Worldwide economic development, rising population and technological development have resulted in a massive increase in global energy demand. This, in conjunction with the current non-sustainable energy production methods, has created a severe environmental crisis. To this end, researchers and policymakers are promoting a transition to more sustainable and energy-efficient technologies to mediate this global warming crisis. Foundation industries are responsible for a large part of this consumption but are among the most challenging sectors to be decarbonised sustainably. The EU has set an ambitious target of 42% industrial sector carbon reduction by 2030. As per an EU estimate, the industrial sector accounts for 27% of the overall energy consumption and for the generation of 30% of heat-related CO_2 emissions. Industrial thermal processes account for 70% of their total energy demand, which is equal to 18.9% of the entire EU energy demand. Thermal processes emit a large amount of waste heat, with almost one-fifth (~400 TWh/yr) classified as high-grade, with good potential for recovery and reuse. Waste heat recovery (WHR) is, thus, among the next global frontiers.

In thermal energy storage (TES), heat is supplied to a device for extraction and use at a later time. TES is highly customisable and capable of resolving supply/demand intermittency issues, making it a very promising solution to WHR problems. TES is a mature technology with considerable market penetration, particularly in high solar energy plants and industries, which generate a lot of waste heat. Latent heat energy storage (LHTES) is the most favourable among the various storage methods. It can store energy with low volume, mass and cost requirements. LHTES has witnessed a considerable publication surge in the last decade, with the total number of citations doubling (2016-2019). LHTES is based on the ability of materials to absorb or release heat during their transition from one state to another (most commonly from solid to liquid state). These materials are called phase change materials (PCMs). The current TES cumulative annual growth rate of 14.4%, has PCMs at the forefront.

However, despite their good performance, PCMs still have several disadvantages. Addressing these is critical for the modernisation of LHTES to meet future stricter requirements. Encompassing PCMs in a solid matrix can largely improve their performance. This is because heat transfer is higher and more homogenous in solid materials, and they do not induce corrosion in structural materials. The resulting material is called a composite PCM (CPCM). The simplest and easily scalable CPCM production method is mix-sintering, which involves mixing the PCM with ceramic, carbon or metal grains, compressing the mixture into the desired shape and then sintering it. However, CPCM fabrication is a complex process, and even after 15 years of material design, their porosity is sometimes still high, and the PCM fraction in the CPCM is not all very high. It is clear that the full potential of CPCMs has not yet been realised. There is substantial room for further performance enhancement in heat transfer through porosity minimisation and energy density through PCM fraction increase (PCMs can store more heat than solids)

Nanoparticles (NPs) are particles of matter between 1 and 100 nanometres (nm) in diameter. A fluid containing NPs is called a nanofluid. Adding NPs in liquids has been proven to have a considerable effect on their properties. The main concept is that PCM properties can be tuned through NP suspension in a highly beneficial way to CPCM porosity and energy density. Scarce existing literature reports and preliminary data provide strong evidence towards this.

To this end, the first objective of this project is to prepare a series of nanofluids combining a wide range of PCMs with NPs of various sizes, shapes, types and concentrations. These will be investigated with a focus on their properties that can enhance CPCM performance. The nanofluids will then be combined with a broad range of matrix materials commonly encountered in the literature to prepare CPCMs. These CPCMs will then be evaluated in terms of properties that dictate LHTES system performance. Following this extensive experimental data accumulation process, statistical modelling will be used to develop generalised mathematical trends that can provide relationships between NP, PCM and CPCM properties. Insights from these relationships will then be used to prepare a CPCM with unprecedented thermal performance, with respect to the state-of-the-art, using the simple and scalable mix sintering method. LHTES material innovation can thus play a pivotal role in a more efficient and sustainable global energy future.

On a scientific level, this project can vastly improve the CPCM fabrication process and consequentially accelerate TES material design and optimise TES performance. At the same time, its fundamental outreach can provide a pathway to overcome the computationally and experimentally expensive physics of solid-liquid interactions in materials and give leverage to various other disciplines employing such media, like in catalysis, groundwater flow, oil and gas extraction, CO_2 capture and storage, membrane synthesis and medical applications.