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Expanding the Use of Molten Salt for Renewable Energy Storage and the Role of Green Technology Policies

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Expanding the Use of Molten Salt for Renewable Energy Storage and the Role of Green Technology Policies

Abstract

The transition to net zero carbon emissions necessary to limit global warming importantly involves greater use of renewable energies, especially solar energy, and scaling up renewable energy storage and generation. This paper discusses expanding the use of molten salt for renewable energy storage and generation, in an environmentally friendly way and making use of existing infrastructure. This includes using molten salt to store solar energy in concentrated solar plants, replacing coal by molten salt to power thermal plants and thereby convert existing coal thermal plants to renewables, and linking these two uses. Additionally, the use of molten salt in thermal batteries for grid-scale energy storage and in green hydrogen production is explored. The paper also delves into the significance of green technology policies in facilitating the use of molten salt for these applications.

JEL-Codes: Q000, Q480, Q580, Q400, Q500, Q550.

Keywords: molten salt, energy storage, renewable energy, solar energy, concentrated solar power plants, grid storage, conversion of thermal coal plants, green technology support policies.

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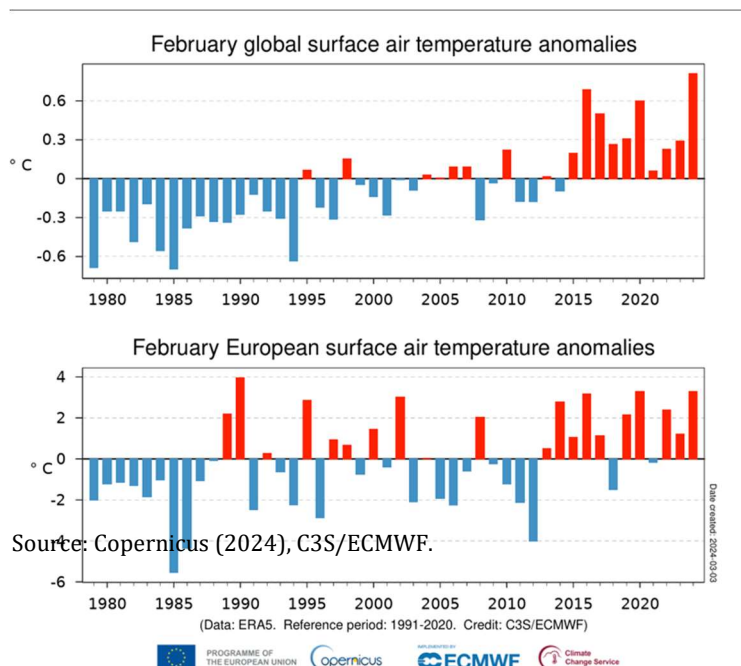
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1. Introduction

February 2024 was the warmest February globally since records began, with an average surface air temperature 1.77°C above the February average during the pre-industrial level reference period of 1850 to 1900, and 0.81°C above the February average for 1991 to 2020 (Figure 1) (Copernicus Climate Change Service, 2024). It was the ninth month in sequence which was the warmest for the corresponding month since records began. The global average surface air temperature in the year to February 2024 was also the highest since records began, 1.56°C above the average during the pre-industrial level reference period, and 0.68°C above the average for 1991 to 2020.

According to standard climate change models, global temperatures are expected to increase by around 3°C compared with pre-industrial levels by the end of the century if current climate policies are unchanged (IPCC, 2014). Consequently, climate policies need to be strengthened to reduce carbon dioxide emissions (IPCC, 2022). Climate policies include carbon taxes and carbon emissions trading systems (Metcalf and Stock, 2020; Kohlscheen et al., 2021; D’Arcangelo et al., 2022), and other policies such as green technology support policies (Stern, 2008; Ploeg and Venables, 2022; Gerlagh et al., 2014). The crucial transition to achieve net zero carbon emissions, essential for limiting global warming, requires a significant increase in the utilisation of renewable energies, particularly solar energy, and the expansion of renewable energy generation and storage capacities.

Figure 1: Surface air temperature anomalies in February 2024 relative to February average for 1991-2020



Source: Copernicus Climate Change Service (2024), C3S/ECMWF.

The use of renewable energy for electricity production has increased, but it is being held back by a lack of sufficient production and energy storage capacity, and needs to be expanded more, and faster. Renewable energy production, in particular of solar and wind energy, is volatile and therefore requires much greater energy storage capacity to smooth out its availability by storing energy produced at peak times for feeding into the grid at times when little energy is being produced.

Renewable energy storage is also held back by adverse environmental effects and social costs of some renewable energy storage materials, such as of lithium-ion batteries.

The UK's Institution of Mechanical Engineers notes that one of the hurdles for energy storage of renewables is their large-scale implementation, and that while many projects exist on a smaller scale, important hurdles are sufficient investment and commercialisation of these smaller scale projects (Institution of Mechanical Engineers, 2024).

This paper explores the expansion of molten salt utilisation for renewable energy storage and generation in an environmentally friendly way, leveraging existing infrastructure. Furthermore, it examines the role of green technology policy in promoting the use of molten salt for these purposes.

Molten salt is a very promising way to store renewable energy, complementary to sodium-ion electrical batteries (Hirsh et al., 2020; Zhao et al., 2023; Ould et al., 2024). Molten salt serves as a crucial thermal energy storage medium, and its widespread adoption is important for rapidly expanding future renewable energy storage and generation systems to mitigate the adverse effects of global warming. Renewable energy is already being stored thermally via molten salt storage in a concentrating solar power plants (CSP), but not in sufficiently large amounts yet. The capacity of large-scale molten salt thermal storage in CSP installed commercially globally as of the second half of 2020 was 21GWh_{el} (about 60GWh_{th}), with an average storage duration of seven hours (Bauer et al., 2021). Thermal energy storage with molten salt in CSP can have a high storage efficiency of up to 99% (Prieto et al., 2024). An overview of molten salt energy storage in CSP is provided in the review of Bauer et al. (2021).

Thermal energy storage with molten salt in CSP is a mature technology, but faces challenges in its implementation and operation to be safe, efficient and sustainable, including regarding structural integrity, corrosion, thermal shock and thermal expansions (Prieto et al., 2024). Thermal energy storage of renewable energy for electricity production has not been well developed. It can be quite simple, other forms include for example air, water and bricks (Harrabin, 2024).

Molten salt could be used to power thermal power plants instead of coal (Bauer et al., 2021). Since coal emits the largest amounts of carbon dioxide among fossil fuels, there is a very urgent need to phase it out. Bauer et al. (2021) also review new potential uses of molten salt in conventional power plants and electrical energy storage, noting that for such applications, research projects demonstrating the feasibility in pilot projects are needed.

A big advantage of molten salt for thermal energy storage is that sodium is very abundant and cheap, does not have adverse environmental effects and can be obtained without destroying nature via mining. By contrast, the mining of lithium and cobalt, which are employed in widely used lithium-ion batteries, has large environmental costs due to the massive adverse effects on the environment. Cobalt mining also involves particularly large social costs, often including child labour and bad working conditions. For use as a heat-transfer fluid, molten salt is also more environmentally friendly than other options such as synthetic oil (Kearney et al., 2003).

Another big advantage of molten salt for thermal solar energy storage and use as thermal power source for thermal plants formerly powered by coal is that it can be reused many times, over many years. This is the case since the process of melting when storing energy and cooling into a solid state after giving off energy does not degrade the salt much. According to some estimates molten salt tanks heated electrically can be heated thousands of times for up to 40 years (Harrabin, 2024). There is therefore much less of a problem of needing to recycle the storage material, in contrast to batteries used in electrical storage, which degrade over time, and are environmentally harmful, giving rise to a large recycling problem.

Other advantages of molten salt include that it is liquid at atmospheric pressure, it is a low-cost and efficient way to store thermal energy, its operating temperatures are suitable for steam turbines, and that it is not toxic and not flammable (Sandia National Laboratories, 2005). Another advantage of molten salt is that there is experience with it from its use in the chemical and metals industry as a heat transport fluid (Sandia National Laboratories, 2005; Bauer et al., 2021).

Given the huge potential of molten salt in scaling up solar energy storage and thereby enabling greater use of renewable energies, while using existing infrastructure of thermal plants currently powered by coal to generate electricity from molten salt instead, much more research on it is needed.

The green technology of storing renewable energy with the thermal energy storage medium of molten salt already exists. However, the use of thermal energy storage, as an alternative to electrical battery storage, has so far not received sufficiently high attention, development efforts and policy support it needs to be widely adopted. This paper sets out why policymakers, academic researchers and industry practitioners should speed up the development and application of the thermal energy storage medium of molten salt, and thereby scale up the use of renewable energy storage and generation more quickly in an environmentally sustainable way. This is important because energy storage has been a bottleneck holding back the expansion of renewable energy use, since its production is more volatile.

2. Use of molten salt as energy storage in concentrated solar power plants

Molten salt serves as a thermal energy storage medium. However, thermal energy storage of renewable energy for electricity production has not been well developed. Currently, renewable energy is being stored via molten salt storage in concentrating solar power plants, where mirrors focus sunlight onto salt located at the centre of an array of mirrors. However, this is not done in sufficiently large amounts yet. An overview of molten salt energy storage in concentrating solar power plants is provided in the review of Bauer et al. (2021).

Advantages of molten salt include that it is liquid at atmospheric pressure, it is a low-cost and efficient way to store thermal energy, and that it is not toxic and not flammable (Sandia National Laboratories, 2005). Another advantage of molten salt is that there is experience with it from its use in the chemical and metals industry as a heat transport fluid (Sandia National Laboratories, 2005; Bauer et al., 2021).

An advantage of using molten salt in concentrated solar power plants using mirrors is that the production of large mirrors is cheap and well known, including from building large astronomical observatories. Moreover, mirrors are made from abundant and environmentally friendly material. This is especially relevant for emerging economies which have abundant solar energy available, including in deserts, and can build concentrated solar power plants using mirrors relatively easily.

There is much potential in more research and development of the use of molten salt for energy generation and storage. These include developing better materials for containers of molten salt which can deal with the problem of high corrosiveness of molten salt.

3. Use of molten salt instead of coal to power thermal plants for electricity production

Molten salt thermal energy storage can facilitate the transition of thermal power plants from coal to renewable energy, in both advanced and emerging economies. Its operating temperatures are suitable for steam turbines. Molten salt can be integrated into existing thermal power plants that previously used coal, preserving some of the infrastructure. This approach allows for the utilisation of the existing infrastructure during the decommissioning of coal-powered plants (Aalborg CSP, 2015).

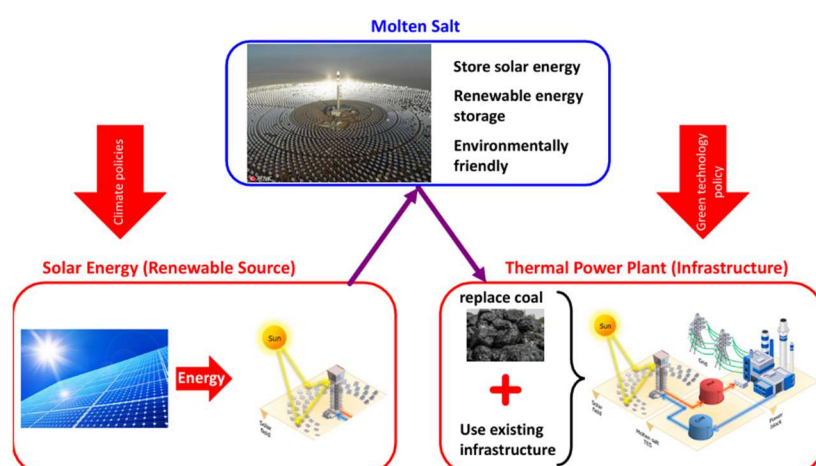
The infrastructure of thermal plants that formerly used coal can be repurposed when converting to molten salt. This includes the steam turbine, generators, condensing heat exchangers, water treatment equipment, and high-value components for switching, transforming, and transmitting high-voltage power. The infrastructure of thermal plants that formerly used coal can be repurposed when converting to molten salt. This includes the steam turbine, generators, condensing heat exchangers, water treatment equipment, and high-value components for switching, transforming, and transmitting high-voltage power; to replace a coal-fired boiler unit, an electric heated molten salt heater and two molten salt storage tanks with integrated steam generation systems are needed (Aalborg CSP, 2015).

Converting existing thermal plants to molten salt from coal provides a big cost advantage in generating renewable energy, since existing infrastructure can be used. Moreover, using this existing infrastructure reduces CO₂ emissions associated with building the infrastructure for renewable energy, since rather than scrapping the old fossil-based infrastructure and building completely new infrastructure, existing components are repurposed and reused.

Moreover, using molten salt in thermal plants formerly powered by coal allows to keep employing workers with expertise in operating these plants, which allows to preserve jobs when converting from coal to renewable energy. This would increase social acceptance of phasing out coal, since jobs are preserved in the renewable alternative, avoiding large increases in unemployment in regions specialising in coal power plants. This would in turn lower resistance to and speed up phasing out coal.

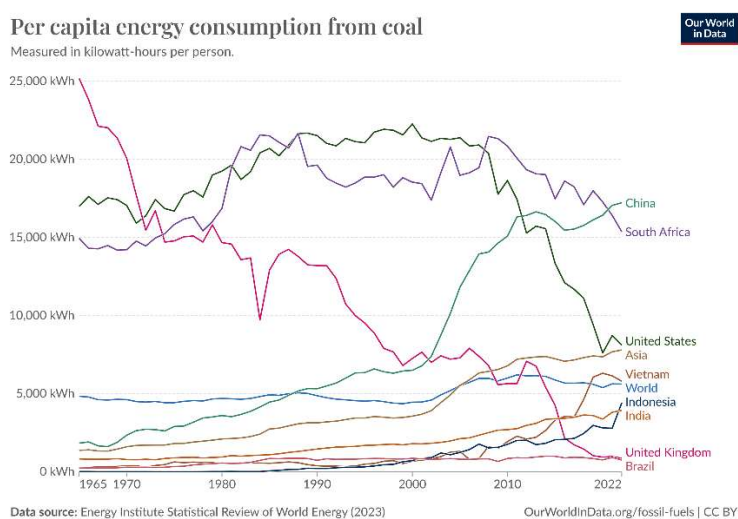
Such thermal power plants converted from coal to molten salt can then also be integrated with other renewable energy technologies, including concentrated solar power plants, photo voltaic plants and hydrogen plants (Aalborg CSP, 2015). Bauer et al. (2021) review new potential uses of molten salt in conventional power plants. In particular, using molten salt produced with concentrated solar power plants in thermal power plants allows to generate electricity from solar energy with less volatility, reducing the need for burning fossil fuels as a backup. Integrating the use of molten salt in CSP with that of powering thermal plants formerly powered by coal is illustrated schematically in Figure 2. Solar energy is stored thermally in heated molten salt in a CSP. This molten salt is then transported to a thermal plant formerly powered by coal and used to power it instead. After giving off its energy, the salt can then be reused in the CSP to store solar energy thermally, leading to a sustainable and environmentally friendly cycle of generating and storing renewable energy which can be repeated many times.

Figure 2: Linking use of molten salt in CSP with powering thermal plants



The economic development of some emerging economies (EMEs) in recent years has importantly been powered by coal, with per capita energy consumption from coal in Asia rising to above the global average in 2022 (Figure 2). Per capita energy consumption from coal has risen particularly strongly in Sout East Asian countries, including China, India and Indonesia (Figure 3).

Figure 3: Energy consumption from coal per capita



Source: Energy Institute Statistical Review of World Energy (2023); OurWorldInData.org/fossil-fuels .

Advanced economies (AEs), where coal use has fallen (eg in the United Kingdom and the United States) (Figure 3), need to provide technology transfer to EMEs to help them replace coal plants with renewable energy plants. Molten salt is a very promising candidate technology, since it can use the existing infrastructure of thermal plants powered by coal, while replacing the coal with molten salt produced via solar energy. Keeping and adapting the infrastructure of the thermal plants formerly powered by coal is a big advantage, since it allows large reductions in the cost of phasing out coal in favour of renewable energy production. This is especially important for emerging economies whose fiscal positions are not as strong as in advanced economies, and which are more constrained in financing the phasing out of coal.

4. Molten salt thermal batteries for grid-scale energy storage and green hydrogen production

Molten salt thermal energy storage can be used as a scalable grid-based energy storage, where surplus electricity is stored in molten salt during periods of surplus in the grid, which is then discharged when supply is low and demand high (Aalborg CSP, 2015), as a complement to electrical sodium ion batteries. A prototype new molten salt thermal battery for grid-scale energy storage has already been developed (Lavers, 2021). An important challenge going forward is to reduce costs, and lower the temperature at which it is operational (Lavers, 2021). Bauer et al. (2021) review new potential uses of molten salt in electrical energy storage.

A big problem holding back grid-based molten salt thermal energy storage is that it is not clear how grid energy storage will be paid for. Given the network externalities in building large-scale grid storage infrastructure, this needs to be specified, coordinated and regulated by policymakers. Examples of existing models to pay for grid energy storage in the United States include renewable energy and storage power purchase agreements, and tolling and capacity contracts (Thomson et al., 2023). Examples of regulation include that in the United States the Federal Energy Regulatory Commission issued orders (No. 841 and No. 2222) relevant for grid energy storage in 2018 and 2020 (Thomson et al., 2023). The US Inflation Reduction Act of 2022 extended investment tax credits to qualifying energy storage technology property (Thomson et al., 2023).

Molten salt can also be used to produce green hydrogen in a cleaner and more efficient way (Kamali, 2020; Xie and Kamali, 2022). This can be achieved by performing the electrolysis needed for green hydrogen production at a lower voltage of 1V instead of 2V, by dissolving steam in high-temperature molten salt electrolytes, followed by an electrochemical reduction of the dissolved hydrogen ions (Xie and Kamali, 2022). Molten salt could be used in scaling up the clean production of green hydrogen especially in emerging economies with deserts, where concentrated solar power plants using mirrors can be operated to store solar energy in molten salt, which could then be used to produce green hydrogen.

5. Role for green technology support policies

Since the costs of environmental degradation incurred in the course of energy production are not included in the price of energy, there is a role for green technology policy in addressing this externality by steering energy production towards renewable sources which are environmentally friendly and sustainable, including the combination of molten salt thermal storage with solar energy discussed in this paper.

Concentrated power solar energy plants using molten salt and mirrors are particularly well suited for emerging and developing countries with deserts, such as Chile and countries in the Sahel zone. There is a role for green technology policy in facilitating the transfer of green technology from advanced economies to such emerging economies, which is needed for the use of molten salt in concentrated solar energy plants, in thermal power plants, and to produce green hydrogen.

Many emerging economies in South-East Asia have strongly increased their consumption of energy from coal per capita in recent years (Figure 3), and they need to reduce their reliance on the use of coal for energy production. For such emerging economies, molten salt provides a good way to convert coal thermal plants to renewable energy. Green technology support policy would help in transferring the technology needed for such a conversion of coal-based thermal plants to

molten salt-based thermal plants from advanced economies to these South-East Asian emerging economies.

Also many advanced economies, which have many coal thermal plants in place, face the need to reduce and stop energy generation from coal. For such advanced economies, molten salt also provides a good way to convert these coal thermal plants to renewable energy, and green technology support policy in these advanced economies would help in speeding up this conversion.

More research and development is needed for these different ways to use molten salt for scaling up the production and use of renewable energy, including for use in concentrated solar energy plants, for converting coal-based thermal plants to molten salt-based solar plants, for grid-scale energy storage, and for producing green hydrogen. Research institutions in advanced economies have much to offer in speeding up and expanding this research, and making their findings available to emerging economies for scaling up the use of molten salt for renewable energy generation and storage there.

Multilateral financial institutions, such as the European Investment Bank, the Asian Development Bank and the Inter-American Development Bank, could help with the financing of molten salt-based projects in emerging economies.

Since molten salt thermal batteries can be a means for large-scale grid energy storage, there is a role for green technology policy in designing the grid infrastructure, which is subject to network externalities, including deciding how grid storage is paid for and how it is regulated.

6. Conclusions

This paper discussed expanding the use of molten salt for renewable energy storage and generation, in an environmentally friendly way and making use of existing infrastructure. These include using molten salt to store solar energy in concentrated solar plants, replacing coal by molten salt to power thermal plants and thereby convert existing coal thermal plants to renewables, and linking these two uses. They also include molten salt thermal batteries for grid-scale energy storage, and using molten salt in green hydrogen production.

Molten salt holds great potential for renewable energy storage and generation. By leveraging its capacity as a thermal energy storage medium, molten salt can effectively store and distribute energy from renewable sources, such as solar and wind power. This technology offers a sustainable solution for addressing the intermittency of renewable energy, thereby contributing significantly to the global transition to cleaner energy sources. Moreover, the integration of molten salt into existing thermal power plants provides a practical pathway for the conversion from coal to renewable energy, while ensuring the preservation of valuable infrastructure. Embracing molten salt technology is important for accelerating the adoption of renewable energy and combating climate change.

The paper also discussed the role for green technology policy in supporting the use of molten salt for scaling up renewable energy storage and generation sustainably. Since the costs of environmental degradation incurred in the course of energy production is not included in the price of energy, there is a role for green technology policy in addressing this externality by steering energy production towards renewable sources which are environmentally friendly, including the combination of molten salt thermal storage with solar energy discussed in this paper.

There is also a role for green technology policy in facilitating the transfer of the required green technology from advanced economies to emerging economies, in particular for a conversion of coal-based thermal plants to molten salt-based thermal plants. Since molten salt thermal batteries can be a means for large-scale grid energy storage, there is also a role for green technology policy in designing the grid infrastructure, which is subject to network externalities, including deciding how grid storage is paid for and how it is regulated.

The green technology of storing renewable energy with the thermal energy storage medium of molten salt already exists, but it needs to receive more focus, development efforts and policy support in order to be widely adopted, as an environmentally friendly alternative to electrical battery storage. This is important since energy storage has been a bottleneck holding back the expansion of renewable energy, due to its more volatile production.

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