Programme Area: Smart Systems and Heat

Project: Enabling Technologies

Title: Technology review and gap analysis

Abstract:

This document provides an assessment of the development pathways of four technologies from a technological perspective:

- Hybridised ASHP with gas boilers for individual dwellings, optimised for the British conditions;
- High-density thermal storage for individual dwellings;
- Home Energy Management Systems (HEMS) and sensors for residential applications;
- Building Energy Management Systems (BEMS) and sensors for non-domestic applications.

These technologies have been pre-selected by the ETI as technologies that could. The report was initially published in July 2013. Some details and analysis may be out of date with current thinking.

Context:

This project identified gaps in the range of potential smart systems technologies to accelerate the development of component technologies which are required for any successful deployment and operation of a future smart energy system. This £500k project was announced in February 2013 and was delivered by a consortium of partners that includes Hitachi Europe, EDF Energy, Element Energy, David Vincent & Associates and Imperial Consultants.

Smart Systems and Heat – Work Area 1:

Enabling Technologies

Task 5a – Technology review and gap analysis

Final Report

12th July 2013

Contents

1 Introduction

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- Hybridised ASHP with gas boilers for individual dwellings, optimised for the British conditions;
- High-density thermal storage for individual dwellings;
- Home Energy Management Systems (HEMS) and sensors for residential applications;
- Building Energy Management Systems (BEMS) and sensors for non-domestic applications.

These technologies have been pre-selected by the ETI as technologies that could, with appropriate development, play a significant role in a future smart heat system over the medium term (e.g. 2030).

In particular, the document provides a high level assessment of:

- The current state of development of the technology
- The key areas of technical development required
- Non-technical market constraints for each technology assessed at a high-level
- The timescales and key milestones in these development pathways
- The level of investment required to achieve the technical developments identified
- The opportunities for the ETI to accelerate technology development and commercialisation
- Impact of technology development on performance and costs
- Role of the technologies under different electrification scenarios

This document provides a summary of the main findings of the research. A comprehensive report on the technology analysis is provided in a separate PowerPoint document.

2 Methodology

The assessment of development pathways has involved consideration of each technology at the component level. The work is focussed on technical aspects, although we have also identified non-technical 'components' which will require further consideration. For example consumer engagement is considered a key 'component' of the pathway for Home Energy Management Systems (HEMS).

The overall approach to the assessment is summarised in the following:

- Component level assessment - for each technology the key development needs were identified and assessed on the basis of their criticality and the difficult of achieving the developments
- Key development needs assessment – the most critical development needs identified in the component level assessment are assessed in greater detail, including identification of milestones, timescales and investment bands related to addressing the developments
- High-level assessment of non-technical barriers conditioning the development of the four technologies (i.e. market and consumer constraints)
- Impact of technology development on performance and cost
- Assessment of the role of the technologies under different electrification scenarios
- Identification of engagement opportunities for the ETI.

The report identifies key development needs through the analysis of a set of technical and non-technical barriers. Through the component-level analysis we have attempted to identify components that seem to be important factors in the likely commercialisation and uptake of the technologies.

Once the most critical components were identified, a further sub-component analysis was carried out, in which the milestones, timescales and estimated investment bands for the key technology development needs were addressed. The potential collaboration partners and the level of engagement (e.g. field trials, research funding) for the ETI were also assessed.

3 Scope of Task 5a

While the development needs we have identified in these key components are considered to be of high importance, they are clearly not the only developments that will be required. Solving these issues will not guarantee that the technologies will achieve widespread commercial deployment. There are a wide range of other barriers that will need to be overcome. Some of the key barriers are as follows:

- **Cost** – cost is a barrier for all of these technologies. Only BEMS currently has commercial products that have achieved significant uptake in the UK. Some of the development needs identified here will help to address costs to an extent, but further cost reductions, e.g. through scale-up of manufacture and systems optimisation, will be required.

- **Lack of awareness / consumer acceptance** – the technologies are not well-known to consumers (and in some cases not to the construction and engineering industry). The need for trials and consumer engagement work is identified as a development need for several technologies. Substantial effort will be needed for each technology.

- **Suitability to the building stock** – this is particularly an issue for heat pumps, although the hybridisation with gas boilers helps to overcome this constraint, and for high density thermal storage materials, where incorporation into standard building products is a challenge (particularly for the domestic sector). While HEMS and BEMS suffer less from a suitability issue, significant developments in other products are needed for the full benefits to be achieved (e.g. smart appliances).

- **Supply-side constraints** – The global nature of these technologies mean that UK manufacturing capacity is not likely to be a strong barrier, but availability of local suppliers and installers with the requisite skills could be a limiting factor on market growth. This is likely to be more of an issue for Hybrid Air Source Heat Pumps and High Density Thermal Storage.

It was not part of the scope of Task 5a to carry out a broader assessment of systems and non-technical development needs which would inform and shape a development specification. It is recommended that such an assessment be carried out as part of any subsequent engagement investigation or due diligence.

4 Overview of development needs

High level development needs over the medium term and the impacts of each stage in terms of performance and costs for Hybrid Air Source Heat Pumps, High Density Thermal Storage and Home Energy Management Systems are provided in the following pages.

An overview of development opportunities for BEMS was not included given that it is a technology already commercially available and that several of its technology developments are parallel to those for HEMS (e.g. BEMS aggregation development through standardised communication and interoperability and Cloud based EMS). It is worth mentioning, though, that in the case of BEMS there are opportunities for development of sensors and actuators to enable building automation and controls for Demand Side Response and for producing tailored Energy Management Services for each building.

Regarding High Density Thermal Storage, sensible heat storage was not addressed in this study due to its high volume requirements that hinder their suitability in urban residential buildings.

In the diagrams on the following pages, the main short, medium and long term development needs are presented in blue boxes, with a summary of performance and cost implications of each development below them. Additional information, such as current costs, cots breakdown by component and cost reduction opportunities are also presented where available.

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H-ASHPs

NON-TECHNICAL

Supply chain development and technology deployment

Increased insulation of buildings
- Enables overall system cost reduction

Trials and consumer engagement / acceptability
- Largest level of cost reduction through economies of scale

Training of installers with required skills
- Achievement of nominal COP

- One of the main drivers for cost reduction
- 2020: 20% installation cost reduction
- 2050: 35% installation cost reduction

TECHNICAL

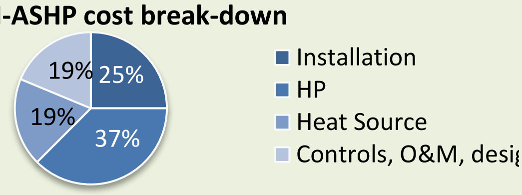
Component integration: prototype development and demonstration

Technology integration with HDTS, HEMS and smart grid

Control interface monitoring in real space for extended range H-ASHPs
- Increased operation range
- Coverage rate*: ≥50% (retrofit)
- Enhanced flexibility
- Enabled for smart systems

- Level of ETI investment: < £5 m
- 2020/2050: 30%/50% potential cost reduction of H-ASHP controls by technology development
- 2050: ~5% overall H-ASHP cost reduction due to cost reduction in controls

H-ASHP cost break-down



Overall potential H-ASHP cost reduction by technology development *(EDF, Heat TINA)***:**
- 2020: 10-30%
- 2050: 40%

Improved compressor performance (increased injection capability)
- Increased operation range
- Improved COP (20%)

- Level of ETI investment: <£10 m
- 2020/2050: 30%/50% potential cost reduction of H-ASHP compressor by technology development
- 2020: ~10-15% overall H-ASHP cost reduction due to cost reduction in compressor

Today — Medium term — Long term

* *'annual heat provided by the heat pump' / 'total annual heat provided by the Hybrid'*

DEVELOPMENT NEEDS | PERFORMANCE IMPLICATIONS | COST IMPLICATIONS

HDTS

Salt hydrate based thermal store

- Overcoming corrosion and loss of energy storage density with cycling
- 4-5 times smaller than conventional hot-water tank
- Level of ETI investment: ~£1 m

Integration of HDTS thermal store and microgeneration

- Increased flexibility for peak-shaving, demand response
- Space gains
- Enables economic benefit when coupled with microgeneration techs

Standardised procedure for installation and monitoring of houses with HDTS installation

- Level of investment: <£1 m

Supply chain development and economies of scale

Improved modelling to verify performance under dynamic loads and develop system design tools

- Enable market penetration through environmental and economic benefit communication to customers
- Level of investment: <£1 m

Bio-based micro-encapsulated PCMs

Cost-effective salt-hydrate microencapsulated PCMs

- High potential of salt hydrates: double volumetric latent heat than paraffins and non-flammable
- Salt hydrates lower cost than paraffins

Fire retardation capability for paraffin PCMs

Cost-effective micro-encapsulation techniques for paraffin based PCMs

- Despite the fact that 50% of micro-encapsulated PCMs costs arise from micro-encapsulation, this is a mature process, and hence extensive cost reductions seem unlikely

Today → Medium term → Long term

THERMAL STORE HDTS DEVELOPMENT NEEDS

BUILDING FABRIC HDTS DEVELOPMENT NEEDS

HEMS

Develop attractive consumer proposition through Energy Management Services development

Trials of technology and consumer proposition

Gas boiler controls, thermostats and Thermostatic Radiator Valves (TRVs) for retrofitting

- Retrofit these elements to the current gas boiler based central heating systems is important to create a market

Consumer interaction management

- Development of consumer Relationship Management (CRM), Asset Management, and Service call centre with consumer information system

Functionality – Balancing multi-objectives

- Development of thermal dynamic model to reduce the Demand Response impact on Quality of Life
- Development of control history analysis with pre-setting preference
- Enable market uptake

Integration with Heat Pumps, mCHP, smart appliances

- Enables control and potential DSR participation
- A HEM can enable these benefits, but other routes may also exist, e.g. smart controller integrated into the HASHP communicating with a smart meter

Functionality – Cost-effective user interface: Consumer engagement

- IHD, Mobile applications
- Key for market uptake

Security – Development of cyber-security

- Currently there are no cyber security standards
- Development of anonymous database and L7 security

Interoperability

- Standardisation on HAN communication protocol will provide confidence to developers of sensors/actuators and smart appliance manufacturers, facilitating the scale up
- Interoperability at higher level will enable aggregation and increase functionality

Today → Medium term → Long term

DEVELOPMENT NEEDS | PERFORMANCE IMPLICATIONS

5 Summary of development needs

Based on the *Component level assessment* and the *Key development needs assessment*, which are presented in the accompanying PowerPoint document (appendices to this report), the Consortium identified the key development needs for each technology. These are tabulated below with a summary of the potential impact of achieving the development and an indication of the timescale over which the development could be achieved[1].

5.1 Hybrid Air Source Heat Pump (HASHP)

Table 1. Hybrid ASHP development needs

Component	Development needed	Impact	Timescales
Control interface	• Currently available H-ASHPs tend to be controlled on the basis of outside temperature measurement • Extended range H-ASHP are being developed with control algorithms designed to increase the heat pump's range of operation and optimise against a variety of parameters, e.g. energy tariffs (potential for dynamic response), primary energy consumption, CO_2 emissions etc.	• Extended HP operation range improves environmental performance • Increased flexibility and potential for incorporation in a smart system (e.g. respond to price signals) • Although controls constitute ~8 % of the overall costs (which would mean an overall potential for cost reduction of ~5% by 2050), their development is fundamental for the commercialisation of the hybrid ASHP technology, which is 30-40% cheaper than pure ASHPs	• Currently at modelling / simulation stage • Requires monitoring in real environments • Relatively short development horizon – three years
Heat pump compressor	• Injection capability for higher temperature output • Incorporation of ejectors to reduce compressor energy use • Use of multi-stage compressors	• Provide higher water temperature (at high COP) • Improved COP – ejectors have potential for 20% improvement • Overall cost reduction opportunities of 10-15% arise from improved COP, which implies lower capacity HPs to fulfil the same heating requirement compared to current performance levels	• Developments in compressor technology anticipated within five year period

[1] Note that the timescales are high-level estimates based on current understanding of activity in the industries. There may be scope for ETI involvement to accelerate these timescales, but no attempt has been made to consider timescales for development projects in detail

Component	Development needed	Impact	Timescales
Environmentally friendly refrigerant	• Use of CO_2 as an environmentally-friendly refrigerant is being developed • Improving COP for operation in a narrow temperature band (e.g. typical difference between flow and return temperatures) • Work with propane and ammonia refrigerants is on-going, but there are issues with flammability and toxicity, respectively	• Reduce concerns regarding refrigerant leakage • Possibility of supplying higher temperature hot-water at higher COP	• Several organisations active in R&D • More products / trials expected within five year period
User acceptability	• Reduced fan noise – noise from the fan can be in the range from 40-60 db. This has implications for possible siting of the heat exchanger and user acceptance issues (see user acceptability note below). Work to increase power density and reduce noise is required	• Major potential impact on improved consumer acceptance	• Currently R&D stage – five years for improved products seems reasonable

User acceptability

In England, the installation of an air source heat pump is a permitted development, i.e. planning permission is not required, provided that a number of criteria are met. One of these criteria states that the noise level due to the external ASHP unit does not exceed 42dB $L_{Aeq(5min)}$ at 1 metre from the window of a habitable room in the façade of any neighbouring residential property. For ASHP creating noise levels in the 50 – 60dB range, this leads to separation distances of around 10 to 20m from neighbours' windows. This is a significant restriction on installations in dense areas and particularly in flatted developments. ASHP manufacturers are arguing for an increase in the noise level for permitted developments to at least 45dB $L_{Aeq(5min)}$ at 1 metre from neighbouring windows.

5.2 High Density Thermal Storage (HDTS)

Table 2. HDTS development needs

	Component	Development needed	Impact	Timescales
BUILDING FABRIC HDTS- PCMs	**Encapsulation for building fabric use**	• **Lower cost microencapsulation techniques –** microencapsulation (rather than macro) enhances the heat transfer with the surrounding, but adds significantly to cost (~50% of final product cost). Need for both paraffins and salt hydrates (lower TRL for the latter)	Cost reduction of HDTS impregnated building elements	• Ongoing for paraffins– products available today (gypsum, plasterboard,,etc). New products and encapsulation techniques over five year horizon • Under development for salt hydrates - currently more commonly used in macroencapsulated form
	Fire retardation capability	• **Require further investigation**, as PCMs are flammable – British Board of Agreement Certification will be essential to market penetration	Major impact on market penetration	
	Modelling / Design / Installation	• **Tools for modelling performance under dynamic loads and winter/ summer performance** – lack of knowledge of performance under real dynamic conditions is recognised as a barrier (particularly in domestic buildings) • **Increased knowledge** – Better understanding of PCMs is needed among engineers, specifiers and installers. Contractors need to gain familiarity	• Verification of performance benefits • Facilitate selection of optimum materials for each application	• Short time-scales. Models can be developed now, but real world trial / monitoring needed
THERMAL STORE HDTS - PCMs and Thermochemical	**Salt Hydrated based thermal store**	• **Research/development/demonstration** to overcome corrosion and loss of energy storage density with cycling	Salt Hydrated PCMs avoid the corrosion problems of paraffins, have double volumetric thermal density and are cheaper	Currently there are products at feasibility and demonstration stages in the UK. Commercially available products could be available in a relatively short development horizon – 2/3 years
	Integration with primary heating technology	• **Cost reduction and improved thermal conductivity for heat storage applications** – The cost of advanced thermal storage materials is a key barrier (particularly in comparison to the incumbent, i.e. hot-water). Better heat transfer properties are required to increase utilisation of storage space. Technology development tailored to different heat sources and systems	• Increased uptake of heat stores with heat pumps • Increased flexibility for peak-shaving, demand response	• Currently in R&D and simulation phase. • Significant development needed (five years)

5.3 Home Energy Management Systems (HEMS)

Table 3. HEMS development needs

Component	Development needed	Impact	Timescales
Energy Management Service (EMS) Functionality	• **Development of balancing multi-objectives** – balancing cost and benefit with Quality of Life consideration is key for consumer acceptance • **Interface for the retrofit** (e.g. boiler control interface, integration with intelligent thermostat) • **Consumer engagement** – cost-effective user interface (e.g. IHD, Mobile App) is key • **Development of consumer interaction management** – Consumer Relationship Management (CRM), Asset Management, and Service call centre with consumer information system • **Compensation of heat model characteristics with respect to outside temperature** • **Common functional specification and common standards** – specification required for physical, functional and interface aspects as well as data requirements. Address interoperability issues for widespread roll-out • **Real time control of consumer loads** – development of control algorithms for optimised response to demand response (DR) programmes	• Creation of an early-adopter market (ahead of smart meter roll-out and demand response offers). Retrofitting to the current gas boiler based central heating systems is important to create a market • Interoperability will increase range of applications for HEMS and also facilitate scale up of manufacture • Optimise energy consumption, flexibility to respond to DR signals – synergy with smart meters	• Increased consumer engagement in the short-term (next five years) consistent with assumptions on DECC's Smart Meter Roll-out strategy • Work in progress towards technical specifications settlement. Expected in the short term (five years horizon) • Development of control algorithms dependent on DR market emergence. Short time development needs for the algorithms
Home Area Network (HAN)	• **Improvement in radio devices** (Wi-Fi routers, networking equipment) – reduce signal loss and sites that require range extension • **Interoperability standards** – need for standardisation of communication standards for elements of the smart system	• Cost reduction and increased applicability • Increase applications / controllable demands • US Department Energy has push Smart Energy Profile 2.0 (SEP2.0) for HAN control to DER (Distribution Energy Resources), Home appliances, sensors and other equipment. Possibility for the ETI to promote it in UK	Standardisation of HAN standards expected in short-term (3-5 years)

Component	Development needed	Impact	Timescales
HEMS aggregation functionality	• **Standardised communication between HEMS and external communications hubs** (e.g. Community Energy Management Systems) • **Interface for the retrofit** • **Development of cyber-security and privacy protection** – at this point, there are no cyber-security standards. The development of anonymous database and L7 security is a technical trend	• Significant increase in applications, e.g. demand response, control of distributed storage, Virtual Power Plant etc. • Crucial for consumer acceptance	• Issue is solvable – attractive consumer offer needed to create market demand • Data security needs to be resolved for smart meter programme

Development needs in sensors and actuators were not addressed in detail (given the scope and timescales of Task 5a it was necessary to focus on the HEMS technology level rather than component level). However, it was found that there are opportunities for development in sensor technology to provide cost reduction and improvement in performance (systems-on-chip). Potential areas for development also include the integration of sensors and interfaces to enable display of electricity consumption/price information at the appliance level and the integration of actuators for space heating equipment with an intelligent thermostat.

Energy Management Service (EMS) Functionality – Development of multi-objective balancing and retrofitting interfaces with heat sources

For the successful incorporation of HEMS into the market, development of multi-objective balancing is of paramount importance. This means that cost, benefits and Quality of Life need to be tailored to each market segment.

Functionality is required that can drive cost-benefit improvement, which might include reduction of energy consumption, applicability of HEMS to new tariff structures, simplified energy cost management (e.g. comfort, saving, super-saving options) and upgradability of HEMS (enabling technology uptake by a small initial investment with the option of upgrading over time).

On the Quality of Life (QoL) aspects, functionality enabling thermal comfort and privacy protection will be key. Potential development needs enabling comfort are the development of a dynamic thermal model to ensure that demand response impact on QoL is limited and the integration of functionality to analyse the control history to enable pre-setting of user preferences –making HEMS easier to control.

Retrofitting of controls to gas boilers, where there is a remarkable improvement opportunity, will be an important driver to create a market for HEMS. An intelligent thermostat is the major controls component required for this, as is the need for good system design and component selection.

5.4 Building Energy Management Systems (BEMS)

Table 4. BEMS development needs

Component	Development needed	Impact	Timescales
BEMS aggregation	• **Development of standardised communication and interoperability** – BEMS is currently a vendor-specific service. Incorporation of BEMS into wide communication network will enhance BEMS applications • **Functionality** – current BEMS communicate only with the building manager (either in the building or remotely via a facilities management service provider looking after a buildings portfolio. Future BEMS could offer 3rd party communications to aggregators or network operators in order to manage peak loads on the power network). • **Cloud based BEMS services** – reduce costs and resource burden on customer systems. Improve service latency and network congestion	• Facilitate demand response programmes and integration with smart meter systems • Facilitate virtual power plant concepts and control of distributed storage • Cost effective introduction of BEMS in medium/small buildings • Without additional communication functionality to 3rd parties, the opportunity for BEMS to make a more effective contribution to reducing peaks and carbon emissions is missed	• 5 to 10 years. Technology development is not the issue, but standardisation will require significant investment and coordination across industries. Could be achieved more quickly if there were sufficient market pull or regulatory pressure
Controls	• **Sensors and actuators to enable building automation** – controls will need to be optimised in order to respond near real time. Although there is a good understanding in controls, these will have to be tailored to consumer loads, integrated in the system, and tried in real environments • **Interoperability standards** – these enable the aggregation of BEMS in Community Energy Management Systems • **Technology for incorporation of legacy equipment within smart BEMS** – this development implies the connection of the legacy equipment lacking network interfaces by technologies such as RF or PLC	• Increase applications for BEMS and available efficiency improvements by enabling communication with existing systems	• < five year development programme for new sensors and controls

Component	Development needed	Impact	Timescales
Monitoring and data analysis	• **Collection and analysis of data on energy consumption in range of building types** – facilitate development of tailored energy management and demand response offers	• Increased consumer uptake • Development of tailored demand response offers • Better Energy Management Services	• Short-time scales possible – < three year programme

6 Potential engagement opportunities

6.1 Summary

Potential engagement opportunities for the ETI are summarised below. The opportunities have been broadly classified by type, i.e. technology development / IP creation, need for trials, need to standardise, consumer engagement etc, and by proposed level of priority for the ETI.

Table 5. Potential engagement opportunities

Technology	Opportunity for ETI intervention	Type of opportunity	ETI Priority
Hybrid ASHP	• **Assist hybrid interface development** – main need is for monitoring in real world environment. Opportunity for properly designed field trials in a range of operating environments	• **Tech. dev. / IP & Trial**	**High**
	• **Compressors with increased injection capability** – high efficiency operation for increased operation range. Opportunity to fund R&D	• **Tech. dev. / IP**	
	• **Natural refrigerant** – low environmental impact with potential high temperature COP benefit. Engage with active consortia – possibility for field trials	• **Tech. dev. / IP**	
	• **Noise reduction** – given the planning constraints for noise standards, this aspect of performance needs attention	• **Tech. dev. / IP & Trial**	
High Density Thermal Storage	• **Improved modelling to verify performance and develop system design tools** – models can be developed now, but real world trial / monitoring needed	• **Tools / IP**	**High**
	• **Develop cost-effective microencapsulation techniques** – ETI could engage in manufacturing/ process development	• **Tech. dev./ IP**	
	• **Trial thermal stores based on HDTS, e.g. in conjunction with microgeneration** – Opportunity for the ETI to engage in trials for system integration	• **Trial**	
Home Energy Management System	• **Consumer engagement and business models are key issues** – field trials needed in conjunction with partners able to provide consumer offering. Potential to trial in conjunction with energy supplier / DNO and integrate with DSR trials. Different business models will offer different ways of accelerating market take-up; will overcome high first cost barriers; and will offer opportunities for additional services – eg 3rd parties network management, etc.	• **Consumer engagement / trial**	**High**
	• **Development of functionality** – integration with boilers, microgeneration, EV charging and algorithms for dynamic response (e.g. response to tariff signals); also explore opportunities to combine HEMS with other consumer needs such as home security	• **Tech. dev./ IP**	
	• **Interoperability** – development of common technical specification and communication protocols. Work with industry to develop common standards	• **Standardise**	

Building Energy Management System	• **Aggregation of BEMS in Community Energy Management Systems (CEMS)** – this implies development of standardised communication between BEMS, of additional BEMS communication functionality to 3rd parties and of cloud-type BEMS	• **Standardise**	**Low**
	• **Development of building automation and control for DSR by using smart meters**	• **Tech. dev. / IP**	
	• **Development of bespoke BEMS** – Tailored by building type and management organisation	• **Tech. dev. / IP**	

6.2 Partners and scale of investment

For each of the engagement opportunities identified in the prior section, a list of organisations currently active in addressing the development need is provided in the table below.

Table 6. Partners and scale of investment

Technology	Aspect	Potential collaborators (Inst. = research institute, other orgs. are companies)	Level of investment
Hybrid ASHP	Interface/controller	• The SmartEnergyLab / Fraunhofer-Gesellschaft (DE, Inst.)	£ 1m
	Compressor	• Bitzer (DE), EMERSON Climate Technologies GmbH (DE), Panasonic (Japan), Mitsubishi Electric (Japan), Dorin (IT)	£ 2 – 8m
	Natural refrigerant	• Green HP and NxtHPG consortiums and the participating institutions and companies	£ 4 – 8m
High Density Thermal Storage	Modelling / design	• The Danish Building Research Institute, Aalborg University (DK, Inst), Fraunhofer Institute (DE, Inst.), Brighton University (Inst.)	£1m
	Microencapsulation	• Datum Phase Change (UK, SME)	£1 – 5m
Home Energy Management System	EMS	• PassivSystems (UK, SME), GreenWave Reality (DK, SME)	£ 1 – 1.5m per app £20m end to end platform
	User Interface (e.g. IHD, Mobile App)	• Green Energy Options (UK, SME)- involved in several trials in the UK, Landis + Gyr (US), Current cost (UK, SME), Efergy, 2 Save Energy (UK, SME), DIY Kyoto (UK, SME), Tendril (US, SME), AltertMe (UK, SME)	< £ 10m (trials)
	HAN	• Telecom companies, smart appliances suppliers, technology providers	> £ 10m

	Aggregation	• Utilities, DNOs, technology providers	
	Interoperability	• Telecom companies, smart appliances suppliers, technology providers	
Building Energy Management System	Aggregation	• Coordination of BEMS companies, utilities, telecoms, network providers	> £ 10m
	Automation / control	• AES Controls Systems (UK)	< £5m per application

Note that the list of organisations active in each of the development areas is not intended to be exhaustive. It was not within the scope to identify organisations that have a particular interest in partnering with the ETI or to filter on the basis of particular criteria for ETI engagement. However, as part of the stakeholder interviews for the technology review, several companies expressed their willingness to collaborate with the ETI to further develop their technologies.

7 Role in decarbonisation pathways

7.1 Role of technologies under different electrification scenarios

The future decarbonisation pathway will depend on a range of drivers such as:

- Strength of the decarbonisation agenda (e.g. low, high, delayed, accelerated)
- Fossil fuel and carbon prices
- Economic growth
- Wider energy policy – security of supply, interconnection etc.

Potential decarbonisation scenarios can be characterised by differing assumptions regarding the nature of energy demand and supply, for example:

- Level of energy efficiency uptake
- Grid decarbonisation / generation mix – uptake of renewables, nuclear, gas, CCS
- Low carbon technology uptake – electric vehicles, heat pumps, distributed renewables
- Electrification versus an on-going role for gas (e.g. balanced transition proposed by Delta EE in WA3).

Assuming the decarbonisation agenda is given high priority – eg through strong Government intervention measures (regulation, properly enforced; incentives; etc), a key feature will be the extent to which demand is electrified.

The extent of electrification has implications for the levels of energy efficiency uptake required and nature of the generation mix.

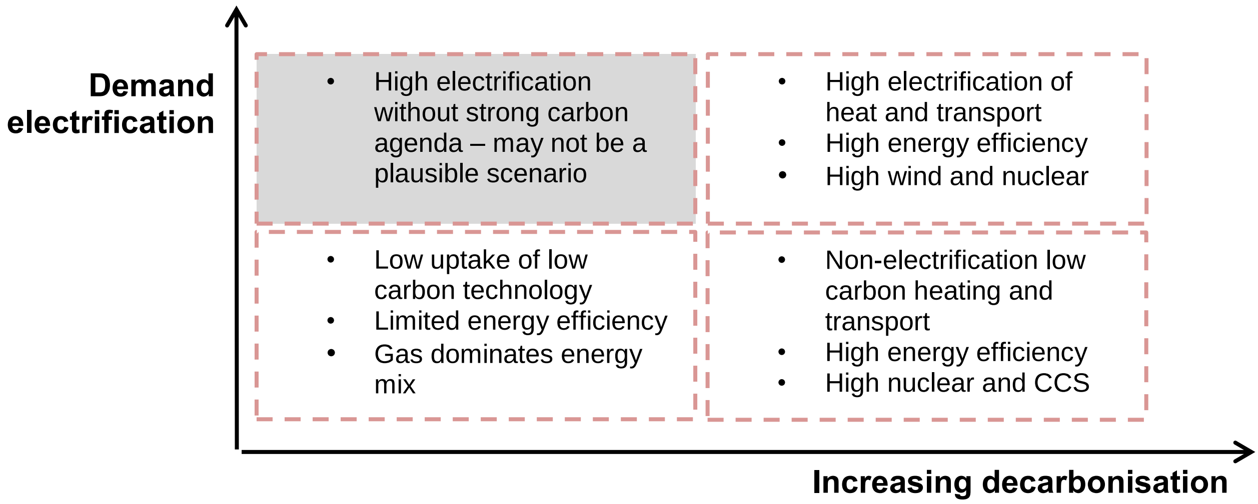


Figure 1. Scenarios across different levels of demand electrification and increasing decarbonisation

The role of the four technologies, in terms of the likelihood of significant deployment, can be considered in the context of the future decarbonisation pathway and in particular the extent to which energy demand is electrified.

Table 7. Role of technologies in decarbonisation pathways

Scenario	Key features	HASHP	HDTS	HEMS	BEMS
Low electrification	• Non-electric low carbon heating technology. • Limited renewables, nuclear and CCS ramp up	• Possible role due to increased efficiency • Lack of grid capacity may limit uptake	• Some role in improved fabric efficiency and occupant comfort • Use as thermal store limited	• Despite weaker role due to lack of demand response programs, there is a role for gas boiler controller	• Continued role in commercial energy efficiency and building automation
Balanced demand	• Some deployment of EV and heat pumps • Energy efficiency to reduce demand • Diverse grid mix – wind, nuclear, CCS	• Potential for a strong role • Flexibility to switch between gas and electricity provides grid benefits	• Used for fabric efficiency and comfort control • Growing role as thermal store	• Potential role – dependent on EMS demonstrating consumer benefits	• Continued role in energy efficiency. • Driver for aggregation depends on need for DSR
High electrification	• High electric demand due to heat pump and EVs • High efficiency to manage demand growth • Ramp up of wind, nuclear and CCS	• Potential strong role – demand response capabilities are attractive • Lack of investment in new gas infrastructure may limit applicability, e.g. new build sector • May not be cost-effective to maintain gas grid infrastructure in highly electrified scenario (gas price increase due to reduced volumes) – HASHP may be transitional	• Strong role as thermal storage – enabling load shifting as part of demand response • Potential synergy with increased domestic cooling (e.g. related to heat pump functionality)	• Strong role – necessity for demand management leads to development of consumer offers and utility benefits	• Strong role – development of traditional BEMS into aggregated systems. • Demand response, distributed storage, virtual power plants

7.2 CO_2 saving potential estimates

Carbon reduction potential estimations for each technology have been made on the basis of DECC UEP projections for domestic and commercial electricity and gas usage and simple assumptions on technology penetration. Grid carbon intensity is assumed to drop to 0.3 $kgCO_2$ / kWh in 2020 and 0.05 $kgCO_2$ / kWh in 2030 (Climate Change Committee trajectory).

Table 8. CO_2 saving opportunities

CO_2 saving ($MTCO_2$ / yr)	2020	2030	Assumptions
Hybrid ASHP	2	10	• A simple calculation demonstrates 15% saving compared to condensing boiler at current grid intensity • This increases to 35% at 2020 grid carbon and 65% at 2030 grid carbon • 10% penetration in 2020 and 20% penetration in 2030
High density thermal storage	0.7	2.5	• 10% reduction in heating energy consumption • 10% penetration in 2020 and 33% penetration in 2030
HEMS	1.7	4	• 10% energy reduction across both electricity and gas energy use* • 20% penetration in 2020 and 50% penetration in 2030
BEMS	0.5	1.0	• 15% energy reduction across both electricity and gas use* • 20% penetration in 2020 and 50% penetration in 2030

* In the case of HEMS and BEMS the saving levels assume occupants/managers act on data provided.

Note that CO_2 savings are the direct savings attributed to reduction in energy demand for the stated levels of penetration into the housing stock (penetration levels are illustrative scenarios, not forecasts or results of detailed modelling). It is also worth noting that savings for each technology are not additive.

Demand reduction is a key measure in any technology development scenario and robust action to encourage demand reduction is needed in order to get the most out of the technologies.

Although direct carbon savings are modest, HDTS and HEMS / BEMS are important enabling technologies. They can have beneficial impact on the network – eg. facilitating peak load management, demand reduction and time-shifting demand

Of the four technologies included in this assessment, the largest CO_2 saving from direct demand reduction or low carbon energy generation is expected to be delivered by the hybrid ASHP. This is particularly as a result of the benefit of grid decarbonisation on the CO_2 saving potential of heat pumps. Clearly, however, there will be a limit on the carbon emissions reduction from hybrid ASHPs dependent on the pace of electricity decarbonisation and the continuing use of gas to meet at least part of the space and water heating demand.

7.2.1 Benefits of enabling technologies

In the case of HDTS, HEMS and BEMS in addition to the direct carbon saving potential, innovation will enable benefits to be delivered by other technologies (including heat pumps). We have not attempted to quantify these enabling benefits in CO_2 terms, but they are qualitatively summarised below.

Table 9. Enabling impacts of HDTS, HEMS and BEMS

Technology	Enabling impacts
High Density Thermal Storage	• Incorporation of thermal storage with heat pumps has several potential benefits if deployed at scale: - Enables heat pump to meet peak heat demands with low carbon heat - Improved load factor - Potential to shift heat pump operation – participate in demand side response programmes. - Reduce grid reinforcement costs and contribute to grid balancing (i.e. with advent of increased inflexible generation) • Large volumes of hot-water storage required to deliver these benefits. HDTS offers potential for incorporation in space constrained houses (note there are competing technologies, such as cold vapour cycle storage)
HEMS	• Can also provide benefits for heat pump deployment (and potentially other heat sources such as microCHP) – facilitates control and potential DSR participation (note that a HEM can enable these benefits, but other routes may also exist, e.g. smart controller integrated into the HASHP communicating with a smart meter). • Can also provide means for control of EV charging and optimising the use of PV via battery storage • Likely to play important role in increasing network utilisation and system balancing
BEMS	• Similar enabling benefits to HEMS, although more sophisticated energy management may be possible in a commercial building environment.

8 Conclusions and recommendations

Hybrid Air Source Heat Pumps

Of the four pre-selected technologies, hybrid heat pumps offer strong opportunities for the ETI to engage in the near term.

Table 10. Hybrid ASHP overall summary and recommendations

Technology challenges	Technology benefits / opportunities	Opportunities for ETI
Further development of this technology requires monitoring in real environments. Currently, control algorithms are at modelling / simulation stage Noise could negatively impact customer acceptance Costs are still high compared to gas boilers and cost is therefore still a key barrier to uptake of the hybrid heat pump technology	Technology seems to be of high potential, offering benefits in key areas compared to stand-alone heat pumps: - Lower cost due to smaller heat pump capacity - Better suited to retrofit into existing buildings with high flow temp heating systems (although modifications may still be required to ensure best heat pump performance) - Reduced grid impact and high flexibility for demand management - Reduced defrosting issues	• Component technologies are available, but a key requirement is to trial and monitor to facilitate the development of interface unit and control algorithms and to address potential noise issues • ETI seems well-placed to provide a suitable trial environment and timescales for technology availability are consistent with ETI trial timescales • Trials will assist technology development and are important to verify technology performance, e.g. in terms of real-world efficiencies • Some technology development opportunities related to the ASHP, particularly better performing compressors and use of natural refrigerants. Potential opportunities for investment in development

High Density Thermal Storage

High density thermal storage has significant potential, both as a fabric measure and to enable other technologies.

Table 11. HDTS overall summary and recommendations

Technology challenges	Technology benefits/ opportunities	Relevance to the ETI
BUILDING FABRIC HDTS		
Paraffins are currently the most commonly used advanced thermal storage materials, but they are relatively high cost, low heat capacity and also have issues regarding flammability. The key challenges are cost reduction and heat capacity improvement. Further developments in new materials with higher latent heat capacities such as inorganic salt-hydrates and bio-based materials, cost effective microencapsulation techniques able to improve thermal conductivity and a better understanding of the potential benefits of HDTS, through modelling tools and monitoring of performance in-situ are needed.	Advanced thermal storage materials such as phase change materials are under consideration as a high thermal mass building fabric material and as a potential thermal store material for incorporation in the heating system.	• Much of the fundamental materials research needed to improve HDTS materials is likely to be funded by large chemicals companies (e.g. BASF, DuPont etc.). However, there is also significant research going on in universities with opportunities for IP generation and spin-out potential • There are opportunities for the ETI to help to fill the knowledge gap concerning high density thermal storage materials, i.e. concerning their performance under dynamic loads and applicability to different building types. This could be a relatively low cost engagement with significant potential benefits to the industry
THERMAL STORE HDTS		
Development of salt-hydrate HDTS and integration of HDTS with primary heating technology are the main technology challenges	HDTS materials as a thermal store could be an important enabling technology in conjunction with technologies such as heat pumps. Advanced heat storage can assist heat pumps to meet peak demands, reduce required heating capacity, provides flexibility for load-shifting and participation in demand response. HDTS facilitates incorporation of heat storage in space constrained buildings and therefore could be beneficial for heat pump uptake.	• The integration of HDTS as a thermal store with microgeneration technologies is potentially a key enabler, increasing uptake and unlocking additional benefits such as demand response. Research is required to increase heat transfer rates and improve stability • Field trials needed to monitor and optimise performance and to assist further development. Further modelling and simulations also required to aid system design and understand potential benefits

Home Energy Management Systems

Many HEMS challenges are market rather than technical barriers. There is an opportunity for the ETI to engage in trials and consumer engagement.

Table 12. HEMS overall summary and recommendations

Technology challenges	Technology benefits/ opportunities	Relevance to the ETI
Key challenges are as follows: • Developing a consumer offer – currently no market pull for HEMS and consumer proposition is limited. Retrofitting is a key. If the tariff changes from flat rate to variable rate and usage capacity (kWh) is limited after smart meter roll-out, potentially more incentives could be provided • Standardisation / interoperability – standardisation on HAN communication protocol needed to facilitate developers of sensors / actuators and smart appliance manufacturers – current uncertainty is likely to create a 'wait and see' approach. Interoperability at wider communication level also required to enable aggregation and increase functionality Potential for HEMS in future is closely reliant on the smart grid and will be driven by electrification of energy demands and high renewables penetration.	HEMS could be an important enabling technology in conjunction with technologies such as heat pumps, providing flexibility to respond to DR signals Additionally, they are able to offer enhanced energy services, balancing costs and benefit with quality of life	• As consumer engagement is key, there is a strong need to trial HEMS. The ETI is well-placed to participate in this. Any technology trial needs to trial not just the technology but also the nature of the proposition to consumers, e.g. an Energy Management Service or a combined energy management and home security service. This could be in conjunction with electricity market participants such as electricity suppliers or DNOs (trials of this nature are taking place through the LCNF). • A number of smaller technology developers are active, e.g. developing IHDs with attractive interfaces / functionality, communications hubs for home automation and load control, data analysis and EMS. Potential for investment in these technologies. Return on investment highly dependent on development of a market – requires understanding of consumer proposition • Communications networks and standards – development is likely to be driven by standardising organisations such as ZigBee Alliance, HomePlug Powerline Alliance, KNX (Konnex Association) etc. Partnering with these organisations might be an opportunity for the ETI to accelerate the interoperability.

Building Energy Management Systems

BEMS is relatively mature, although aggregation of systems is a key next step from the demand side response perspective. Opportunities for ETI involvement are less clear.

Table 13. BEMS overall summary and recommendations

Technology challenges	Technology benefits/ opportunities	Relevance to the ETI
BEMS is relatively mature, a range of systems are available and several large players are active in this market. Unlike HEMS, there is currently a commercial market based on energy efficiency and building automation. Currently BEMS is offered as a vendor-specific service, hence several of the future challenges are concerned with aggregation: - Interoperability - Standardised technical specification - Cloud-based BEMS Incorporation of legacy equipment into BEMS is a challenge, e.g. wireless connectivity with equipment without network interfaces.	Aggregation will bring potential for more sophisticated energy management services, e.g. ability to respond to demand side response signals, control of distributed storage etc.	• Opportunity to engage with BEMS technology developers and be additional to their activities is limited, given their mature state of commercialisation • Communications infrastructure issues for BEMS aggregation also likely to be delivered by large organisation and rely on innovation across other sectors • Better EMS, properly designed, installed and commissioned, offers to building owners / managers requires improved understanding of load profiles of a range of non-domestic building types. This data is currently lacking, hence monitoring, data collection and analysis is a potential opportunity for the ETI to engage through trials