Tech UPGRADE

Project Summary for the Socio-Economic Impact Analysis

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Excellence

Problem Addressed

The EU's Clean Planet for All strategy targets a net-zero greenhouse-gas economy by 2050. Over 75% of emissions come from electricity, heat, transport, and industrial activities. Industrial processes alone produce 78% of these emissions, with process heat representing the largest share (47%). Around 70% of industrial process heat is still supplied by fossil fuels, especially natural gas, which exposes the EU to geopolitical dependency, most notably on Russian gas, triggering initiatives like the REPowerEU plan.

Decarbonizing industrial heat is therefore critical and aligns with UN SDG 7 (Affordable and Clean Energy). Solar heat and waste-heat recovery could play decisive roles, but their temperature levels are typically too low for many industrial applications. Roughly one-third of the EU's waste heat (about 100 TWh/year) lies between 100–200 °C, and many district heating networks operate at 60–120 °C. To use these resources effectively for processes requiring 150–250 °C, efficient and affordable heat-upgrade solutions are essential.

Current high-temperature vapor-compression heat pumps (VCHPs) generally operate only up to 120–150 °C, and prototypes aiming for 160–180 °C remain limited by compressor constraints, electricity consumption, low exergy efficiency (~30%), and environmentally harmful working fluids. Thermoacoustic heat pumps (TAHPs) and chemical heat pumps (ChHPs) also face major technological and economic barriers, including low COPs, high complexity, or limited temperature capabilities. Absorption and adsorption systems are particularly constrained by low COP_h values (<0.5–0.7), temperature limits, and long payback periods.

These limitations highlight the necessity for a novel, feasible, and sustainable alternative for upgrading heat to 150–250 °C.

Objectives and Ambition

TechUPGRADE aims to develop and demonstrate (at TRL 5) an innovative thermochemical heat-upgrade system, **a Hydration Heat Transformer**, available in two designs and capable of boosting low-grade heat from waste heat, solar collectors, or district heating to 150-250 °C. The concept minimizes electricity use by driving the system mainly with low-temperature heat.

The system exploits reversible dehydration/hydration of salt hydrates ($MX \cdot nH_2O \leftrightarrow MX + nH_2O$), where manipulating the water-vapor partial pressure raises the reaction's equilibrium temperature and enables heat upgrading. Different salt hydrates will be selected based on required source and target temperatures.

The technology integrates the following functionalities:

1. **Temperature lift (150–250 °C)** using very little electricity, unlike VCHPs and TAHPs.

2. **Built-in heat-storage capability** due to the thermochemical mechanism (when needed).

Technical Objectives

Key objectives (with KPIs) include:

- **SO1:** Identify and optimize salt hydrates for 150-250 °C operation, with full conversion <10 min, energy density >300 kWh/m³, >10 to 100 cycle stability, and production cost <3 €/kg.

  Strontium bromide ($SrBr_2$) has been selected as a candidate material to support SO1, given its potential to meet the required operating temperature, conversion time, energy density, and cost targets.

- **SO2:** Design reactors enabling cyclic dehydration/hydration without structural degradation for ≥200 cycles.

- **SO3:** Develop proof-of-concept structured materials and demonstrate >100 °C temperature lift and ≥100 operating cycles at 150-250 °C.

- **SO4:** Define optimized system-integration strategies achieving LCOH <4-6 c€/kWh and paving the way for industrial demonstration.

- **SO5:** Enable valorization of various low-value heat sources (waste, solar, district heating <2-4 c€/kWh) to deliver upgraded heat at <3–6 c€/kWh with minimal electricity use and net-zero emissions.

These goals are measurable, feasible, and supported by prior work from consortium partners (DLR, UT, TUW), who previously reached TRL 3 in related thermochemical heat-storage/transformer technologies.

Proposed System

The project will design and test a prototype thermochemical system using salt hydrates for heat recovery and upgrading. Using $SrBr_2 \cdot H_2O$ as an example:

- **Dehydration** stores heat using low-grade waste/solar/district-heat input.

- **Hydration** releases heat at much higher temperature (150-250 °C) when exposed to steam at elevated pressure.

A schematic process includes:

- Dehydration with ~156 °C HTF from waste-heat recovery.

- Condensation of released water vapor for reuse.
- Transfer of dehydrated particles to the hydration reactor.
- Hydration at ~156 °C and 560 kPa producing output temperatures up to ~256 °C.
- Recirculation of particles and internal heat exchange with minimal auxiliary electricity for pumps, fans, and conveyors.

The system can incorporate an additional storage tank for dehydrated particles, enabling flexible heat-supply timing. On a COP basis comparable with VCHPs, the system could achieve COP > 20. In thermochemical terms, COPh > 0.7 (ambition: 0.8), significantly surpassing absorption/adsorption technologies.

State-of-the-Art

Europe's industrial heat demand (~8150 PJ) is overwhelmingly supplied by fossil fuels. Low-grade waste heat is abundant but generally unsuitable for direct reuse, requiring temperature-upgrade technologies.

VCHPs:

- Typically limited to 120–150 °C.
- Higher temperatures impose compressor, refrigerant, cost, and design challenges.
- Market studies highlight significant financial potential but also issues of source–sink matching, high discharge pressures, and limited suitable refrigerants.

TAHPs:

- Operate using acoustic waves without refrigerants or compressors.
- Achieve efficiencies comparable to VCHPs but with low COPs at high temperature lifts and currently unsuitable for high-temperature applications.

Chemical Heat Pumps:

- Absorption (AbHPs) and adsorption (AdHPs) concepts can recover and upgrade heat.

- AbHPs offer COPh up to ~0.47 for single-effect systems with temperature limits near 165 °C, high CAPEX, corrosion challenges, and slow response.
- AdHPs can reach COPh 0.3–0.8 but are complex, expensive, and poorly suited for very high temperatures.

TechUPGRADE's innovation differs from sorption systems by using true **chemical hydration reactions** (coordination bonding) with low-cost salt hydrates, enabling high-temperature output, competitive COPh, and favorable LCOH.

Progress Beyond the State-of-the-Art

TechUPGRADE introduces several breakthroughs:

- **Heat upgrading with very low electricity use**, driven mainly by exo/endothermic reactions.
- **Minimal moving parts**, reducing wear and O&M costs.
- **High-temperature capability (150–250 °C)**, beyond current VCHP and TAHP reach.
- **Adjustable design** for multiple heat sources and temperature ranges.
- **Simple case-specific adaptation** for different industrial environments.
- **Advanced reactive materials** (e.g., $SrBr_2$ and alternatives) with good cyclic stability and low cost.
- **Scalable and modular design** suitable for systems from tens of kW to tens of MW.
- **Seamless integration** with solar thermal, waste heat, and district heating.
- **Full automation and digitalization** including self-optimization, forecasting inputs, and a 3D digital twin.
- **Intrinsic thermochemical heat storage** by adding a dry-salt storage tank.
- **High efficiency**: COP >20 (electricity basis) and COPh ≥0.7, with strong exergy performance.

Technology Readiness and R&I Positioning

Current components of TechUPGRADE exist at varying maturity levels:

- Salt-hydrate thermochemical heat-upgrade concepts have been validated at lab scale (TRL 3).
- Material-level R&D is around TRL 2-3 depending on the specific reactions and gases.
- Reactor-level concepts range from TRL 2 to TRL 4.
- The project will assemble, test, and validate first-of-its-kind prototype systems under relevant industrial conditions.

The project's overall goal is to reach TRL 5, demonstrating the integrated technology in a representative operational environment (35 kW test setup with concentrating solar thermal at Absolicon, Sweden).