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# Heat Commodification for a Sustainable Energy Future

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**Abstract:** The concept of heat commodification is proposed as a sustainable solution for global energy management, with heat being treated as a tradable commodity in an international market. In such a market, heat would be assigned a value based on factors such as available enthalpy, heat grade (temperature), and the time at which it is delivered. Heat, as the currency of this market, would allow for a decentralized and dynamic exchange system. A central heat market could be established, extending down to individual households where excess heat—such as waste heat from household appliances—could be stored and traded locally, potentially through a peer-to-peer model or a virtual marketplace. A key innovation in this system would be the development of modular heat storage solutions, analogous to gas bottles, that allow consumers to store excess heat and exchange it within the market. These "heat packets" would be rechargeable with heat, as opposed to gas, and could be traded both physically or digitally. To ensure inclusivity and sustainability, it is suggested that these heat packets be based on nature-inspired storage materials that can efficiently store renewable or waste heat with minimal environmental impact. Specifically, thermochemical storage media, such as salt, would be employed to facilitate charging and discharging processes using water as a trigger. Such solid-state storage systems would allow heat to be stored indefinitely with minimal heat loss to the environment, even in lower temperature conditions. This paradigm shift could enable the cross-continental transport of heat packets, revolutionizing the global energy market. The proposed system would also eliminate the need for electricity grids and reduce inefficiencies associated with energy conversion, as heat can be stored and utilized directly for both heating and cooling applications. Furthermore, the reliance on heat-driven refrigeration systems would obviate the need for electricity-driven heat pumps or chillers. This approach offers a potential solution to global energy challenges by facilitating a sustainable and efficient heat exchange network on a global scale.

**Keywords:** Heat market; Heat commodification; Heat storage; Heat exchanger; Heat management policy

## 1 Introduction

Thermal energy management has always been a subject of great interest. Accordingly, a great deal of information can be found in the literature on the very topic [1–3]. Process intensification, waste heat recovery, thermal energy storage, loadshedding, power-to-heat, and renewable heat generation [4–6] have gained more attention in recent decades and contributions have been made to minimize the impact of heat transfer, to or from processes, on the environment.

Currently, despite the environmental concerns, about two-thirds of heating energy demand is met by burning fossil fuels. Similarly, the refrigeration sector significantly contributes to global warming, where over 10% of the global greenhouse gas emissions are attributed to this sector [7]. Most of the cooling units are powered by electricity, which, in turn, is predominantly generated using fossil fuels, which is over 60% of the global electricity generation, according to the International Energy Agency (IEA). While essential, decarbonization of these two huge sectors, heating and cooling, poses a formidable challenge. It can be noted that, in essence, both sectors are technologically mature, with their longstanding modern development motivated by the need to solve practical problems at the lowest possible cost. The current and future challenge faced by both sectors, nonetheless, is to minimize their environmental impact while maintaining the low costs and still delivering to meet the functional requirements, i.e., providing heating and cooling within the required temperature range. These requirements depend on the applications and processes wherein heating and cooling of components or streams are needed.

Commensurate with the challenges, measures are in place for energy transition. For instance, ambitious yet necessary goals have been set by the Dutch government to ensure climate-neutral energy systems by 2050. Furthermore, following the recent events and war in Ukraine, energy security is the cornerstone of all government policies across the globe. The IEA declares the current situation as an "energy crisis significantly boarder and more complex than those that came before." Unfortunately, however, the Netherlands still heavily relies on gas. Despite the war, the gas consumption only dropped by 22% compared to the year before the war. Interestingly, the residential sector in the Netherlands consumes more gas than the industry. In either case, gas is burnt to generate heat. The generated heat is used for different applications across a wide range of temperatures ranging from around 30°C for underfloor heating to over 1400°C for industrial gas turbines. It makes perfect exergetic sense to both generate and use heat over the same temperature range as opposed to, for instance, burning gas at a temperature two orders of magnitudes higher than what the actual demand temperature is set on (for instance, underfloor heating). A simple alternative is to recover the heat wasted from a high-temperature process to feed a process that operates at a lower temperature while the source and sink temperatures are not different by much (pinch) or at least are within the same order of magnitude. Figure 1 shows an idealized example. For instance, utilizing the heat wasted over 500-1000°C in Germany and converting it to electricity are enough to make the entire coal-fired power plant fleet in the Netherlands completely redundant. In turn, the heat currently wasted in the Netherlands can be supplied to the Czech Republic in a heat market so that the households in the Republic would switch away from burning coal and coal products at home to generate about 32 PJ of heat per year (the number in 2019 is expected to drop according to the trend) [8]. Hence, "responsible" generation and use of heat, across the (political) borders, can be practiced with transportable (mobile) heat. This can be facilitated through the storage of heat, which, in turn, can happen over different ranges of temperature using different techniques.

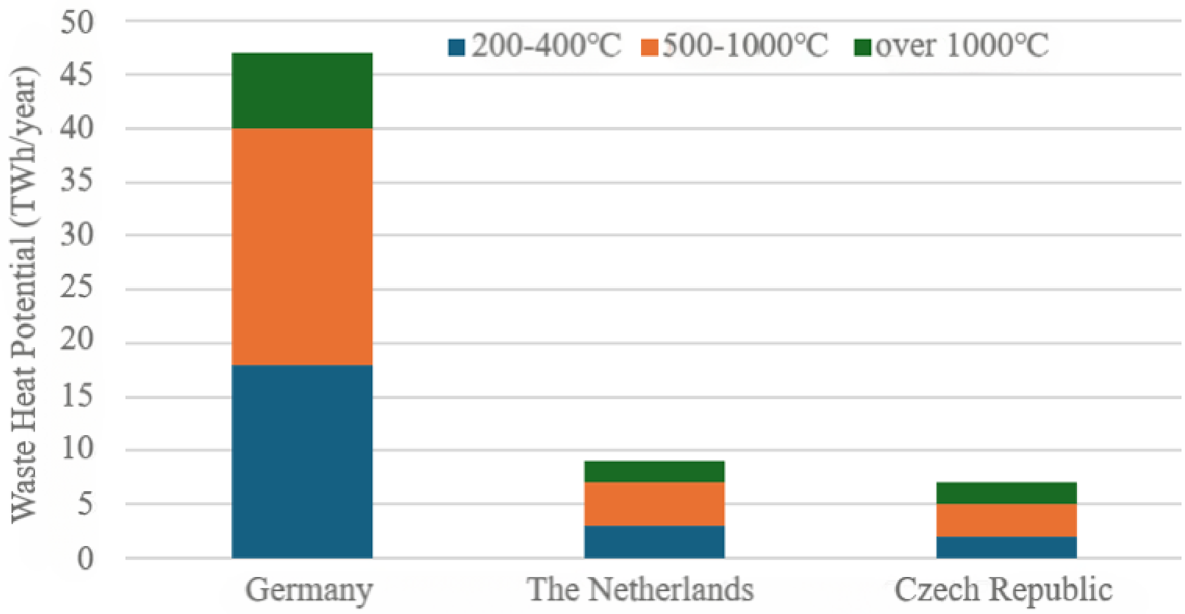


**Figure 1.** Waste heat potential in three different countries

Source: Data was reproduced [9].

In parallel, the growth in renewable energy generation brought about the need for energy storage. Excess energy, generated off-peak, can be directly stored as electricity, such as in electrochemical batteries, or as heat through power-to-heat, as an option instead of curtailment. Renewable energy generation depends on both time and location. Solar and wind electricity generation demonstrate a steep growth trend, with over an order of magnitude in a decade starting from 2010 and yet more growth anticipated. Meanwhile, both solar and wind energy are known to be intermittent in nature. Moving the wind farms offshore can increase the capacity factor, albeit at an extra cost to transmit the electricity from where it is generated to where it is needed. Similar challenges were faced by the Australian Enhanced (or Engineered) Geothermal System (EGS) over a decade ago [10]. Although geothermal energy inherently offers higher capacity factors, the highest with no need for storage among renewable options, the extension of an electricity grid from the power plant to the nearest community is prohibitively expensive (about $1 m per km for grid extension).

In general, both temporal and spatial mismatch between source and sink of energy hinder the development of a project. With heating and cooling, this is more challenging, as they both, in most cases, have to rely on the electricity grid or fuel transport (mostly both) as an extra burden. When it comes to heating or cooling, neither electricity nor the fuel are the desired products. The former powers a heat pump (or can be used directly with a resistive heater), while the latter merely carries energy to be released upon combustion. Hence, finding a way around this extra imposition would reduce the levelized cost of heat by an order of magnitude, if not more.

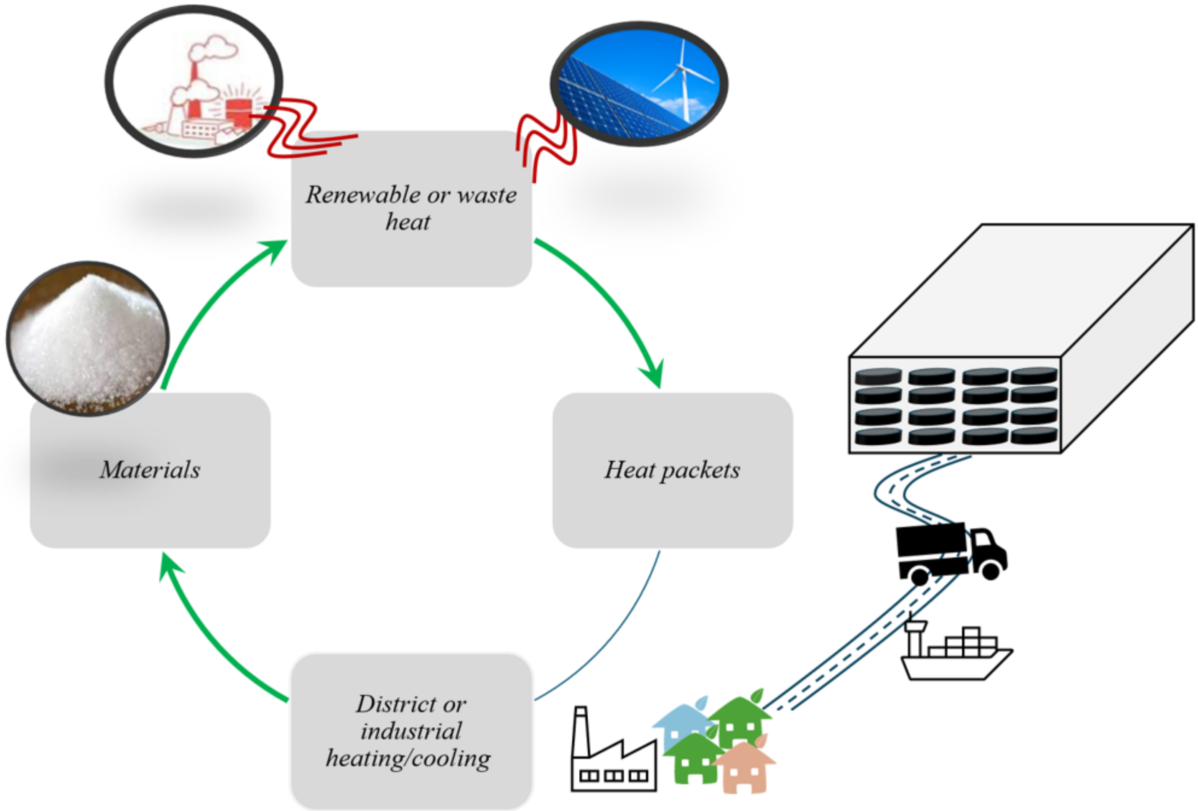


**Figure 2.** The technological basis of the heat market concept schematically demonstrated

Hence, this study envisions the use of renewable heat or the recovery of waste heat from non-renewable sources/processes with no reliance on a grid for a heat career or heating/cooling production enabler. The heat can be used to heat a process or it can be applied to run heat-driven refrigerators to cool down another process or a living/working space (Figure 2). As mentioned, the temporal and spatial gap between heat/cooling demand and generation poses a challenge. Hence, storage of heat is offered as a solution. Sensible (hot water tanks) or latent heat storage (ice) has been used in many practical applications. Comparatively, the former is less expensive while the latter offers higher energy density. Both techniques are susceptible to heat loss when subject to a temperature gradient (which is unavoidable as the ambient temperature is always different from that of the storage medium). As an alternative, thermochemical heat storage relies on chemical reactions to charge and discharge the storage medium. Usually, heat is stored at a higher temperature to be released at a lower one. What makes them, nonetheless, a perfect fit for long-term storage of heat is their indifference to the ambient temperature. That is, heat can be stored in a thermochemical storage unit without being lost to the environment, regardless of the ambient temperature. This study suggests the use of solid-state thermal energy storage systems, among them thermochemical units, to close the aforementioned temporal and spatial gaps between the source and sink of heat. These storage units, heat packets within the international heat market, can be charged at a source and discharged at a sink, which can be physically located far away from the source with (or without) a prolonged phase (time) lag.

## 2 Methodology

Heat storage using thermochemical systems, in particular the material development aspect of it, has been investigated in great detail, as a recent survey of the literature indicates [11]. Without ruling out other options, merely to signpost the way forward aiming at developing heat packets for the future heat market, this study focuses on salt hydrates. They can be charged by adding heat, where the water content would evaporate, leaving behind “lower hydrate” which contains a high level of energy, as shown in Eq. (1).

$$\text{Salt. } (n+m)\text{H}_2\text{O}_{(s)} + \text{ Heat } \leftrightarrows \text{ Salt. } n\text{H}_2\text{O}_{(s)} + m\text{H}_2\text{O}_{(g)} \tag{1}$$

Removal of water vapor ensures that lower hydrates do not lose the energy charged in them. The heat locked in the storage material can only be released when lower hydrates are exposed to water, the reverse reaction (right to left) in Eq. (1). This also implies that the storage system would keep the heat in, regardless of the ambient temperature, though it should be moisture-tight.

Such high energy densities as 8.75 $\mathrm{GJ/m^3}$ for salt hydrates have been recorded [12]. To put things into perspective, on average new Dutch dwellings consume about 10 GJ of heat over the entire year [13]. This heat demand can be met by the use of industrial waste heat or direct capture of renewable heat, such as the use of PV-T systems or through power-to-heat. It can be added that the average solar heat incident, direct normal irradiance, in the Netherlands hovers around 3.5 $\mathrm{GJ/m^2}$. That is, the entire heat demand of an average building can be met by exclusively relying on solar heat with seasonal storage. More interestingly, the system can combine natural recyclable salts with water to receive, store, and discharge heat. Containers and ancillaries, built around this salt-water core, can be carefully designed to rely on natural and sustainable materials. This can certainly be accompanied by a proper life cycle analysis (LCA).

## 3 Results

Heat is a form of energy, while conventionally electricity is used as a reference point. Thermodynamically, energy is the capacity to generate work. Similarly, exergy has been developed as a concept to gauge the maximum useful work from a system as it reversibly comes to equilibrium with its surrounding environment.

With both concepts, energy and exergy, nonetheless, work has been tacitly drifted away to mean “electricity generation” as the preferred form of work generation/potential. Accepting heat as a commodity would change human (consumption) behavior in dealing with it. Knowing the monetary value of a product is the minimum requirement for the same product to be treated responsibly. As a pioneering work, it is beyond the scope of this study to get into details of human behavior and human-system interaction. Technologically, on the other hand, a sound background has been set to illustrate that heat can be stored, over long periods of time, in solid state and transported across long distances.

The idea of cross-continental heat transport is not new. As early as the 1800s, ice was exported from the US to India [14]. With technology at that time, almost half of the exported ice was melted by the time it reached the final destination. Yet it was a lucrative business sustained for long enough before refrigeration technology completely took over. In the interest of brevity, this study does not discuss technological details and challenges (those of material development have been actively addressed [15], while design aspects, both at the component and system level, remain relatively untouched). This study seeks to provide a broader perspective on the handling of heating and cooling, emphasizing the overarching concept rather than delving into minute technicalities. In what follows, case studies are presented to further cement the points made by the proposed concept.

### 3.1 Case Studies

#### 3.1.1 Space heating

Burning gas for space heating makes no exergetic sense. Moreover, as a fossil fuel in nature, gas is associated with scarcity. Therefore, it is politically weighted and pollutes the environment when being burnt. Run by electricity, reversible heat pumps are offered as an alternative for either space heating or cooling. Using non-renewable electricity to run heat pumps only lowers the impact of the heating/cooling sector on the environment compared with the conventional practice of burning fossil fuels, while pollution issues persist, such as the scenarios considered by Marina et al. [16]. Alternatively, using renewable electricity to run heat pumps can be suggested. In that case, for instance, a household can generate electricity using photovoltaic (PV) panels to run heat pumps (assuming that renewable electricity is always available, i.e., generated, stored, or credited through tokens [17]). With an average conversion efficiency of about 15%, a PV panel loses 85% of the solar energy incident on the surface. Commercial reversible heat pumps can be applied with a (generous) seasonal coefficient of performance (COP) of about 4. Hence, multiplying this COP with PV electricity conversion efficiency translates into 60% overall efficiency in converting solar energy input to space heating or cooling. Another option is to use a solar collector that absorbs the solar energy and converts it directly to heat at efficiencies (for commercially available units) starting from 70% all the way to 90% at a reasonable price. As anticipated, higher solar irradiance in summer and the need for space heating in winter call for seasonal storage. Using solid blocks to store heat in them and transport them from warmer regions to colder areas, such as national or international transport, gives rise to a more efficient and sustainable use of solar energy in this example. One also imagines storing waste heat from industries in solid blocks to be trucked to urban areas for district heating or within the same industrial area using, such as conveyor belts which is the common practice in mining and mineral industries. The acceptance of heat as a commodity allows the development of business models which will, in turn, pave the way for commercialization and widespread acceptance of these applications.

### 3.1.2 Space cooling

Overproduction of electricity from renewable sources congests the grid and contributes to negative pricing. On the other extreme, peak hours stretch the grid thin. These two events are not expected to happen simultaneously at the same location. Interestingly, nonetheless, the two can be connected using inexpensive mobile heat storage units which can be traded in an international market. In a way, the gaps in one event will be comfortably filled with the excess in another. That is, the out of phase problem can be addressed through the storage and transport of heat without relying on fuel or the electricity grid.

In general, the demand-supply mismatch pushes the market (oil, gas, power, etc.). In this particular context, when it comes to the power grid, the power-to-heat concept comes into play. Similarly, district heating networks need to adjust to heat demand. As such, grids mainly provide heat, such as the waste heat from datacenters, and there is limited use for the waste heat in summer; this potential cannot be well unleashed. Hence, the use of sorption chillers lends itself well to such cases. The same heating network may not be needed for cooling purposes; hence, the use of a heat market comes in handy. The heat wasted from a datacenter can be absorbed by the solid storage blocks which can be, in turn, transported to a different location to power a central sorption system or decentralized units. It can be shown that running such adsorption chillers off the so-called stored heat halves the cost and lowers the system volume by 40% compared with the same sorption technology running on a hot water stream. This is partly because the discharging moist air stream can be combined with the chiller cycle. Moreover, this adsorption system works with heat instead of electricity which takes the stress off the electricity grid in summer for countries with extreme cooling demand. Blackouts are not uncommon in Australia during hot summer periods and a heat market not only disconnects the heat demand from that of power (and fuel) but also redefines the cooling and refrigeration sector which experiences significant technological developments; see for instance [18–20].

## 4 Conclusions

Business as usual within the heating and cooling sector would lead to irreversible damage to the environment. Incremental modifications cannot make changes at a rate comparable with that of which global warming affects people's lives and future. Hence, this study proposes a radically new concept and a vision for the future. Herein, heat is to be commodified and treated in an international market which can be stretched easily to an individual level, which is trash to treasure. This would build on an understanding that heat and electricity are forms of energy and their use, market development, and management should not be intertwined. In general, converting energy from one form to other entails losses which are quantifiable using laws of thermodynamics. While the electricity market is mature, a sister structure for heat is called for. This, in turn, would minimize the inevitable energy conversion losses. Such an international market needs to rely on transaction rules dominated by customer needs. Such rules and specific requirements would need to be developed in the future. Moreover, this study, without being dogmatic, suggests the use of solid-state thermal energy storage or heat packets within the future heat market. As it stands, such heat packets can be made of natural, sustainable materials and are easy to be shipped around without being prone to perpetual temperature-driven heat losses. The development of other materials or transport techniques pertinent to new technologies to serve the international heat market would also be a future research direction. While beyond the scope of this study, it can be acknowledged that human (and organizational) behavior and perception are vital to the survival and adoption of this new concept.

## Data Availability

Not applicable.

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## Conflicts of Interest

The author declares no conflict of interest.

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