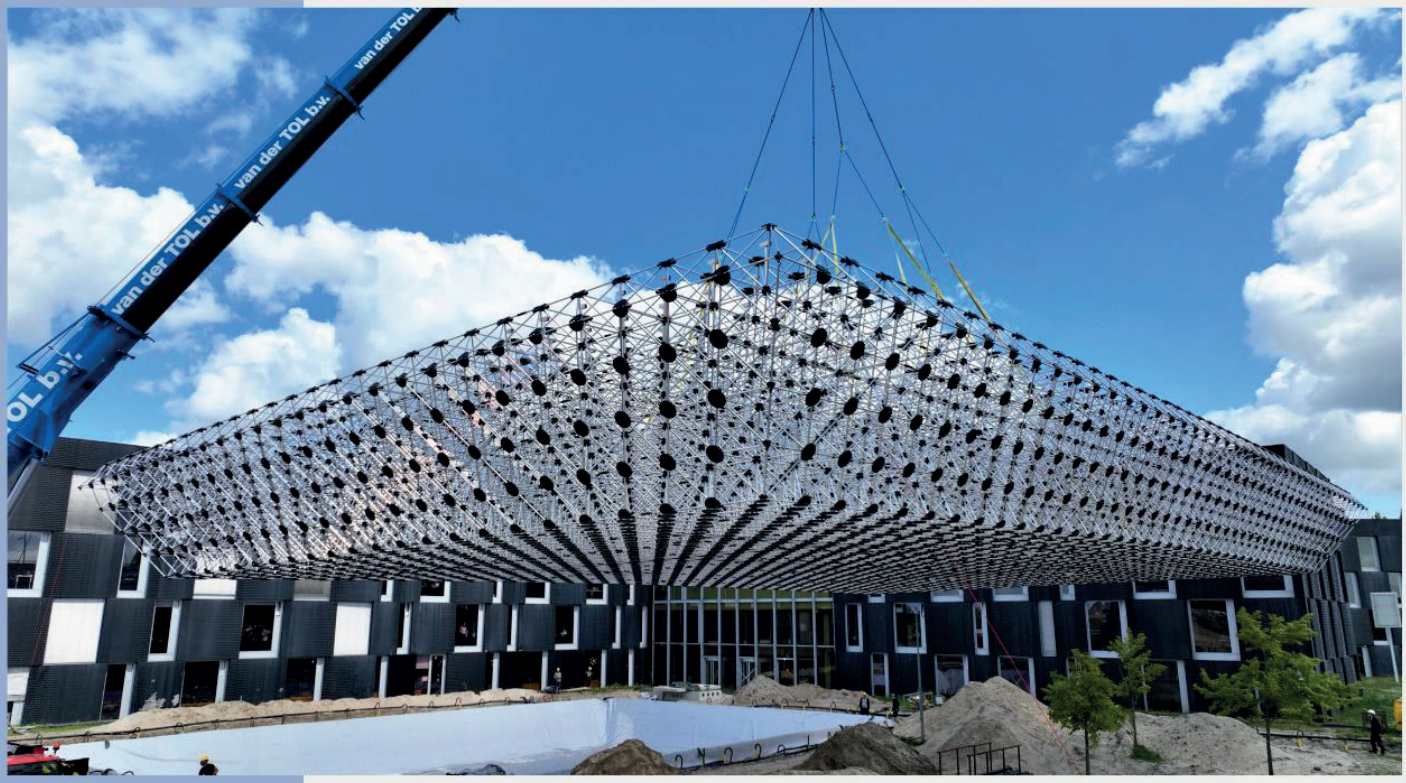
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WHITEPAPER: HEAT BATTERY FOR ENERGY HUB IN ROOSENDAAL

PROJECT SUSTAINABLE ENERGY AND RESOURCE RECOVERY



2026

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1. Project Context and Objectives

1.1 Current Situation and Challenges

Renewable technologies such as solar and wind energy are currently taking up an important role in the energy transition. The challenge with sustainable energy sources is its intermittent nature, in which there is a gap between the surplus energy in summer and the lack in winter. Another common problem associated with renewable energy is the issue of grid congestion, in which both supply and consumption have to be limited. In particular, these issues are very relevant for local energy hubs that strive for maximum renewable energy use at a reliable price

Within the Energy Trading Platform Roosendaal (ETPR), the large-scale solar generation with fluctuations in energy demand, cause the above-mentioned issues of inefficient energy utilization. Thermal Energy Storage (TES) offers a solution for these challenges, by converting excess electricity into heat, and storing it until later requirement. This is specifically useful in the case of seasonal storage, where excess produced solar energy in summer is conserved, and released as space heating during winter.

1.2 Project Objectives and Scope

This project aims to identify the most suitable TES systems for application in the Majoppeveld industrial estate. The study focusses on a heat battery with a capacity of 0.5 MW and 25 MWh.

To achieve this goal, four categories of TES technologies were researched: the sensible heat storage, phase change material storage, thermochemical, and underground storage. The technologies were assessed against one another using a Multi-Criteria Analysis (MCA), which provides assessment criteria like technical, environmental, operational and social. This assessment finally results in a comparison of the available technologies, supported by the identification of the most suitable technology to store energy in Majoppeveld.

2. Principles of Operation and Suppliers

2.1 Sensible heat storage

Sensible heat storage is an easy and economical thermal energy storage system that stores energy by raising the temperature of solid or liquid materials without changing their initial phase. The amount of thermal energy stored is determined by the material's mass, specific heat capacity, and temperature change [1]

2.1.1 Operating principle for Hocosto's water-based heat storage system

This system is an underground thermal heat storage technology that works by storing thermal energy in water. It has strong insulation provided by Polyisocyanurate (PIR); therefore, it is possible to store heat for long periods of time at temperatures up to 80°C. The total size of this system is decided by the energy consumption of the building or region where the battery is installed. The system is modular in design and is built with an aluminium internal structure. Furthermore, a closed hydraulic circuit powers the heat battery. The water inside the storage module remains contained within the storage unit, while external heat exchangers manage the addition and removal of thermal energy. Charging the thermal storage can be fully integrated into clean energy systems, including solar collectors, industrial waste heat, photovoltaic (PV) arrays, wind energy, and heat pumps. Depending on whether the battery is set up for long-term seasonal storage or short-term daily operation, different physical dimensions, spatial footprints, and buffer capacity requirements apply[2].

2.1.2 Advantages and Limitations

A key advantage of this subsurface structure is its structural integrity, where the ground layer above the battery (approximately 80cm of dirt) allows the surface area to be repurposed for alternative infrastructure, such as parking spaces or playgrounds. Its modular design allows storage capacity to be adapted to the energy demands of a building or community. The system can be integrated with multiple renewable energy sources, including solar thermal collectors, photovoltaic systems coupled with heat pumps and wind energy. However, the system can have high initial capital costs for excavation, installation, and integration with heating systems[2].

2.1.3 Supplier and contact information- HoCoSto Renewables B.V.

HoCoSto (Hot-Cold Storage) is a Dutch company specializing in underground thermal energy storage systems based on Seasonal Thermal Energy Storage (STES) technology. The company develops, manufactures, and installs modular underground heat storage systems for residential communities, commercial buildings, and industrial facilities. Their systems store thermal energy in insulated underground water reservoirs, enabling renewable heat generated during summer to be used during winter[2].

- **Address:** de Ambachten 14, 4881 XZ Zundert, Netherlands
- **Email:** info@hocosto.com
- **Website:** https://hocosto.com
- **Chamber of Commerce (KvK):** 89068866
- **Main Products:** Seasonal Thermal Energy Storage (STES), underground heat batteries, district heating storage systems, and thermal energy management solutions.

2.1.4 Current projects: Meer & Deel Eindhoven

The Meer & Deel Project, in Eindhoven's Vredeoord area, is a prominent sustainable housing complex that makes use of HoCoSto's seasonal heat storage technology. The project comprises 40 sustainable housing units linked by a common communal energy infrastructure. The system contains an 800 m^3 subsurface thermal storage unit with a capacity of around 81.2 MWh. Solar thermal collectors and photovoltaic panels mounted on rooftops provide renewable energy, which is stored during periods of excess production and then used to meet heating demand [3].

2.2 Latent heat storage

Latent heat storage utilizing Phase Change Materials (PCMs) is an advanced thermal energy storage technology. It is based on the temporary storage of high-density thermal energy by utilizing the chemical material's transition between solid and liquid states. The technology absorbs energy during melting and releases it during solidification at a nearly constant temperature, enabling the storage of large amounts of heat within a highly compact physical footprint for domestic or industrial use [4], [5].

2.2.1 Operating principle

The phase change material heat battery works by absorbing thermal energy from an external source, such as heat pumps, solar photovoltaics, or industrial waste heat, and storing it primarily as latent heat of fusion. Unlike sensible-heat systems that rely on a large temperature rise, this system stores energy as the internal PCM melts from solid to liquid. During discharge, cold water or a heat transfer fluid pass through the internal heat exchanger, causing the PCM to solidify and release its stored latent heat back into the system at a consistent, stable delivery temperature. The modular design of these batteries allows the system configuration to be tailored to specific power and capacity requirements. Modern commercial units utilize high-performance insulation, such as vacuum insulation panels, to minimize standing thermal losses. Because the system operates and stores energy at the specific melting point of the material rather than escalating to extreme temperatures, the thermal gradient with the surrounding environment is minimized [6], [7], [8], [9], [10] .

2.2.2 Advantages and Limitations

A key advantage of this system is its exceptional thermal retention, which achieves an estimated energy loss of 0% per day under standard conditions. The core material is fully bio-based, biodegradable, non-toxic, and carries an estimated 100-year operational life, eliminating environmental leakage concerns. Furthermore, this dense storage mechanism allows the core material to occupy roughly one-quarter to one-third of the space required by traditional water-based storage systems, offering incredible volumetric compactness. However, the system faces significant limitations in terms of storage duration and integration, as it is only suitable for daily heat storage, making it physically and economically unfit for weekly or seasonal storage lasting several months. Because PCMs have low intrinsic thermal conductivity, scaling them to handle larger demands requires massive, cost-prohibitive internal heat exchanger networks to maintain adequate heat transfer rates. Additionally, the round-trip efficiency is slightly lower, ranging between 80% and 85%, and the system only allows for passive coupling with renewable energy sources like wind and solar [6], [11].

2.3.3 Suppliers and contact information - BioPCM

That company specializes in plant-derived fatty acids and bio-based oil formulations intended for structural thermal mass buffers and building insulation[11].

Global Headquarters: 813 Winston St, Greensboro, North Carolina 27405, United States
Phone Number: +1 (336) 629-3000 / Toll-Free Sales: +1 (800) 283-7887
General Inquiry Email: info@phasechange.com

2.4.4 Current projects

Real-world operations demonstrate the practical scalability of BioPCM technology across several commercial applications. A primary success involves integrating passive ENRG Blanket systems directly into the ceiling and wall cavities of corporate offices across the United States. These installations act as a quiet thermal mass buffer that absorbs excess heat during peak daytime hours, reducing the total energy demand placed on mechanical HVAC systems without needing moving parts. Beyond building integration, BioPCM transport containers are extensively deployed across global pharmaceutical logistics networks to safeguard sensitive medications by maintaining steady ambient or sub-ambient temperatures during international transit [11].

2.3 Thermochemical heat storage

2.3.1 Operating principle

The thermochemical storage (TCES) system works on the basis of the following reversible reaction:

$$A + Energy\ (Heat) \rightleftharpoons B + C$$

In the reaction, the TCES material (represented by A) absorbs heat, and decomposes into products B and C. These products are stored separately until heat is required again. Upon combination under controlled conditions, the inverse reaction occurs, and the chemically stored heat is released.

The two TCES technologies investigated in this study are the salt-hydrate system by Cellcius, and the iron fuel cycle by RIFT. The former technology uses salt potassium carbonate (K_2CO_3) and water. The storage process entails the dehydration of the salt, followed by seasonal storage, and releasing of heat by reintroduction of water to the salt[12], [13]. The second technology combusts iron powder with oxygen to generate heat. The resulting iron oxide powder is subsequently regenerated using hydrogen [14]. Both technologies are characterized by long-duration storage, with negligible energy losses.

2.3.2 Advantages and Limitations

The main advantage of TCES can be attributed to the ability to store energy for long periods of time without self-discharging. This is due to energy being stored in the chemical bonds of the reaction products, rather than thermically. This makes the technology very suitable for seasonal heat storage. Subsequently, TCES materials posses a higher energy density than sensible heat materials, which results in a more compact storage volume. Potassium carbonate is a widely available, inexpensive and environmentally friendly material. Iron Powder is abundant and regenerative.
Limitations in TCES systems are associated with the general complexity of reactors, heat exchangers, and material handling. For the (K_2CO_3) salt hydrate system, commercial availability is limited due to the discontinuation of Cellcius' business activities. For the iron-fuel system, regeneration of reactants requires hydrogen, which increases complexity and challenges in coupling with other renewable energy sources. Moreover, the iron reactor is prone to issues like slagging, where particles clump together, reducing the successful combustion. Both technologies have successfully been demonstrated but have not reached market maturity yet.

2.3.3 Suppliers and contact information

Cellcius

Former headquarters: Eindhoven, North-Brabant, Netherlands.
Website: https://www.cellcius.com
Key contact: Joey Aarts (PhD Researcher at TU/e, and involved in the Cellcius project)
Main applications/product: Seasonal Thermochemical Energy Storage for residential and district heating.
Current status: Cellcius had discontinued operation since March 2025, due to financial and scaling challenges. Technology remains technically validated.

RIFT (Renewable Iron Fuel Technology

Headquarter: Helmond, North-Brabant, Netherlands.
Website: https://www.ironfueltechnology.com
Key contact: Timo van der Laar
General contact: info@ironfueltechnology.com
Main applications/products: Iron fuel boilers, generators for decarbonized renewable heating (industrial, district).

2.3.4 Current projects

Potassium Carbonate (K_2CO_3): Cellcius

Cellcius has demonstrated the thermochemical storage technology in multiple pilot projects.

- In three locations in Eindhoven, France, and Poland, demonstration systems of approximately 70 kWh were installed. In these projects, the practical charging and discharging of potassium carbonate system was demonstrated. This demonstration showed that heat was indeed stored for long periods without thermal losses, and that heat is released at suitable temperatures for residential heating. This project also indicated. The three locations provided difference climate zones between −3 °C and 25 °C, to evaluate operation under different conditions. Subsequently, the project validates the durability of the system to a stability over 25 years. [15]
- Although the successful demonstration of the technology, since March 2025, Cellcius ceased operation. This was mainly due to financial and commercial challenges. The technology of the system did not contribute to the cease of operation.

Iron Fuel / Iron Powder: RIFT

The Iron Fuel technology has been demonstrated in multiple pilot and industrial projects. Below is an overview of these projects

- In May 2023, a demonstration field was established in Helmond. This effort was made in collaboration with Ennatuurlijk. The iron fuel boiler (1 MW) successfully supplied 500 residential homes through the local heating network. This demonstrated reliable combustion and heat production. The system subsequently prevented the emission of 5 tons of CO_2 emissions, a reduction of 66% compared to the previous heating system.[16]
- RIFT established a pilot regeneration plant in Arnhem, where the iron oxide powder is reduced back to iron powder, using green hydrogen.
- In March 2026, RIFT has secured a financing of €113.8 million to commercialize the technology. This funding originates from €83.1 million from PGGM fund (specifically the Series B investment round), and €30.7 million from the European Union Innovation Fund. RIFT will use this fund to set up the first commercial iron fuel production plant, and for the deployment of more industrial heat projects. [17]
- Moreover, the first commercial project has already been contracted with Kingspan Unidek, set for 2029. This installation will deliver 340 GWh of heat per year, reducing over one million tons of CO2 emissions over its operational lifetime. This contract indicates the commercial implementation of RIFT's technology. [17]

2.4 Underground heat storage

2.4.1 Operating principle

The operating principle of the ATES system stores thermal energy underground by circulating groundwater between warm and cold wells in an aquifer. During summer, cool groundwater is used for cooling while extracted heat is stored in the warm well. During winter, the stored heat is recovered for heating, and cooled groundwater is returned to the cold well for later use. Through these seasonal charging and discharging cycles, the system provides long-term thermal energy storage and improves the efficiency of the system over time. The systems can operate as Low Temperature (LT) with 30ºC or High Temperature with 50ºC system, depending on storage application.

2.4.2 Advantages and Limitations

The main advantage of ATES systems is its ability to provide seasonal heat storage, allowing the thermal energy produced to be stored for months or years. Additionally, larger storage volume of natural aquifers enables significantly higher storage capacities compared to other thermal energy storage systems.

2.4.3 Suppliers and contact information

DTESS is an Aquifer Thermal Energy Storage consultancy and design specifically for HT-ATES systems.

Headquarters Address: Zomertalinghof 29, 8043 JW Zwolle, the Netherlands.
General Email: bas.godschalk@dtess.com
Key Contact: Bas Godschalk
Phone Number: +31 6 3088 7473

kWa Advisor

KWa Advisor is a Dutch engineering and consultancy firm that provides advice in regards of ATES systems.

Headquarters Address: Regentesselaan 2 3818 HJ Amersfoort
General Email: desk@kwa.nl
Key Contact: Joris Groot
Phone Number: 033-422 13 00

2.4.4 Current projects

The current projects involving HT-ATES systems in the Netherlands are in Koppert Cress (Monster, South Holland) and Agriport (Middenmeer). The Koppert Cress system has been operating since 2012 and uses four warm and cold wells to store heat above 30ºC for greenhouse climate control, with solar collectors providing the heat source. The project serves as a pilot to study heat storage in shallow aquifers at elevated temperatures.

The Agriport project is another HT-ATES system, consisting of one warm, one cold, one monitoring well. It stores heat at temperatures ranging from 25ºC to 90ºC in a deep aquifer of approximately 382 m below ground level. This project was developed specifically to investigate the behaviour of groundwater and heat storage at high temperatures.

3. Evaluation of TES and Identification of the Most Suitable Solution

A Multi-Criteria Analysis (MCA) was used to determine which technology is the most suitable for Majoppeveld. The individual technologies were assessed on criteria such as technical performance, efficiency, storage duration, feasibility, environmental impact, risks, and social acceptance. The final MCA scores obtained from the weighted assessment are summarised below in Table 1.

Table 1: Results of the Multi-Criteria Analysis (MCA): Weighted Scores of Heat Storage Technologies.

Heat battery technology	Weighted score
Sensible heat storage: Underground Water Heat Storage (HoCoSto)	4.54
Phase change material: BioPCM Phase Change Material system	3.90
Underground storage: Aquifer Thermal Energy Storage	3.82
Thermochemical storage: K_2CO_3 system (Cellcius)	3.79
Thermochemical storage: Iron (Fe) based system (RIFT)	

Table 1 presents the scoring of the investigated technologies, based on MCA. It can be seen that the technology that performed best is Hocosto's underground water-based heat storage system, which received the highest score of 4.54, indicating that it outperformed the other assessed heat battery technologies. Following this, BioPCM phase change material systems received a score of 3.9, indicating good performance across the given assessment criteria. The Aquifer Thermal Energy Storage (ATES) received a high score of 3.82 and both the iron (Fe)-based thermochemical storage (RIFT), and the K_2CO_3 thermochemical system (Cellcius) received a score of 3.79. The weighted scores identified how well each technology performed across all assessment criteria.

In conclusion, Hocosto's underground water-based thermal storage system achieved the highest overall score and is considered the most suitable technology for implementation. The system offers a strong combination of high efficiency, low heat losses, seasonal storage capability, technological maturity, and environmental performance. However, the entire assessment was made without including the financial feasibility of the thermal storage systems since information on pricing is commercially sensitive and therefore, suppliers do not want to disclose it immediately. This lack of available cost data represents a notable gap in current evaluation, as initial upfront costs, system installation cost, and maintenance costs are important factors that will directly influence the commercial viability of the final implementation. Consequently, while the MCA provides a ranking based on technical, environmental, spatial, and social performance, the selected final technology remains subject to subsequent economic confirmation. Bridging this data gap through formal commercial inquiries and targeted geological surveys will be necessary to establish a complete business case for the Majoppeveld.

4. Recommendation and Advice

4.1 Recommendation

Based on the Multi-Criteria analysis, Hocosto's underground water-based thermal storage technology is recommended as the most suitable thermal storage system for implementation in Majoppeveld. This technology achieved the highest score of 4.54 and performed well across all evaluated criteria, balancing between technical performance, system efficiency, feasibility, operational safety, environmental impact, and long-term storage capability. Hocosto has a high round-trip efficiency of 99%, minimal thermal losses of 0.1-0.4% per day, and the capacity to store heat for extended periods. In addition, the technology has a Technology Readiness Level of 9, indicating that it has already been commercially verified and can be deployed with little technical concerns. However, before implementation, it is important to conduct a thorough site investigation, to investigate the underground condition of the location, space availability and permitting requirements.

4.2 Advice

Although Hocosto outperformed the other thermal storage technologies by being the most suitable for the specific conditions of Majoppeveld, it is advised to keep an eye out for further developments in thermochemical technologies, such as potassium carbonate and iron fuel systems. As described in Chapter 2 of this report, these materials have very high energy densities and almost zero storage losses since the thermal energy is stored chemically in these materials. These technologies have the potential to become compelling options for large-scale seasonal heat storage once they have reached commercial maturity.

Further research should be performed to get a thorough financial assessment of the highest-ranking technologies. The MCA provides insight into technical and environmental performance, but economic aspects were not evaluated. Performances like investment costs, operational costs, maintenance costs, subsidy availability, and energy prices strengthen the decision whether Hocosto's TES remains the best solution in Majoppeveld.

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april 2025 – april 2028

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Thema's
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