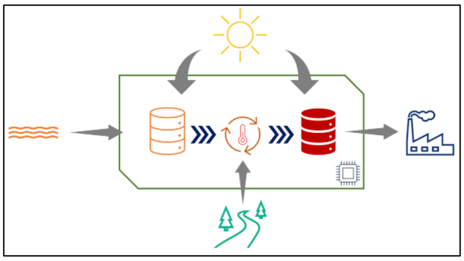

Figure 2: Simplified layout of the SUSHEAT concept.

As it is depicted in **Figure 3**, the waste energy source/s present in the industry are used to charge the low temperature TES. This low temperature energy is restored when decided by the control system, once upgraded by the HT-HP, and stored again in the high temperature TES. The HT-HP is also able to upgrade heat from the ambient either to the low temperature TES, which is later introduced to the high temperature TES once upgraded, or even directly to the high temperature one. Finally, when available, the solar collectors can complete the system, introducing heat directly to the high temperature TES and, when the irradiation conditions are not optimal, it can work at lower temperature to charge the low temperature TES, which is later upgraded, extending the LFC operation and feasibility.
The use of any of the three resources (waste, ambient and/or solar energy), allows a decrease of the fossil fuel consumption, with the corresponding decarbonization, emission of GHG & pollutants and release of waste energy to the environment. These benefits will be optimized for each case-study by the smart control system.

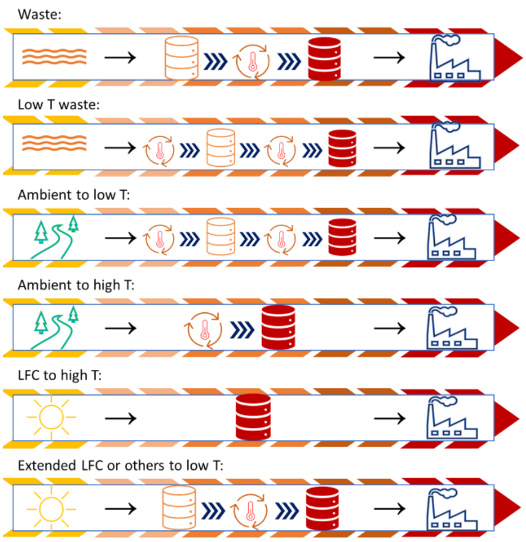

Figure 3: Operating modes of SUSHEAT.

Thus, SUSHEAT will bring an effective self-assessment of the most suited heat upgrade system integration including not only the key enabling components developed in SUSHEAT but, beyond, also leveraging on off-the-self RES-based units, particularly solar thermal collectors even enlarging the feasibility of Concentrating Solar Power systems that can extend its operation working at low temperature. By developing industry-focused self-assessment tools, and directly engaging different industrial stakeholders, SUSHEAT will contribute to identify the target industrial processes and sites which would benefit from the concept and provide solutions to maximize the industrial efficiency while contributing to the sector's decarbonization.
With the development and validation of the three key components, SUSHEAT will prove the effectiveness and techno-economic viability in various industrial sectors and its availability to be efficiently hybridized with off-the-shelf RES based components. The complete SUSHEAT concept will be tested at KTH laboratories to replicate the operational conditions of a dairy (Mandrekas) and fish-oil (Pelagia) Case Studies.

3 CONSORTIUM AND PROJECT IMPLEMENTATION

The consortium is made up of 14 partners, including universities, research centers, SMEs and big companies from 11 different countries: Spain, Sweden, Norway, Romania, UK, Austria, Germany, Hungary, Italy, Slovenia and Greece. UNED (Spain) coordinates the project, that is divided into 7 work-packages (WP), as shown in **Figure 5**.

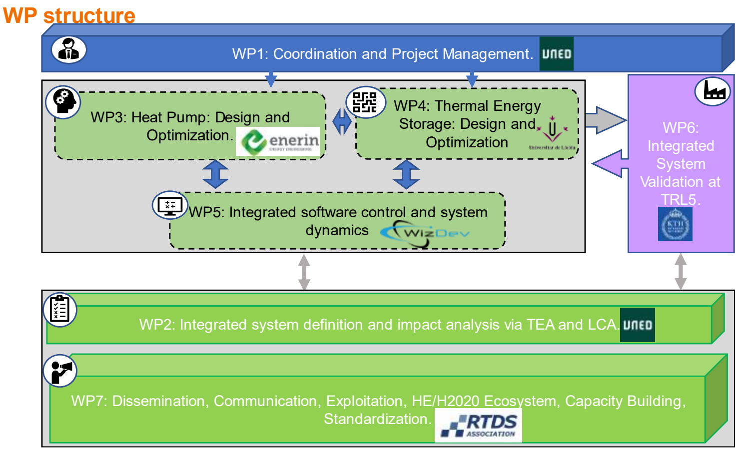

Figure 5: PERT, WP interdependencies within SUSHEAT.

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