Integrating thermal storage materials into energy systems

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Executive Summary

According to the Department of Energy and Climate Change (DECC), heat accounts for nearly half of the energy consumed in the UK and a third of carbon emissions. Around 80 per cent of this heat is used in homes and commercial buildings to provide water and space heating, with natural gas being the main fuel source. Unlike electricity, different sorts of heat are required for different purposes and this adds a level of complexity to the challenge of decarbonizing heat demand.

This report summarises feedback from industry and academia on the opportunities associated with the integration of thermal storage materials into existing energy systems. Representatives developing Phase change materials, Inter-seasonal storage, Cryogenics and Thermochemical storage gave their opinion on how innovation funding could help. A complete list of the main challenges identified by the delegates can be found later in this report with highlights detailed below.

Technical Changes

Further improvements are needed to reduce the unit size and increase the energy density of mobile thermal storage devices. A device that could offer improved storage capacity in a heat network compared with water, for a similar price would be attractive.

Support should be given to National grid and the distribution network operators to explore the opportunities for managing an increased load through the existing electricity system due to industrial waste heat being converted to electricity for transportation. Attention needs to be focused on industrial waste heat as an opportunity for the electrification of heat.

Better visibility of the 'comfort' of the building environment is required. Demand side management tools and system control panels, which are user-friendly and require little or no intervention from the homeowner would balance the heat load on a heat network and allow the homeowner to be more aware of their home environment. System controls should incorporate value add data, for example, weather data to automatically adjust the environment when hot or cold weather is forecast.

Economic Changes

Business models that investigate the system wide integration of thermal storage technology are required to make it more attractive to all stakeholders – waste heat source/heat generators, network operators and home owners. Selling heat as a service with utility companies providing the equipment to homeowners as part of the package should be explored further.

Policy Changes

New legislation to encourage the adoption of novel low carbon thermal technologies would help to increase the integration of thermal storage into existing energy systems. For instance the deployment of the condensing boiler across the UK was a great success because government mandated that all new boilers had to be condensing boilers. Something similar could help to kick start the use of thermal storage materials and drive innovation.

Integrating thermal storage materials into energy systems

Background

According to DECC, heat accounts for nearly half of the energy consumed in the UK and a third of carbon emissions. DECC's 'Future of Heating' Strategy paper 2013 revision states "*the residential sector includes four million households currently heated by alternatives to mains gas with many having to rely on expensive, higher carbon forms of heating. These households will gain from switching to low carbon heating because their heating bills and carbon emissions are higher than average".*

However to fully investigate the heat challenge it is important to recognise that, unlike electricity, different sorts of heat are required for different purposes for example; where is it needed, what is it needed for, when it is needed and how hot it needs to be. With this is mind the Low Carbon Innovation Coordination Group (LCICG) established the Heat Technology Innovation Needs Assessment (TINA) to identify the key innovation needs to inform public sector investment in low carbon innovation. The TINA focused on heat pumps, heat networks and most importantly for this report, heat storage. The TINA states "*Innovation in these technologies could reduce UK energy system costs by £14-66bn1 to 2050, with heat storage also offering additional value by enabling other system adjustments. Innovation can also help create a UK industry with the potential to contribute further economic value of £2- 12bn to 2050. Significant private sector investment in innovation, catalysed by public sector support where there are market failures, can deliver the bulk of these benefits with strong value for money"*

Following consultation with InnovateUK, as well as a number of companies working in the thermal storage industry, the Knowledge Transfer Network (KTN) attempted to identify the opportunities for deployment of innovative thermal storage materials and to scope out the specific challenges that could be addressed through innovation funding.

Key opportunities identified

On the 23rd March 2016 the Knowledge Transfer Network hosted a small workshop to gather feedback from industry and academia on the opportunities associated with the integration of thermal storage materials into existing energy systems. Representatives developing Phase change materials, Inter-seasonal storage, Cryogenics and Thermochemical storage attended. A list of organisations that attended the workshop is in the appendix.

The group was asked to consider the opportunities relating to the whole system rather than a particular technology and to be as specific and detailed as possible about the opportunities and challenges, which needed to be addressed. The group discussed the opportunities associated with two main scenarios;

Linking thermal storage to renewable energy sources for district heating

- How can renewable heat generation such as heat pumps, CHP or solar thermal be connected to storage materials in a heat network?
- What is the energy performance of the storage unit (relative to water), the operating temperature range, the cost and scalability of the thermal storage device, the mobility of the thermal device?

Storing high-grade heat recovered from industrial sources

- How can thermal storage materials help to store high-grade heat (<400C) from industrial processes such as steel processing, glass and ceramics manufacture? What are the opportunities for capturing the waste heat without impacting the industrial process?
- How can the stored high-grade heat be transported to areas of heat demand? i.e. rather than using the waste heat onsite or in the local area, can mobile storage units be used to transport the heat further afield?

The discussions produced a list of opportunities from across the two scenarios, which were prioritized by the group. The challenges are described below in order of importance, high to low.

Conversion of industrial waste heat to electricity for transportation (7 votes)

With high temperature industrial waste heat, heat loss is a challenge when transported by water in pipelines or stored in mobile thermo chemical storage units. The solution could be

to convert the waste heat into electricity to be fed into the grid and used for heating in areas of high demand i.e. storage heaters.

Intelligent energy stores in the home (7 votes)

There is a need to optimize thermal management through the use of network management tools to enable the efficient transfer of heat to the recipients on the network.

Business Models (6 votes)

The industry needs to design business models to demonstrate the benefits of thermal storage to all the stakeholders i.e. the energy generator/waste heat supplier, heat network operator and end user.

- Domestic thermal stores need to be high density but also loft friendly.
- The CAPEX as well as the OPEX needs to be affordable for all the stakeholders.
- The system and its components need to be reliable and long lasting – at least comparable with gas boilers.
- The thermal store needs to be part of a heat and power network connected to the grid.

Conversion of waste heat to cold for transportation (6 votes)

The waste heat from industrial sources could be converted into cold to be stored in small units/modules for transportation.

High thermal density storage (5 votes)

There is a need for the development of high thermal energy density storage materials, for instance thermochemical materials such as 'metallorganics'

Nearby or onsite utilization (4 votes)

Though the group was asked to think about opportunities for transporting waste heat beyond the local area the delegates thought further development was needed to improve efficiencies in onsite utilization of waste heat either for heat or power.

Heat as a service (4 votes)

There is a great opportunity to sell heat as a service to the end user. Rather than each occupant having to buy a gas boiler they sign up to a contract to have heat delivered as a

service through a heat network. The utility or DNO would own the equipment and ensure that the occupant was provided with heat to standards agreed in the contract – similar to the radio rentals model. This could be at a district scale or eventually city scale.

Small reactor thermo chemical units (4 votes)

One opportunity could be to develop small reactor thermo chemical storage units. The thermochemical fluids could be pumped (without heat loss) to where it is needed and heat extracted using a small reactor. The ancillary equipment would be much smaller than having water tanks or other large storage units in the home.

System level control (3 votes)

One suggestion for thermal storage within a building is to have a central thermal store with controls to balance the heating and cooling within the property. The store could be connected to a local heat network to accept additional heat when required. A combination of water and phase change material storage.

High temperature and low volume thermal storage units (3 votes)

The ultimate goal for thermal storage materials is to develop a high temperature, low volume storage unit connected to a heat pump. An aggregator would control the system to balance the thermal energy demand. The solution is a low volume, thermocycle with a secure supply of heat.

Improved cycling rate (2 votes)

There is a need to develop thermal stores that can charge and discharge quickly to provide flexibility or the service.

Property level storage (2 votes)

'Individual property heat stores versus system heat storage' i.e. small heat pumps in each property linked to small thermal stores or a centralized heat store and CHP on a heat network. More needs to be done to evaluate the pro and cons of both systems.

Load balancing for heat pumps (2 votes)

Renewable energy can provide a variable output. At times of peak load thermal materials could provide the buffer for the system. Dealing with the 'must take' issue.

Improved high-grade heat storage (1 vote)

There is a need for innovation funding to develop improved grades of heat storage. Currently thermal storage materials for temperatures below 100C are almost commercial. However thermal stores for temperatures over 150C are extremely difficult to produce.

Additives (1 vote)

Additives could be used to enhance current storage technologies making them high-density liquid storage systems. Efficiencies could be improved using additives

Using electric vehicles for waste heat transportation

High-grade heat from industrial processes could be converted into electricity and fed into electric vehicles (EV). The EV would transport the energy to the heat network to be converted back into heat.

'Coalman' service modular units

Delivery of heat could be as a service i.e. 'coalman' delivery model – order the storage units as you require them. The delivery of storage materials in a suitable sized format. This would only be achievable with the appropriate energy density.

Solid thermal materials

There is a need to develop solid-state thermal energy stores. The stores could reside underground with insulation to maintain the heat for long periods of time. However at high temperatures solid thermal stores have stability issues. Potential from inert materials for a mid temperature heat store or the use of recycled glass materials as a solid heat store. However recycled glass is used quite heavily in the glass production industry so there may be competition for the waste stream.

Detailed discussions

Once the opportunities had been described and prioritized, the delegates were split into two groups to discuss the top two opportunities in more detail. They were asked;

- Where are we now in relation to opportunity?
- How might we make the opportunity a reality?
- Do we have the right skills?
- Who would we need to partner with internationally? (if at all)
- What are the untapped benefits associated with this opportunity?

These discussions are documented below.

Conversion of industrial waste heat to electricity for transportation

Currently waste heat is captured at a number of industrial sites around the UK but the waste heat is usually converted to power for use onsite or at other commercial buildings nearby. A variety of processes are used to harness the waste heat including;

- Thermoelectrics – creating electrical power from the temperature difference. This is a very flexible system and can be installed in many locations but it can be inefficient.
- Steam generation – creating steam from the heat to drive turbines. This is much more efficient but lacks flexibility

In terms of storing the waste heat, low energy density materials are used and the power generated is dependent on the efficiency of the system and the temperature requirements. There are no examples in the UK where the stored heat energy has been transported a reasonable distance i.e. more than 5km.

Converting the heat into electricity for transportation through the national grid could be one solution. Once delivered through the grid the electricity could be used to heat water for a heat network or fed into storage heaters for individual buildings. The barrier to this opportunity is the age of the electricity grid and its capacity to cope with the additional demand.

The alternative is to store the waste heat in mobile thermal storage units using innovative materials to reduce losses and increase the energy density of the units. The heat can be stored and transported as heat or converted to cold using cryogenics releasing the heat again when required. All these technologies are fairly low in terms of the TRL scale and will need funding support to be able to store the high temperature waste heat (<400C).

These two opportunities are very different and the group discussed the metrics that could be used to decide the best option for a given site. Some of the metrics suggested include;

- Energy density compared with water
- Volume and weight of device
- Cost of storage materials versus upgrading grid infrastructure

In terms of skills, to make mobile thermal storage devices a reality the group agreed that the UK has the experience in process engineering and design to develop technologies that have an energy density 3-4 times higher than existing thermal materials. The UK has a good standard of academic knowledge in the area of materials science as well as modeling capabilities to simulate the materials in an energy system. These skills are being harnessed to improve the energy density of thermal storage and they should be encouraged to partner with material developers and system integrators in the industry too. Government should build links with the Fraunhofer Institute to learn lessons from their R&D.

Further development of transportable thermal storage devices would have applications for developing countries too especially in isolated communities.

An intelligent thermal energy store in the home

Currently homes have very simple electric heating controls in the form of a thermostat on the wall. It allows the homeowner to set a temperature for their home environment. However this is not a very intelligent option if it relies on the homeowner to control it, especially as many will turn up the thermostat when they're cold as if it was a gas fire.

There are several new control systems such as 'Nest' on the market which allow the home owner to control the comfort of their environment but they are not compatible with heat networks or some of the more innovative thermal storage technologies which is leading to separate heat network controls systems being developed.

What is required is an intelligent system that integrates all the energy systems in the home to deliver a comfortable environment for the homeowner. This could be achieved by using heat storage linked to heat pumps to balance the load. Aggregating heat pumps across a network of homes would help to reduce the impact on the grid. Integrating innovative thermal storage would further mitigate for the losses that are likely to be experienced. Centralised control of the heat pumps on the network would reduce the complexity of the system for the homeowner. There are new systems being developed that are likely to be on the market by 2017 that manage the flow of heat from the source to demand via heat stores and further testing is required to see how home owners will interact with these new devices.

Exploration of available datasets that could add value to the control system and improve the homeowners experience is needed. For instance linking the system to Met office data could allow the system to adjust dependent on forecast for the local area. This would be most effective for heat pumps where the difference in temperature can affect the efficiency of the system.

Further development is needed to design the optimum business model to ensure that all stakeholders in the energy system are engaged and understand the benefits of converting to a low carbon thermal system rather than continuing to rely on their gas boilers. One option might be that the utility owns the equipment that is installed in the home and charges the homeowner for the service of providing heat. Another option might be to ask the homeowner to relinquish control of the heating in their home and in return they benefit from low cost heat.

The group agreed that the UK has the necessary skills to develop intelligent control systems linked to a thermal store and they were confident that if the product was right consumers would buy it. However consumers would need to be made aware of the benefits and educated on why they should opt for low carbon thermal storage over water tanks and gas boilers. The recent legislation, which required standard boilers to be replaced with condensing boilers proved to be a very powerful driver for change. The Government could support the deployment of thermal storage by issuing a similar mandate.

Recommendations for government

Transportable thermal storage

Further improvements are needed to reduce the unit size and increase the energy density of mobile thermal storage devices. A device that could offer improved storage capacity compared with water in a heat network but at a similar price would be attractive.

Business models

Business models that investigate the system wide integration of thermal storage technology are required to make it more attractive to all stakeholders – waste heat source/heat generators, network operators and home owners. Selling heat as a service with utility companies providing the equipment to homeowners as part of the package should be explored further

Poor infrastructure and grid capacity

Support should be given to National grid and the distribution network operators to explore the opportunities for managing an increased load through the existing electricity system due to industrial waste heat being converted to electricity for transportation. Work has been conducted to understand the impact of heat pumps being deployed widely but attention needs to be focused on industrial waste heat as an opportunity for the electrification of heat.

Legislation

New legislation to encourage the adoption of novel low carbon thermal technologies would help to increase the integration of thermal storage into existing energy systems. For instance the deployment of the condensing boiler across the UK was a great success because government mandated that all new boilers had to be condensing boilers. Something similar could help to kick start the use of thermal storage materials and drive innovation.

Thermal controls

Better visibility of the 'comfort' of the building environment is required. Demand side management tools and system control panels, which are user-friendly and require little or no intervention from the homeowner would balance the heat load on a heat network and allow the homeowner to be more aware of their home environment. System controls should incorporate value add data, for example, weather data to automatically adjust the environment when hot or cold weather is forecast.

Appendix

List of companies who contributed to this report

1. Highview Power
2. University of Warwick
3. Tata Steel/SPECIFIC project
4. European Thermodynamics
5. CCm Research
6. University of Birmingham
7. ICAX
8. Glen Dimplex
9. Cambridge Design Partnership

Sunamp weren't able to attend the workshop but shared their comments after the event, which have been incorporated into the main body of the report.