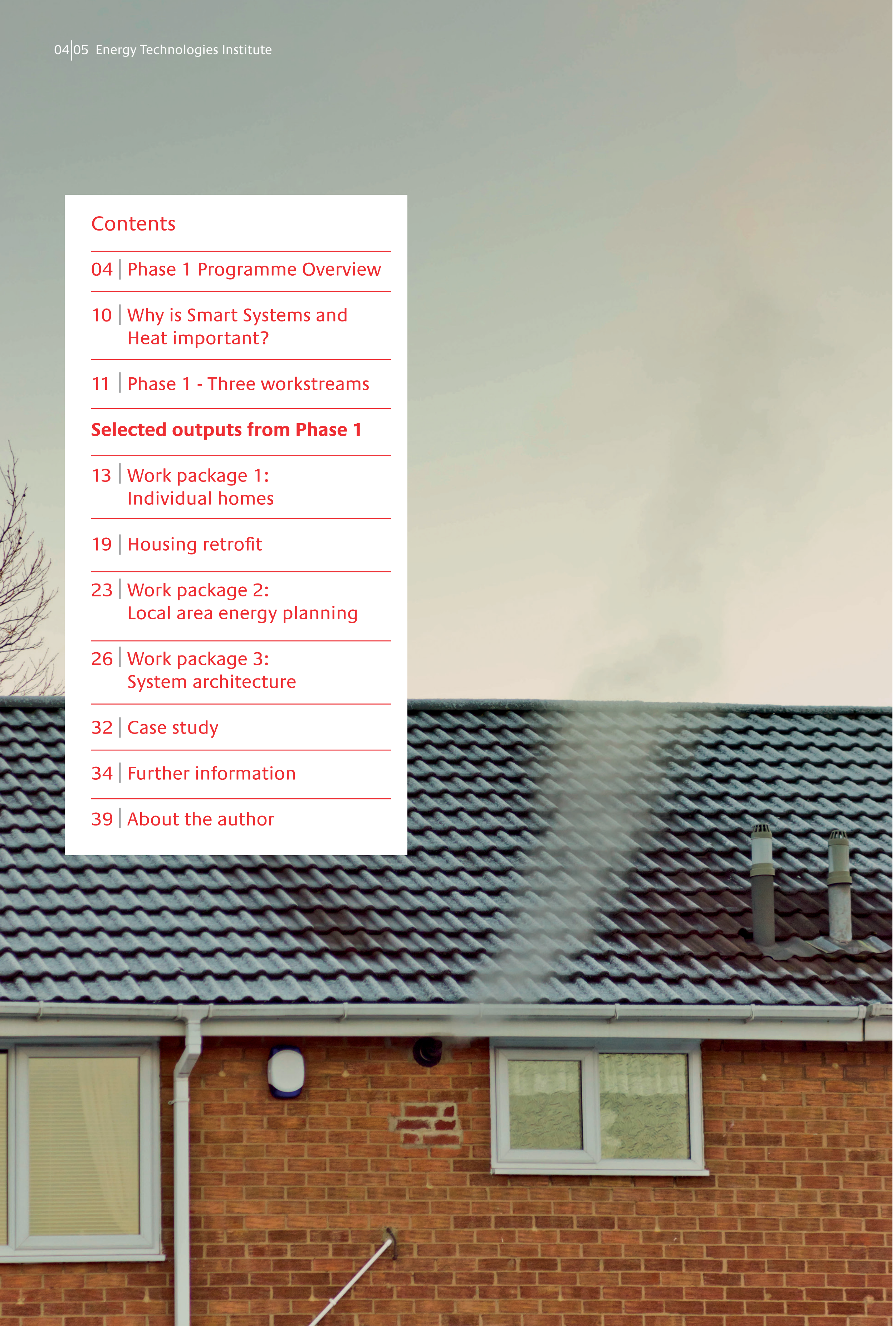
energy technologies institute

An ETI Insights Report

THE JOURNEY TO SMARTER HEAT

Delivered by

CATAPULT Energy Systems



Contents

Providing domestic, industrial and commercial heat is the UK's largest emitter of greenhouse gases. The scale and complexity of the transition to **low carbon heat** requires an almost immediate start.

CO_2

ETI research has focused on tackling **three interconnected areas:**

1 **Heating needs and controls within the home**

2 **Heating infrastructure and building retrofit at a local level**

3 **The operation and governance of the whole system**

THE JOURNEY TO SMARTER HEAT –

CONNECTING THE UNDERSTANDING OF CONSUMER NEEDS AND BEHAVIOUR WITH THE DEVELOPMENT AND INTEGRATION OF TECHNOLOGIES AND NEW BUSINESS MODELS.

Our research shows that **consumers** are more enthusiastic about the idea of **comfort** and **cleanliness** as a service, rather than **energy purchase.**

Significant fabric retrofits may be required in around

10 million dwellings

Commercial, policy and **regulatory** opportunities need to converge, which will take time. The possibilities are different to the **traditional concept of "utilities".**

CATAPULT Energy Systems

The Energy Systems Catapult (ESC) is taking the research forward to establish a **"living lab"** of **c.100 homes** to help businesses, policy makers and regulators **develop** new business models, products, policy options and **regulatory frameworks.**

PHASE 1 PROGRAMME OVERVIEW

- Providing domestic, industrial and commercial heat is the UK's largest single use of energy and the largest emitter of greenhouse gases. Therefore as part of meeting climate change targets, the country simply has to decarbonise its heat supply. There is no single technological answer to the decarbonisation of heat.

- Robert Sansom's famous analysis of heat was produced in 2011, while working at Imperial College as part of a UKERC programme. It has become the poster for the challenge of heating buildings.

- The ETI Smart Systems & Heat programme (SSH) was launched in September 2011, following 18 months of scanning the global landscape of smart systems projects, and shaping the proposition with input from a wide range of stakeholders. Almost uniquely at that time, the ETI programme focussed on the challenge of heat (in the UK).

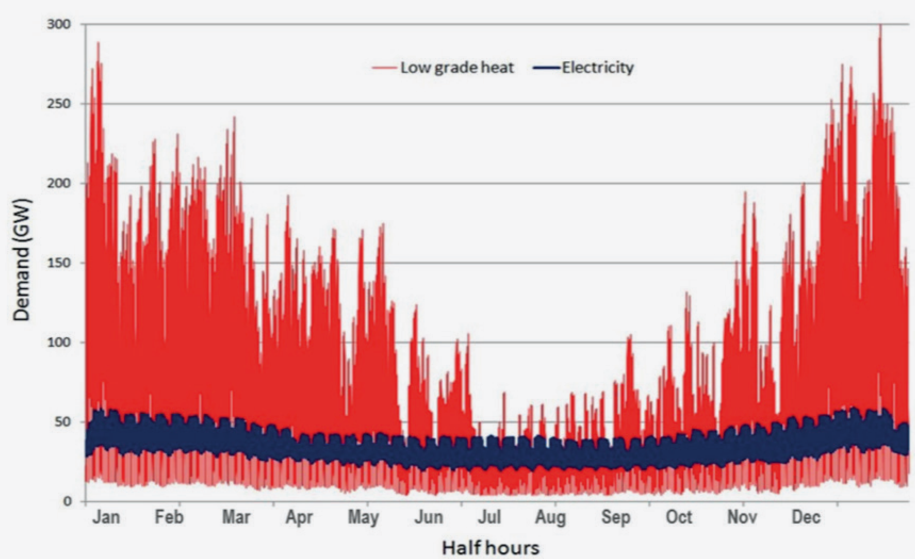
The chart below demonstrates the enormous costs of meeting peak demand twice a day in the winter.

This insight marks the completion of the first phase of the programme, in which tools, data and capabilities have been developed to take the programme forward into larger scale development of solutions. The programme passed to the Energy Systems Catapult (ESC) in November 2015. ETI continued to act as the funder and client for Phase 1, while ESC has been developing further projects to take the programme forward with a wider group of stakeholders.

The programme has been based on connecting the understanding of consumer needs and behaviours with the development and integration of technologies and new business models. This has created enhanced knowledge for use by industry and the public sector to build market and investor confidence, helping innovators to address issues of market failure alongside unlocking commercial opportunities for low carbon heating. The programme tackled three interconnected areas: heating needs and controls within the home; heating infrastructure and building retrofit at a local level; and the operation and governance of the whole system.

Figure 1
2010 energy use in buildings, Sansom 2011, UKERC meeting

How can we develop a low carbon energy system that is smart in both its design and operation?



To make low carbon heating technology appealing to consumers, it needs to tackle common problems such as over and under heating and enhance home life, including cleanliness and comfort.

We have researched people's experiences of and expectations for cleanliness and comfort at home. Surprisingly there is a significant degree of latent dis-satisfaction with the status quo, not least because the design and control of current heating systems in many homes does not deliver good comfort levels. While this creates an opportunity for improvement, it also creates two challenges:

- Consumers are unlikely to believe that a supply chain that is not currently fully delivering will be able to do a better job when presented with an unfamiliar and more complex set of heating technologies.

- The greater costs and complexities of low carbon heating systems require more sophisticated design tools and controls to deliver a good outcome.

We carried out research with an experimental zonal heating control system in real homes, backed up by extensive consumer research and the construction of detailed models created by combining features of these real homes. The causes of over and under heating are quite clear and the comfort and cost benefits that consumers reported experiencing are a direct consequence of the better controls.

Most participants experienced a significant increase in comfort and ability to get what they wanted from their heating system, at about the same or lower cost. Many of them were very animated and enthusiastic when discussing these experiences of being more in control and getting better outcomes. The care that went into the user interface design seems to have paid off.

Further work with the participants showed that a majority of them were much more engaged and discerning than before. For example they were enthusiastic about the idea of comfort and cleanliness as services, rather than energy purchases. A control group of consumers by contrast were not enthusiastic about the idea of services. Improving the sense of control and the experience of heating gave the team credibility with these participants, whereas the control group retained their expectations of under-performance.

Modelling of potential fabric and heating system upgrade pathways for our exemplar dwellings revealed a number of significant findings:

- Advanced heating control offering multi-zone control is critical to the performance, sizing and operating costs of low carbon heating systems, enabling much smaller appliances and lower peak electricity demands.

- Significant fabric improvements are either necessary to deliver cleanliness and comfort in many dwellings with heat-pumps, or are important to cost-effectiveness.

- Without this advanced heating control, it is possible for fabric improvements to deliver both worse comfort and higher costs than before.

Other work on a systems approach to the cost and performance of building fabric retrofits within Phase 1 showed that improvements are possible, but significant investment in the buildings supply chain will be required to deliver them. Depending on how successful this investment is in finding better solutions and ways of working, significant fabric retrofits may be required or at least valuable in around 10 million of the existing 28 million dwellings in the UK housing stock. Building new homes to be both very efficient and "low carbon ready" is a low regret decision, which should be progressed with some urgency.

Any strategy for decarbonising homes needs to recognise the enormous diversity of both buildings and households.

The commercial building stock is even more diverse

The Cambridge Housing Model[1] has nearly 15,000 different housing types to represent the housing stock across the UK, of which the top 50 represent around 3% of the stock. Consumer research in Phase 1 has shown differences between individuals who have distinctly different approaches to comfort and cleanliness, in the relationship they want with their energy supplier and in the way they think about improvements and heating system replacement. Households typically have several occupants, so the diversity of households is also large[2].

The ESC have significant information on consumer and housing segmentation and can use it in different tools. They are continuing to develop this capability.

Figure 2
Diversity of dwellings by age and type
©EDF Energy

[1] A Guide to the Cambridge Housing Model, Hughes, August 2012, Cambridge Architectural Research
[2] See also: Beyond average consumption- Development of a framework for assessing impact of policy proposals on different consumer groups, Vicki White, Centre for Sustainable Energy, March 2014

As well as low carbon heating in individual homes, the programme also considered how different local areas across the UK might engage in better local area energy planning to support decarbonising heat. Working with local stakeholders in Newcastle-upon-Tyne, Bury in Greater Manchester and Bridgend, a series of detailed options were developed, reviewed and translated into strategic options to help support spatial planning of the energy transition. Each local area has a very detailed set of evidence behind these options, which will act as a foundation for further planning.

Looking at the evidence and analysis for each area, it is clear how significant local differences are between the three areas, and how important it will be for local areas of the UK to develop their own detailed spatial plans. Central government will of course retain the responsibility for national infrastructure, markets and regulation, and energy supply at the national level within the framework of policies for Clean Growth. Much of the detail however can only be developed and delivered at a local level. From our three pilots, it is also clear that the Devolved Administrations and devolution within England will also be key. Welsh government and the Greater Manchester Combined Authority have both played a significant role in the pilots. Within the different local parameters, there are issues which appear in every area:

- Making network choices in different places, as between reinforcing the electricity network to support heat-pumps, building out district heating from city centres, or converting the gas grid to hydrogen. It is not possible to decide on the future of any one of these three network types in isolation.

- Expectations and financing for improving the quality of the local housing stock and switching to low carbon heating systems. The social and economic contexts for owner-occupied, privately rented and social housing are different, but all are important. Treating each building as a separate entity ignores both the importance of network choices in an area and also the supply chain, building archetype and planning implications of a major transition.

- Potentially significant consequences for economic, social and physical health and well-being. Housing stock quality, energy bills, skills and employment, and the investment required to make the transition are all important. There are opportunities and risks in all of these.

- Probably the most important finding from work in this part of the programme is the enthusiasm and commitment displayed in different areas. Even in the absence of a mandate and resources, local government is doing its best to engage with the issues, recognising the profound economic and social importance of the energy transition. There are decisions to be made about mandates and the split of resources between different tiers of government. This is clearly an opportunity for policy makers. Although decarbonising electricity supply is mostly about central actions, the same will not be true for industry, buildings and transport.

- The third area of the programme concerns the operation and governance of the whole system. How are investments in individual parts designed and made? How are commercial contracts and government mandated requirements developed and made? How does the system operate on a second by second to month by month basis? How is the security and resilience of the whole system underwritten and managed? In a world where the liquid fuel and electricity sub-systems are connected through millions of plug-in hybrid cars or the gas and electricity systems through hybrid heating systems, what issues cannot be managed through managing each energy supply separately?

The team working in this area has struggled with the novelty of many of the challenges in the available time and funding window. Just as in the other two areas, significant progress has been made but there is a lot more to do. The observation that the current structure and governance of different parts of the energy system is not capable of supporting the required transition is hardly novel; many different stakeholders have made it. However there is little agreement on what structure would be most appropriate or on how to make the transition.

The team has not attempted to answer this question. It is for government to lead consensus building and testing between the stakeholders, balancing the interests of consumers and taxpayers, the wider public good, current incumbents and innovative new entrants.

The central proposition to emerge from this whole system part of SSH Phase 1 is that system engineering approaches that have been developed and proven in other industries will be key to reshaping our energy system. Complex systems such as the internet, cars, aircraft etc have been developed to be highly functional, resilient and cost-effective through the use of systems engineering concepts and tools. As long as our energy system evolved relatively slowly, and with close supervision from government and regulators, such approaches were not necessary. The scale and especially pace of change now required will need something closer to the highly structured but very dynamic approach that enabled the innovations and development of the internet.

The team has developed a number of tools and examples to show how this might work. Understanding how to use them will require a new way of thinking. It seems self-evident that a major and innovative change in the ways that energy is provided and used in the UK should take place within a structured and disciplined process that reduces costs and risks and enables innovation and competition. SSH Phase 1 has shown how promising approaches that have worked in other industries could be applied to energy. The question now is what governance and industry leadership approach might enable new tools and ways of working to support a UK energy transition.

ETI has published the majority of SSH Phase 1 deliverables in our Knowledge Zone. At the end of this insight a number of the key reports and deliverables are highlighted for those who want more depth in particular areas. The ESC has the capability to apply the results and tools from SSH Phase 1 and the Phase 2 that they are currently running. Key ESC contacts are also highlighted at the end.

Policy makers and regulators need to change how they think, allowing commercial innovators to engage and construct a new energy retail proposition that is enabled by the "connected home"

WHY IS SMART SYSTEMS AND HEAT IMPORTANT?

The UK was the world's largest market for gas-boilers, until China recently overtook us. The combination of UK building stock, historic access to gas from the North Sea, and UK climate have created a rather unusual approach to heating, compared to most other countries. Fossil fuel boilers are ideally suited to producing very high heat outputs from an efficient and low cost appliance, connected to a cost-effective network, where the gas can be stored quite cheaply. The average 15% utilisation of this system is not an issue when equipment costs are similar to fuel costs. Replacing gas as the energy source with low carbon electricity, poses the challenge of meeting winter peak morning and evening heating demands without having much more expensive generating, network and heating system assets with a low average utilisation. Smart design and operation of this system is the only way forward.

This approach requires technical innovation and new thinking about the relationship between the energy system and the people who use it. It will involve new thinking about the market and the delivery structures to support these new relationships between households and providers. Even though most whole systems analyses, including those from ETI[3], show the bulk of heating decarbonisation occurring after 2035, the scale and complexity of the transition requires an almost immediate start. Unless we can show solutions that work at the scale of large towns and small cities, we cannot roll them out across the UK in time.

Consumers will ultimately determine how any transition takes place (they are the end users). Today fewer than 4% have low carbon heating. It is important to understand consumers and what they want from using energy, especially for heat, and match these needs accordingly to a low carbon provision. People buy benefits ultimately, so instead of judging the success of our energy system by how well it works for generators and distributors selling a commodity, the programme is based on the principle of customer experience and engagement.

A typical UK household uses 80% of their energy consumption on the provision of heating and hot water

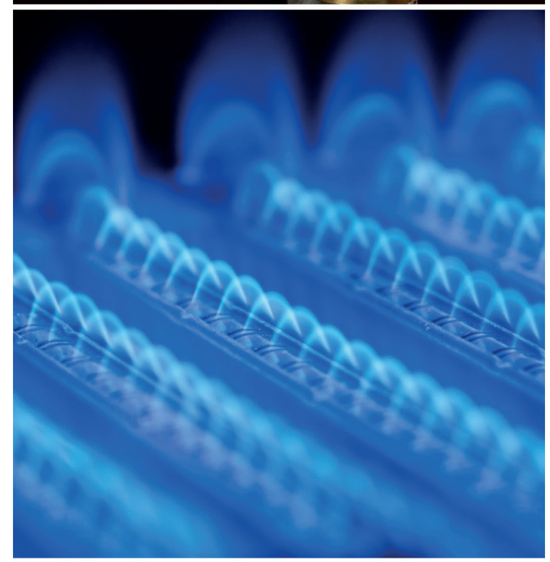
A typical UK household uses 80% of their energy consumption on the provision of heating and hot water, with an annual cost of approximately £750 per year, using gas. Notionally replacing their gas boiler with a heat-pump and their cars with fully electric ones would add around 5,000 kWh of additional electricity consumption for heat and 3,000 kWh of vehicle charging to the existing 3,100 kWh for other domestic uses of electricity. That is assuming that many households would reduce the heating bill with fabric efficiency measures. This level of electrification will present entirely new challenges, outside the historic experience of the current energy industries.

We have also seen how digitisation and the advance of the internet have provided huge social and economic benefits, while challenging and reshaping whole industries. Energy has so far only taken modest steps in using these new capabilities to the benefit of its customers. Digital technologies will provide both further challenges and also opportunities in this transition[4].

Any decarbonisation solution also needs to be flexible and take account of local characteristics. It is important that more advanced local area planning identifies the right technologies to be deployed in the right place at the right time.

[3] Options, Choices, Actions: Updated, Milne, October 2018, Energy Technologies Institute
[4] An ETI Perspective – Tools for Future Energy Systems, Haslett, December 2017, Energy Technologies Institute

PHASE 1: THREE WORKSTREAMS



As the programme developed, it was shaped around three work streams:

1. Meeting the needs of a very diverse range of consumers within a diverse range of homes by replacing the heating system, improving the fabric of the building and enabling consumers to control their environment, while making best use of the supply-side of the system.

2. Developing heating decarbonisation plans for local areas, integrating energy services within and around buildings into spatial plans, making network choices between electricity, district heating, repurposing the gas grid or supplying bio-energy. Understanding the local housing stock and strategies for its renovation, including local supply chains. Integrating energy strategy into economic, social, environmental, housing and transport strategies.

3. The governance, operation and control of the whole system, so that by design and operation it achieves the combined goals of affordability, reliability, sustainability and equity[5].

The programme was structured around Phase 1, where capability, tools and data, and follow-on Phases would be built. These later Phases were intended to be pilots of the solutions identified in Phase 1, to build credibility and importantly to sharpen the tools, capabilities and solutions. As the programme developed, it became clear that ETI would not be able to deliver the later Phases within its planned life, and also that it would not be capable of supporting a large enough team to develop and use the required total capability.

Fortunately the new Energy Systems Catapult (ESC) was launched at about the time this became clear, and the Boards of the two organisations agreed that the SSH capability should transfer into the ESC and deliver Phase 1 under contract to ETI. The ESC would then take the SSH programme forward, into Phase 2 and beyond, with a wider range of partners. The ESC has been able to invest in the required range of

[5] Creating a Fair Future for those in Energy Poverty, Chard, February 2018, Energy Systems Catapult

capabilities and relationships, fitting its mission as an open access capability centre, which supports innovators to access the opportunities arising from the transition to a clean, intelligent energy system.

When the programme was launched, it was unclear whether the gas distribution network could be repurposed to transport hydrogen. Hydrogen was included in the initial scope of SSH and the tools developed in SSH Phase 1 were designed to be "hydrogen ready". The H21 project[6] has shown that this is a credible option and robust evidence is being developed to underpin the costs and feasibility of this option, principally through the HyDeploy and Hy4Heat projects.

As part of its wider systems analysis, ETI has been analysing potential national systems designs with significant penetration of hydrogen. It is too soon to tell how cost-effective and feasible it may be to convert the gas grid to hydrogen and provide hydrogen appliances in millions of homes and commercial buildings. It is attractive enough to be worth investing to make it a real option, although the scale of a national project to make, store and transport sufficient low carbon hydrogen is daunting, even if it does not have to be fully completed by 2050.

At the start of SSH, ETI was acutely aware of the importance of the consumer experience. Previous work with consumers and vehicles and in real homes had shown how complex and diverse consumers can be in their use of energy technologies. There was a low level of understanding of how people in the UK relate to and use their heating today. At the time, consumers were often positioned as responding to the needs of suppliers and policy, rather than as customers for cleanliness and comfort.

We therefore started the programme with a consumer research project, which is an ongoing theme within the programme. If we want people to make the switch to low carbon heating, as consumers and taxpayers, we need to deliver products and services that are attractive to the diverse needs of different types of consumer. Consumers will expect to tailor the services to their needs, not to the constraints and needs of suppliers.

We knew from whole systems analysis that changes to heating have an impact across the whole energy system and that the structure (or architecture) of the whole system, especially its operation and governance, would be an important context to the performance, costs and viability of any heating solution. It was clear that designing cost-effective flexibility into the system and using that flexibility through distributed control would be critical. It gradually became apparent how important the overall structure of markets and regulation would be to enable that efficient design and control, especially to deliver good experiences to households, who ultimately pay for the system as customers and taxpayers.

At that stage of the ETI's life, we had launched a significant number of projects where we had brought together different and highly skilled organisations of different kinds into new teams to tackle very challenging objectives. Although our analysis showed that we would still be very dependent on the expertise of a very wide range of organisations, the novelty of some of the tasks and the challenge of integration across the operation of the whole of future energy systems meant that we could not find anyone who could credibly lead major sub-components of the programme and would therefore need to build a larger and broader than usual ETI team.

[6] H21 NoE report, December 2018, H21 consortium

SELECTED OUTPUTS FROM PHASE 1

Work package 1: Individual homes

During winter 2016-17, the programme operated a trial with a prototype heating control system in 30 homes, with gas-boilers. The aim of the trial was to understand how occupants and buildings interact with heating, by creating a simulation of a mid-2020s "Connected Home". Gas-boilers were used, rather than say heat-pumps, in order to avoid entangling occupant reactions to a new control interface with reactions to a new heating system. The physical trial was accompanied by a significant effort on consumer research.

The main finding was that the majority of occupants became much more engaged in their heating at home, felt more in control, and reported both better comfort and better control over costs. Detailed physical modelling of houses showed that better comfort levels and reduced energy usage were indeed delivered by effective multi-zonal control, as compared to the more traditional arrangement of a timer, thermostat and Thermostatic Radiator Valves.

The diversity of occupant and building behaviour and analysis of the very rich dataset collected over the trial, provide some fascinating insights into the reality of comfort and heating.

Figure 3
People mostly make use of zonal control

Although most people took advantage of the ability to control rooms differently, some did not. In addition, some people had a standard schedule to which they made adjustments when needed; others had a bare-bones heating schedule to which they added extra heating when they really needed it.

When rooms were scheduled to be heated, there was a very wide range of comfort preferences and significant variation (for most people) between rooms.

Although some of the participants were concerned or very concerned about costs, research showed that almost no-one understood what drove the cost of their heating. Some people were not aware that it costs significantly more to heat houses on cold days. People had no idea how much set temperatures, duration of heating periods and number of rooms heated, each contribute to their heating bills. Some limited testing of providing cost information showed that people find this useful, but their propensity to save money is less than their response to questions about cost would suggest.

Figure 4
Comfort preferences are personal and contextual

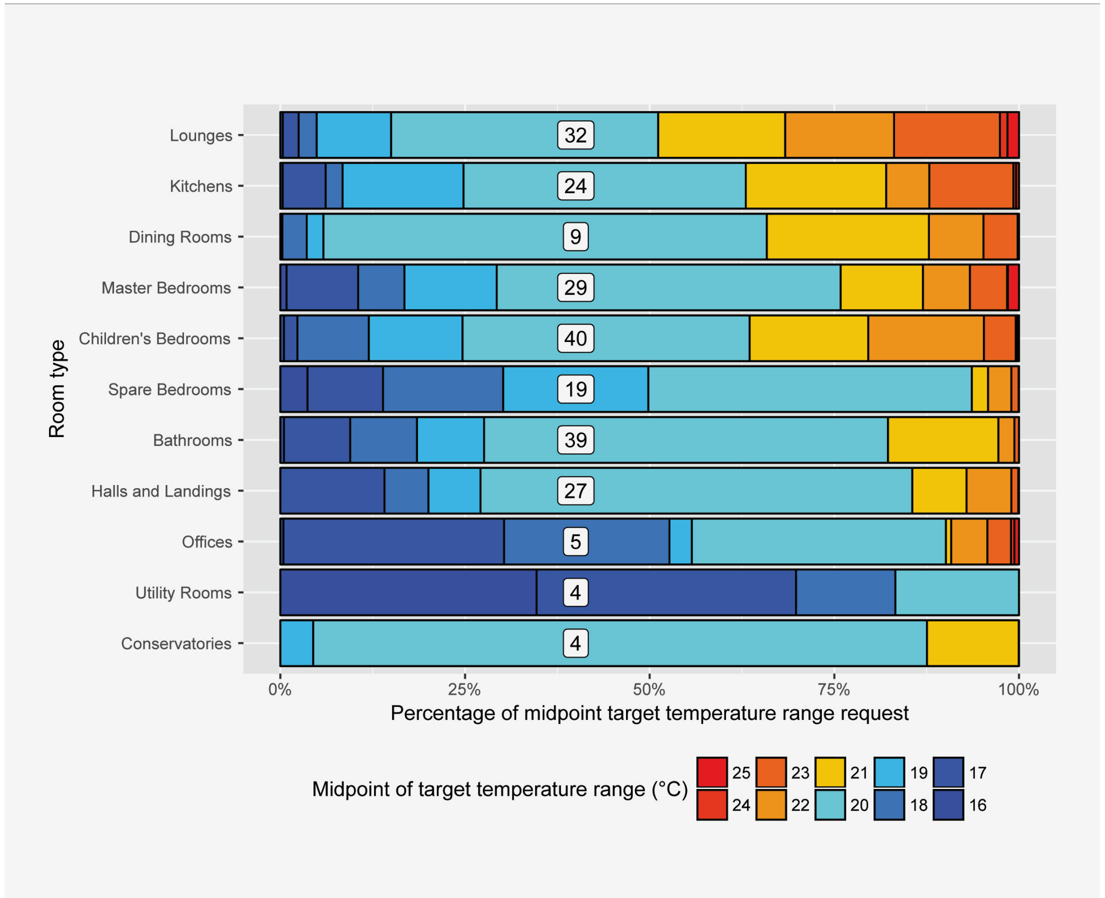
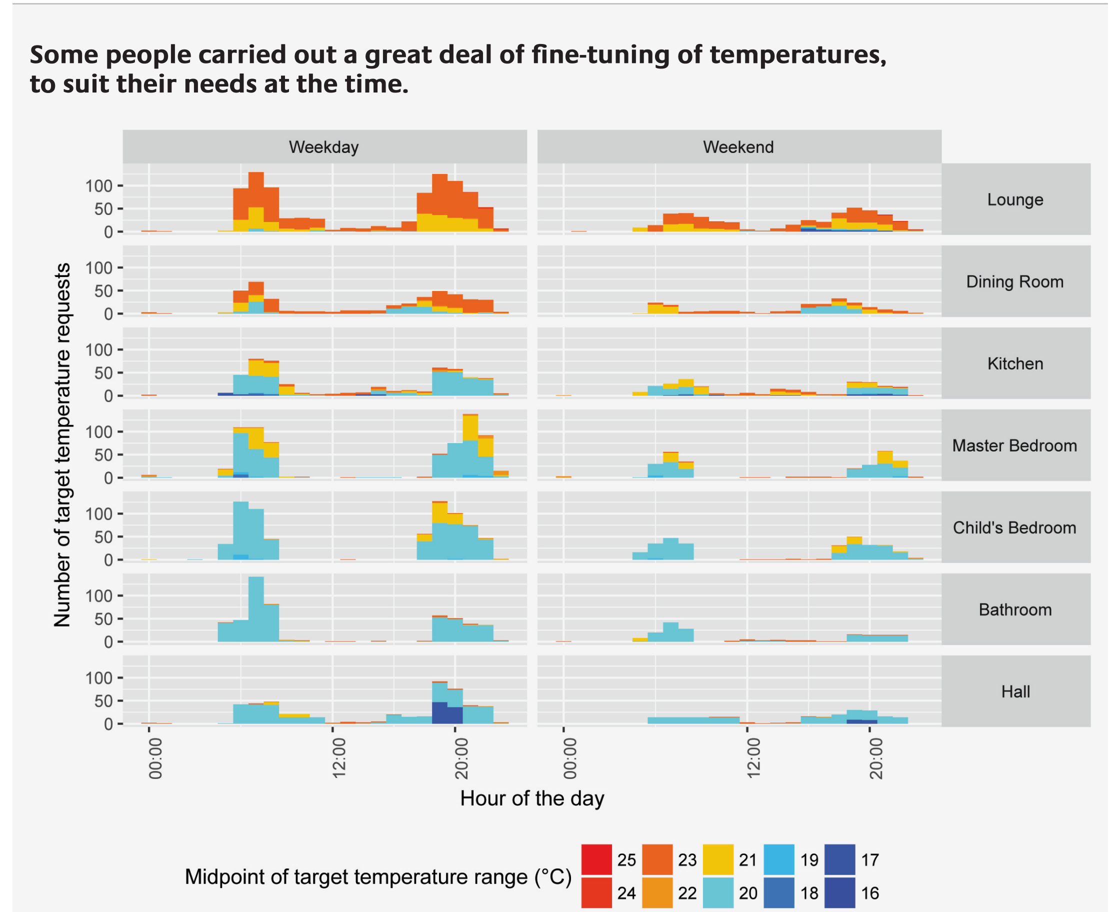


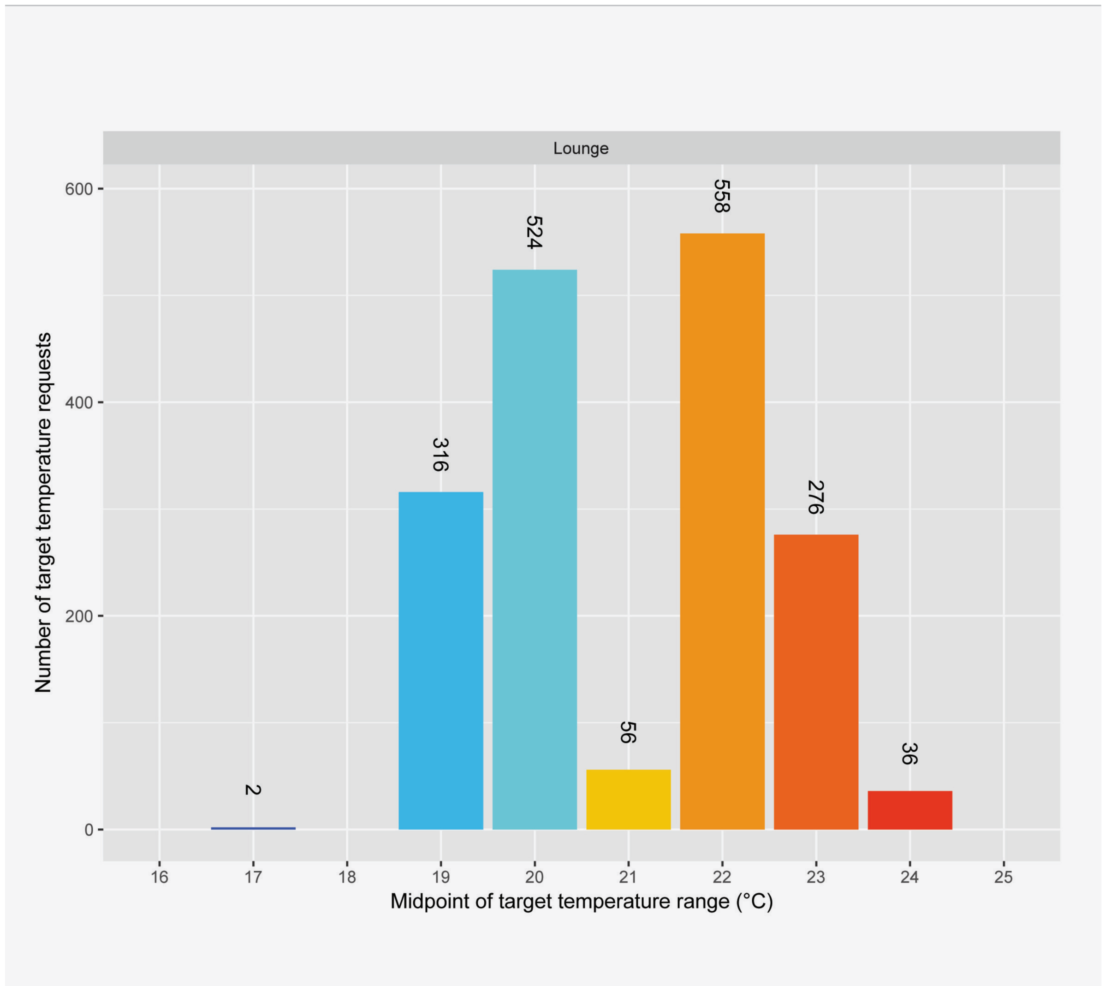
Figure 5
Example of a participant practising fine-tuning



Even when they are quite active in reducing heating usage, comfort is still important to most people, and they are willing to pay for it. A corollary to this is that people who have real difficulty in affording cleanliness and comfort are suffering significant psychological stress.

There were also insights into differences between occupants in the same dwelling. For example the different comfort preferences of two occupants can be clearly seen in the bi-modal distribution of frequent temperature setting requests in this lounge:

Figure 6
Frequent temperature requests from two occupants

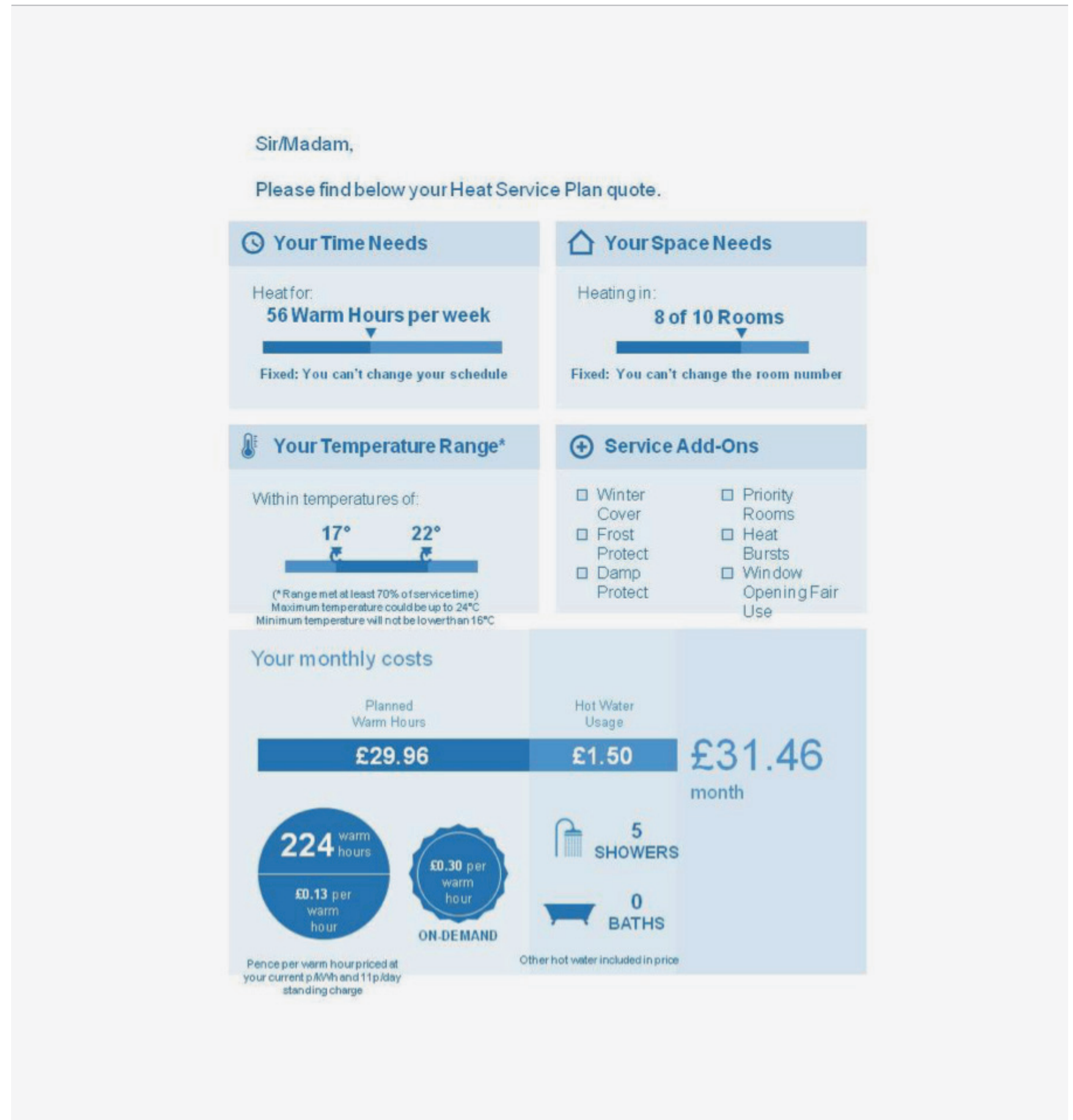


Comfort is still important to most people, and they are willing to pay for it.

The concepts of Heat-as-a-Service and Mobility-as-a-Service, enabled by internet technologies, are increasingly discussed. A workshop with a sub-set of the participants, at the end of the trial, explored how this might work. A similar workshop was held with a control group of people who had not participated in the trial.

It was very clear that the idea did not gain any traction with the control group, whereas the trial participants could engage with it and were mostly attracted to it in principle. Given this positive feedback, Phase 2 went on to explore in more detail how heat plans might work.

Figure 7
Example of a service plan as used in the workshop



HOUSING RETROFIT

The extensive physical and occupant data gathered in the trial was used to construct 5 pastiche dwellings, designed to exemplify typical dwellings and their occupants. Models were constructed of the dwellings and the energy service needs of their occupants, using an advanced dynamic building simulator – Integrated Electric Heat (IEHeat). This was developed specifically for the purpose of modelling fabric and heating system changes in existing dwellings, where measurements of building performance are available. The IEHeat model was calibrated against an experimental programme in the Salford Test House, using both a gas boiler and a heat-pump as the heating system. Modelling of potential fabric and heating system upgrade pathways was carried out for these five pastiche dwellings. These pathways showing the step-by-step improvements to be made to the homes are shown in Table 1.

The main conclusion from this was that decarbonisation requires a combination of new heating systems, fabric improvements and advanced controls. Advanced controls are a critical enabling element and can provide significant comfort and efficiency benefits in the absence of other changes.

The five pastiche dwellings were not intended to be representative of the whole UK housing stock, but do cover some of the most common combinations of fabric and occupancy. For the purposes of this pathway exercise, they were nominally located in different parts of Newcastle-upon-Tyne, where similar houses are found. As a result some were considered for heat-pumps and some for district heating. The availability of district heating infrastructure was taken from the analysis of possible transition plans for those parts of Newcastle.

A large number of alternative fabric and heating system changes were considered and modelled in detail. The models included where new equipment (such as the heat-pump) would be located, which fabric elements would be upgraded, and whether individual radiators would need to be replaced. The comfort and bills of the occupants were driven by data on heating preferences and hot water usage from the trial.

Table 1 - Overview of the 5 upgrade pathways

House		Stage 1	Stage 2	Stage 3	Stage 4
House A 1950s semi-detached		Cavity wall insulation Multizone control (Y1-5)	New doors & windows Four new high output radiators (Y3-13)	6kW ASHP with EITHER existing boiler OR hot water cylinder (Y6-12)	
House B 1920s terraced		Insulate suspended floor Multizone control (Y1)	New doors & windows Insulate walls One new high output radiator (Y3)	6kW ASHP with hot water cylinder OR interface to district heating network (Y6-10)	
House C 1930s semi-detached		More loft insulation Multizone control Four high output radiators (Y1)	8kW ASHP with existing boiler (Y2-5)	Internal wall insulation (Y5-10)	Remove boiler Add hot water cylinder Insulate conservatory and extension roofs (Y10-15)
House D 1970s terraced		Insulate walls More loft insulation Multizone control Two larger, high output, ground floor radiators (Y1)	New windows and doors (Y6)	6kW ASHP with addition of hot water cylinder (Y10)	
House E 1980s detached		Insulate extension loft Multizone control Limit conservatory set-point (Y1)	Opaque insulated roof and ultra-low U windows on conservatory (Y4)	New windows and doors downstairs Larger heated towel rail (Y7)	8kW ASHP OR 8kW GSHP, both with addition of 250l hot water cylinder (Y10)

Retrofitting conclusions

The practicality and costs of different elements of the fabric retrofits were informed by an earlier SSH project, which had set out to carry out significant retrofits on five dwellings, in order to illustrate the practical issues involved and calibrate cost estimates for single dwelling retrofits, with a more effective supply chain. The two key findings from this were:

- It would be possible to carry out more cost-effective and higher performing retrofits with significant investment in supply chain development and a more standardised and off-site led process.

- The average cost and performance of retrofits is well below the "best case" outcomes, as a result of a significant number of problematic and highly problematic projects.

In this project one dwelling was not retrofitted at all, due to disagreements on how to handle a pre-existing significant defect; another retrofit failed catastrophically – with sub-optimal working methods leading to a wall collapse. There is a wealth of important detail in the final reports for the individual projects, which show where the opportunities and risks are for decarbonising homes, while making them more comfortable and keeping the additional costs to a realistic minimum.

SELECTED OUTPUTS FROM PHASE 1

Work Package 2: Local area energy planning

The programme team believed strongly that local transition planning should form an important underpinning of the energy transition. There were three factors in this:

- Network choices for decarbonisation as between electricity, hydrogen and district heating cannot be made as offers to individual homeowners; nor can specific schemes be evaluated effectively by central government. Whatever choices are made, local residents will have to pay for them.

- Installing new heating systems and controls, improving housing fabric and digging up roads to upgrade, repurpose or replace energy networks are all activities with a significant impact on the local economy, workforce and the amenity of an area. Such activities will be far more effective and have lower impact on amenity if well-planned; treating the visual impact of external insulation or sound impact of heat-pumps on a case-by-case basis would create delays, risks and costs that would make the planning system a major barrier to progress.

- When residents are expected to engage with changes to transport and buildings, many of which will require private investments, a democratic mandate will be required. Also individual investments will require confidence in collective investments.

Workshops were held with a sub-set of local authorities from across the UK, based on their responses to an open invitation. These confirmed the view that a significant minority were actively engaged in the issues and saw local energy transition plans as an important, if unclear and challenging task. There were a wide variety of individual priorities, including for example, providing a home market for local businesses, avoiding being pushed into a cycle of depopulation and decline, and supporting vulnerable residents through a risky transition. All of these might be rolled up as ensuring that each local area remained a great place to live and work, as the energy transition, along with other changes, impacted on the lives of their residents. The three local authorities of Bridgend, Greater Manchester and Newcastle were selected through an open and competitive process in response to requests for proposals by 11 authorities. Although there had originally been interest from over 30 authorities, many of them took the view that resourcing the activity could not be made a priority.

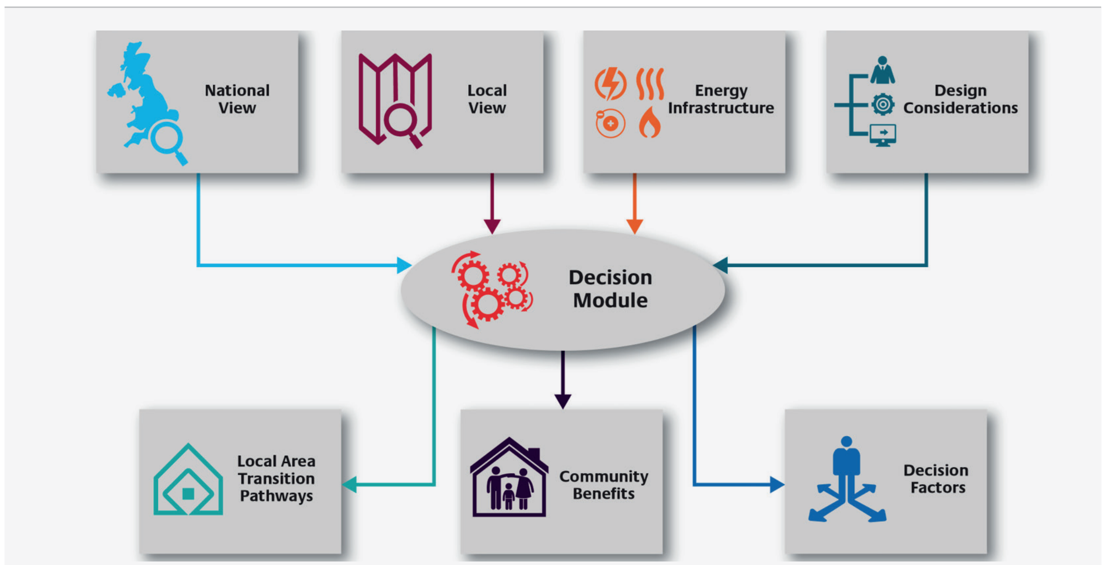
Research by the University of Edinburgh, sponsored by Economic and Social Reseach Council (ESRC) and ETI, shows that a large number of authorities are taking steps to address the energy transition, within available resources, guided by local priorities.[7]

The ESC team worked with a group of local stakeholders in each of the three areas to develop an evidence base to underpin strategic choices. There are roughly three steps in this process:

- Gathering and validating detailed evidence on buildings, networks and energy use in each area and using these to build a planning model to explore and optimise different pathways (down to individual building level in outline).
- Setting targets and exploring their implications; looking at different approaches to the transition and constructing some alternatives that meet the targets; validating some of the key details (eg location of facilities) through engineering studies.
- Developing an evidence base that summarises this work and considering what strategies the local authority might adopt over different time periods in order to progress the transition and prepare to make choices at key turning points.

Initially an evidence base was developed across the whole of Greater Manchester, to support the energy element of the Greater Manchester Spatial Plan. Then Bury was chosen from a number of the individual authorities in the Greater Manchester Combined Authorities, to pilot more detailed transition planning analysis. Between them, Bridgend, Bury and Newcastle have a very wide range of different rural, suburban and city locations, providing a good set of examples of local planning issues. The detailed modelling was carried out by the ESC team using Energypath® Networks, a purpose built local energy systems analysis tool that operates down to individual building and network sub-system level.

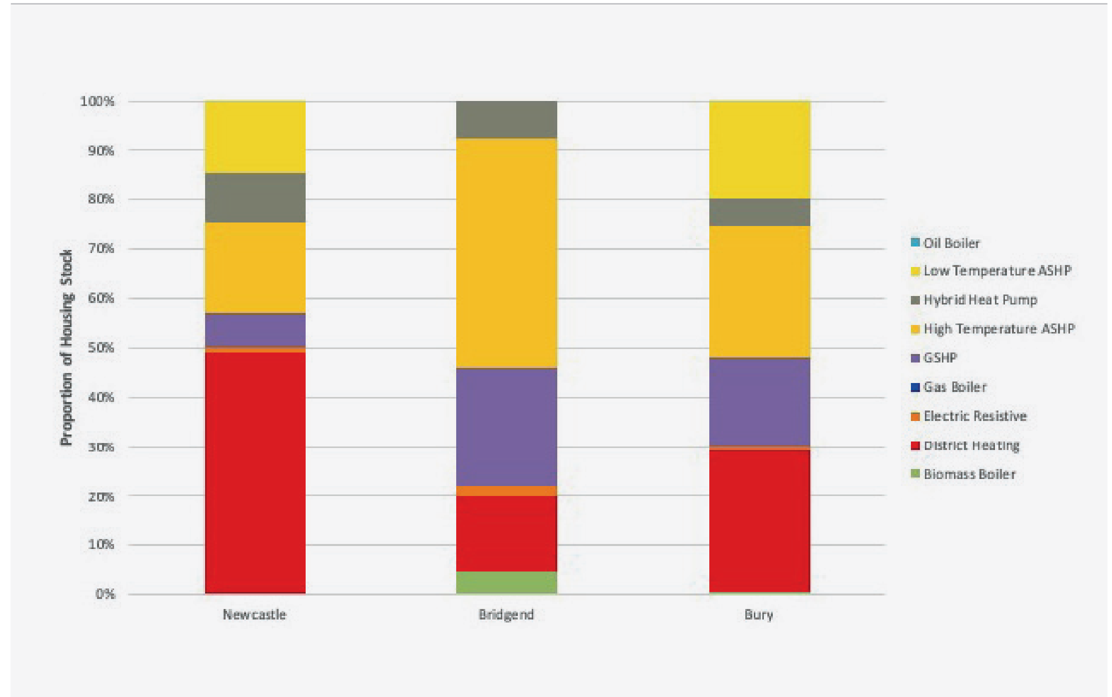
Figure 8
Structure of EnergyPath® Networks



[7] Local engagement in UK Energy Systems, July 2014, University of Edinburgh

The domestic heating mix in each area differs significantly by 2050

Figure 9
2050 split of heating systems in chosen pathways



Today, gas-boilers are the dominant solution for domestic heating, so that we talk about on and off-gas grid areas. In future, the spatial distribution of heating systems is likely to be quite variable and fitted to local characteristics. These strategies did not include the option of hydrogen for heating, either supplying individual domestic boilers, or as an energy source for combined heat & power energy centres in district heating schemes. The availability, cost and embedded carbon content of hydrogen in each of our three areas will depend on central government policy and major national infrastructure projects.

This is an example of the interaction between national and local strategies. The major determinant of local stategies will be the national system for providing low carbon energy vectors such as electricity, hydrogen and bio-energy at local boundaries and the policies and markets within which local plans are developed.

Equally the success of national strategies for economic growth and decarbonisation will depend on well thought out and executed local plans. In all three areas, the largest contribution to local carbon targets and added costs over the next fifteen years is decarbonisation of electricity supply. Growth in the use of electric vehicles will depend on complex interactions between local and national policies and individual consumer and business choices.

The enthusiasm of many local authorities to make progress with the energy transition is commendable. SSH Phase 1 produced a planning guide for local authorities and a report on the implications for central government, with some key recommendations that highlight themes that present opportunities for national policy and strategy development. The ESC is supporting the local areas to develop portfolios of transition projects as part of Phase 2.

SELECTED OUTPUTS FROM PHASE 1

Work package 3: System architeture

Over the seven years since the SSH programme was launched, there has been an increasingly widespread realisation that the current structure and governance of the different UK energy supply industries is not capable of supporting an effective energy transition. There will be issues for liquid fuels, gas networks and electricity networks. District heating cannot compete effectively with other energy distribution systems, unless it has access to finance on a similar basis to the regulated monopoly networks.

Programmes such as the Future Power System Architecture project have explored these issues of structure and governance. SSH Phase 1 has been more concerned about systems operation and control, rather than the nuts and bolts of making the system work. However, how the system operates does depend on its market and commercial structure. A state monopoly supplier of all energy vectors that leaves consumers "beyond the meter" to make their own arrangements to turn energy into something they value, is very different from unbundled competitive supply chains that seek to sell service and experiential outcomes to their customers.

From the start, ETI developed the programme on three core principles:

- It should serve the needs of its users, who pay for it as some combination of customers and taxpayers.
- The ingenuity of policy makers will be applied to create markets and governance that delivers this as far as possible through competitive and technology neutral processes that enable innovation in the service of customers.
- Energy services (mobility, cleanliness, comfort…), like education and health, represent essential social goods where society ensures access and a decent minimum provision.

Given the potentially very significant differences between alternative approaches to energy service supply, we started with the first point by developing a framework for exploring business models for this.

Iterating between some exemplar new business models and a tool for facilitating new model development, led to well-developed versions of both.

Figure 10
Potential new business models

	Home Service Company	Home Comfort Contract	Home Moderniser	Neighbourhood Heat & Electricity	Urban Renewal
Novelty	High	High	High	Medium	Medium
Service Aggregation	High	Medium	As-Is	Medium	Could vary
Degree of renovation	Low – Medium	Medium	Medium – High	Low-Medium	Total – rebuild
Contract term	12 months +	10 yrs + with flexibility	None	Continuing contract	n/a
Financing	Pay-as-you-go + lease option	Long Term Lease Contract	Upfront on mortgage	Pay-as-you-go	Via capital gains
Emotional outcome	Removal of hassle	Guarantee of comfort	Aspirational new feel home	Community empowerment	New homes
# of providers	Few nationals & some locals	Choice of local & nationals	Wide choice of accredited	Single provider	Regional / LA backed

The example new models were developed through stakeholder workshops, using a facilitation toolkit that came to be known as the Business Model Game. This enables participants to develop models that are coherent and consider all of the relevant issues, while addressing the topics that they consider important.

Figure 11
Business model construction

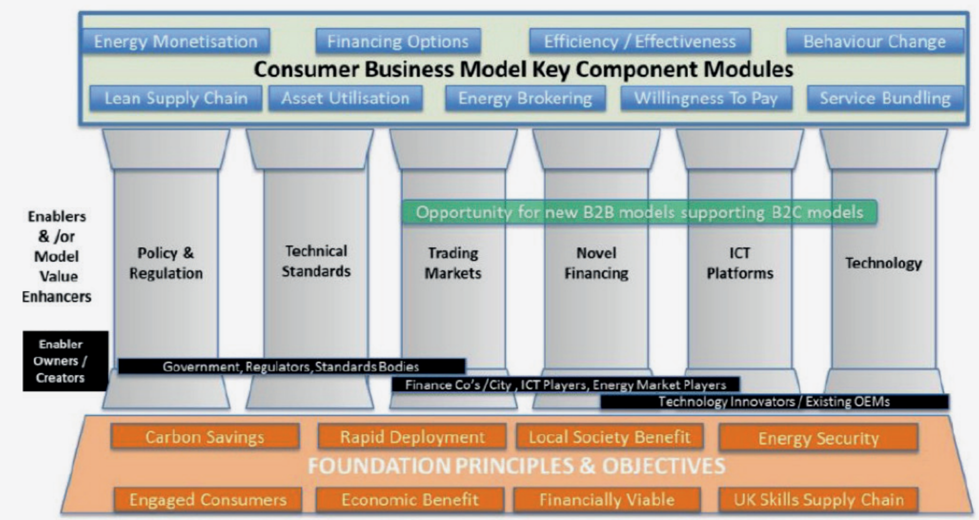
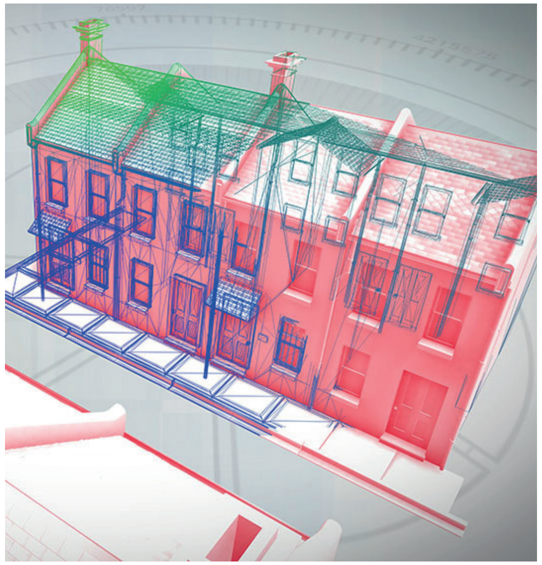


Figure 12
Using the model "game" in a workshop



During the course of this work, the SSH team came to believe that the experiences of moving around, heating and securing one's home, and other energy intensive services, would be transformed over the next thirty years by the combination of internet technologies and new low-carbon energy technologies as social engagement has been by the internet and digital cameras.

The next piece of work looked at the different basic ways that an energy system could be constructed, along the dimensions of:

- Extent of vertical integration of the supply-chain
- Degree of centralisation and regulation of commodity markets and network capacity
- Basis of retail competition (along an axis of commodity price to service delivery)
- Basis on which carbon prices are internalised

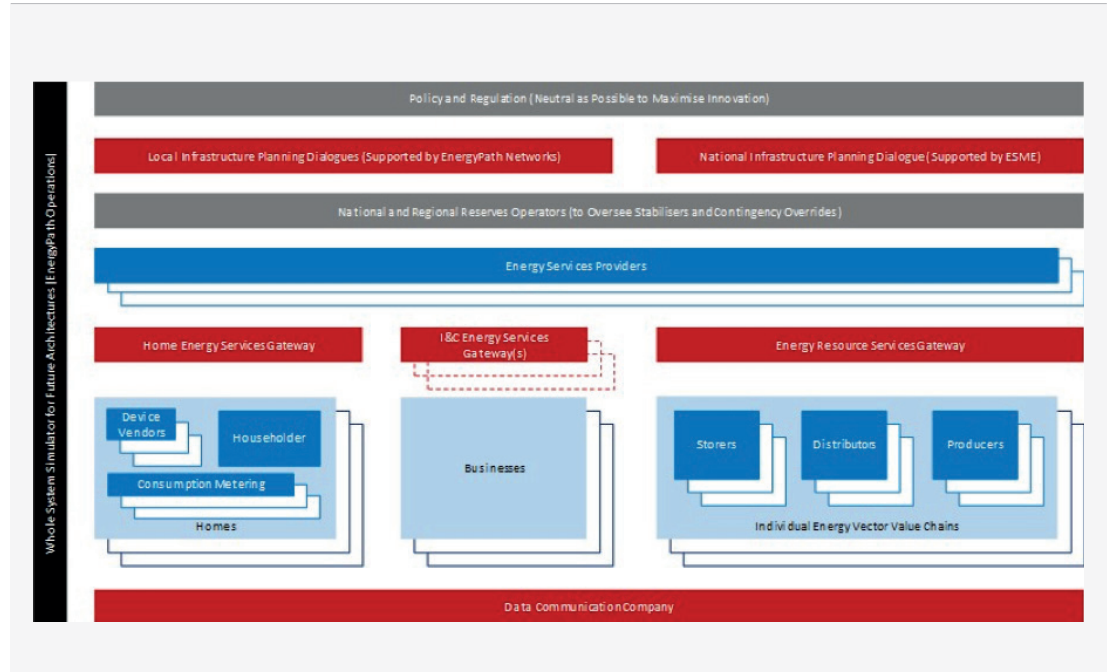
A number of high level architectures, including Business as Usual, were synthesized as plausible combinations of positions on these axes. These were tested against criteria for:

1. **Consumer centricity**
2. **Resource (capacity) constraints**
3. **Security and stability**
4. **Commercial alignment (investability along the value chains)**
5. **Social objectives**

Although some of the high-level architectures were ranked higher or lower on these criteria, there was no clear winner. Additionally, the ranking threw up questions for further exploration; although an architecture may appear to be able to deliver well against one or more of these criteria, real-world delivery depends on practical design. Business as Usual was ranked low on the criteria, consistent with the view of most energy stakeholders; innovation is required, if we are to meet our goals of decarbonisation, customer satisfaction and wealth creation.

One architecture was chosen for further exploration and a test-case for method and tool development. Figure 13 details its technical structure.

Figure 13
Structure of Architecture 10: "Fully unbundled retail of experience based services, with Resource SLAs"



The implications of this change are profound and wide-reaching as exemplified by the table on the facing page. This is a radical departure from the current system, in ways which are uncomfortable and risky, but which hold the potential for significant advantages. This system was chosen for exploration and discussion, not because it is the best choice. It is intended to open up thinking rather than present a fully developed proposition. As was explained at the beginning of this section, it is for government and industry to shape the future of energy supply through restructured governance and decision making processes that enable innovation in the service of social goals and energy users.

It is for government and industry to shape the future of energy supply.

Feature	Business as Usual (Attributes)	Example future architecture (Attributes)	Benefits of approach
Customer Proposition	Sale of kWh	Sale of services with outcomes guaranteed by service providers	Uncouples technology choice from experience which could lead to a better channel to market for low carbon technologies
Commodity Traded	kWh throughout the supply chain which tends towards the marginal cost of production	Focused around 'right-to-use' or 'capacity' to send market signals on the needs and wants of customers within the supply chain	True reflected costs in prices which can be used to inform investment decisions
Addressable value for suppliers/ service providers	State mandated, regulated markets for system operation funded by consumer levy (e.g. DUoS, BSUoS, CfD, FiT etc.)	Payment for differentiated levels of service outcome direct from next actor in the supply chain	Value pool stays with consumers rather than a centralised pot meaning innovators' profitability is influenced by delivering to consumers
Ownership of consumer data	Owned, processed and stored by proprietary organisations	Data accessible through shared gateway with appropriate commercial agreements between parties	Consumers retain control of their data and can share with organisations they choose
Network infrastructure upgrades	Driven through prediction and best information available	Driven from consumer behaviour and supported by local area planning enabling LAs to deliver as democratically elected decision makers	Value is prioritised over "cheapness" Multi-vector trade-offs are possible thanks to planned infrastructure
Localisation of generation and distribution	Driven through prediction and best information available	Drives to install appropriate equipment in the right places given learned customer preferences	Investment indicators are provided by real knowledge of wants and needs to devolve decision responsibility to most appropriate actors
Optimisation of system resources	Currently centralised (TSO) becoming more decentralised (DSO)	Allows for optimisation at house, street, district, regional, national, international level	More flexible operating methods and opportunities
Investment Signals	Auctions, changing policies	Digital platforms unlock insight into consumer wants and needs where the information is used to drive investment decisions	Deeper understanding of supply chain needs and wants leads to better investment decisions

CASE STUDY

The specific case study chosen was of significant penetration of hybrid heat-pumps into a large part of a test area, for example one of the three local authorities in the local planning theme. Hybrid heat-pumps combine an air-source heat-pump for baseload operation for hot water and heating on moderate winter days, with a natural gas, hydrogen, oil or LPG boiler for high power duties. High power duties might include warming up the house after a winter break, keeping it warm through a period of several unusually cold days, or providing multiple bath's or showers over a shorter than usual period of time. For the purposes of the test case, we assumed operation on natural gas, a well-characterised network.

Two pieces of work were done on this test case:

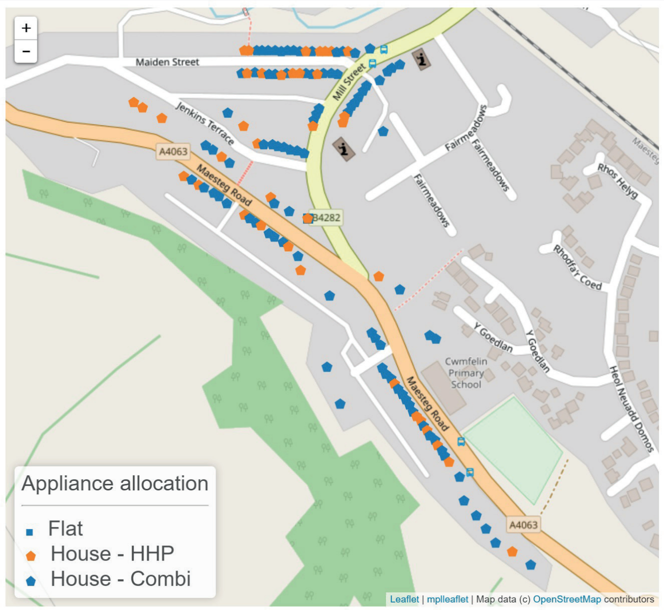
- Detailed mapping of the business processes required to make the system work – for example balancing supply and demand, or changing from one supplier to another.
- Developing a prototype version of EnergyPath Operations (EPO). EPO is a simulation tool that enables the second to second, day to day etc operation of an energy system to be studied.

EPO includes:

- **Physical assets**, such as buildings, networks, heating systems etc
- **User behaviour** (such as building occupants and drivers)
- **Control and communications** (such as local heating system controls and messages passed through the smart meter infrastructure)
- **Business processes** (such as trading, hedging and balancing), including System Operator actions (both local and national)

The development of EPO required leading edge research into two key challenges: the allocation problem, and dynamic network representation.

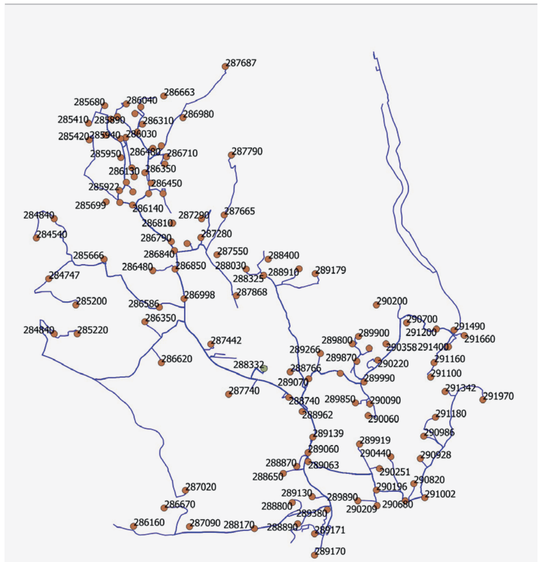
Figure 14
Example of allocation (from EPO) of heating systems during penetration of heat-pumps



The allocation problem considers how energy service demands are clustered in time and space, in order to produce the local and national peaks that determine capacity requirements. Monte Carlo simulation enables sampling to determine frequency distributions.

As the different heating systems operate, to meet the requirements of occupants, the load on the networks changes. Different control systems contribute to this, with complex interactions that depend on business models and the passing of messages between different systems. In order to simulate a few cold weeks in the winter, it may be necessary to consider a very large number of states of the network. Running detailed power-flow models to identify network constraints is not possible within realistic computational resources. EPO therefore replaces the network with an Artificial Neural Network, that has been trained by using many power flow simulations, to represent the network, especially when it hits a limit.

Figure 15
Example 11kV network



Once the nature and frequency of these limiting events have been identified, they can be explored in post processing with more detailed power-flow models.

Although the system operation tools were not fully developed in SSH Phase 1, they provide a solid foundation for further development and thinking, as the governance and direction of energy supply becomes clearer. It would be better to make the required investments in tools and capability, based on greater clarity about the challenges, as seen by those accountable for the changes.

The ETI framed its Smart Systems programme around heat, as the most difficult challenge for a system that is smarter by design and operation. However, recharging electric vehicles is probably the most urgent challenge for system architecture re-engineering. The tools and concepts developed in this third work area are directly applicable to managing vehicle charging.

Whereas heating is a peaky and relatively inflexible load, strongly co-ordinated by weather, charging is a very flexible load. Taking advantage of this flexibility will test the current system governance to its limits and beyond. The tools and concepts from SSH Phase 1, when combined with the kind of consumer research carried out in the ETI Energy Storage & Distribution programme, may suggest novel and better ways of making the best of this opportunity for the electricity system.

6. In this illustrative example, network costs for onshore wind are high, reflecting the assumed location of this capacity in Scotland (based on current policy) and network costing assumptions in EnVision. If we assumed a less constrained choice of location across GB, these costs would be lower.

FURTHER INFORMATION

Accessing More

Nearly all of the programme deliverables have been published in the ETI Knowledge Zone[8]. These are available for public download. Some deliverables have not been published because they contain third party information and for other similar reasons (for example that they might increase the reidentification risk for consumer research data)[9]. Some were not useful, outdated or replaced by later deliverables. Many of the deliverables are very detailed and anticipate a degree of knowledge of individual projects on the part of the reader. Understanding them may require downloading and reading several project documents.

Some datasets are available for download but most of the software tools and their data are held within the ESC, who will be developing them further and giving access to them. If you are interested in using these tools, you should contact the ESC, currently Richard Halsey.

Over its life from 2008 to 2019, ETI conducted its work within the context of a frequently updated whole systems analysis that considered many different futures for the UK energy system, based on learnings from ETI projects and elsewhere. The outputs of the SSH programme should be seen as part of a coherent whole ETI output. For example, there is a strong link between the outputs of SSH Phase 1 and the ETI Energy Storage & Distribution programme (ES&D). The system architecture tools developed in SSH are directly applicable to the challenge of integrating electric vehicles into the future energy system, a challenge covered by the ES&D Consumers, Vehicles & Energy Integration project. Network costs used by ESC in local area energy planning drew on the Infrastructure Cost Calculator, also developed within ES&D.

Outputs from all ETI programmes and strategic analysis are available in the Knowledge Zone and users should treat programme boundaries as containers rather than limits. ETI is planning to publish an Insight based on CVEI in the second quarter of 2019, which will be a counterpoint to the domestic heat focus of SSH Phase 1, but will show how "smartness" will also be required to manage charging.

The ETI Strategic Analysis Function (SAF) also transferred to the ESC in 2018, so that the systems elements of ETI capability have all been incorporated into ESC. Whereas ETI was structured around the execution of projects by third parties within programmes, ESC is a set of capabilities to meet its users' needs. Integration within ETI happened through the SAF. ESC is organised quite differently but still on the basis of whole systems analysis and integration. In that sense the SSH programme Phase 1 has contributed a set of assets into ESC, which will be organised and integrated differently than ETI organised SSH within its total portfolio.

The following SSH Phase 1 reports and other deliverables are highlighted as the key references within each work package. If reading them creates an appetite for deeper engagement, then exploring the ETI Knowledge Zone and speaking to the ESC would probably both be productive.

[8] SSH deliverables in the ETI Knowledge Zone: https://www.eti.co.uk/programmes/smart-systems-heat
[9] Dispelling the Myths Surrounding De-identification: Anonymization Remains a Strong Tool for Protecting Privacy, Information & Privacy Commissioner of Ontario, CHEO Research Institute and University of Ottawa, June 2011

Work package 1: Individual Homes

1. How can people get the heat they want at home, without the carbon? ETI Insight Considers the decarbonisation of domestic heat as a journey from the perspective of the consumer.

2. Trial of a consumer orientated Home Energy Management System (HEMS), ESC report Provides a detailed analysis of the consumer and heating data collected in the winter 2016/17 trial.

3. Housing retrofits: a new start, ETI Insight Summarises they key learning from the ETI retrofit project and places retrofits with the context of housing and energy strategy.

4. Project Conclusions and Opportunities for Improving the Delivery of Whole House Retrofit, Peabody report.
Draws together the key findings and observations of the ETI retrofit project as a series of recommendations and cost estimates for a UK housing retrofit programme.

5. Integrated Electric Heat Upgrade Analysis: final report, ESC report
Describes the application of the modelling and choosing pathways from 5 pastiche dwellings from the winter trial. As well as describing the pathways the report covers the modelling and the technical issues around delivering the pathways in considerable detail.

6. Consumer segmentations: final report, ESC report.
A slide pack, describing the process and findings of a stratified, UK wide, 3000 in-home set of interviews to determine consumer attitudes to using heat, switching suppliers and boiler replacement. A subset of 530 participants were also involved in a subsequent choice experiment on heat purchase, including a building survey to estimate realistic costs.

7. Consumer segmentation question sets, worksheets.
The question sets for the segmentation and choice experiments are available for download.

8. Consumer segmentation raw data sets.
ETI has assigned the rights to these to the ESC and organisation and institutions interested in working with these should contact the ESC.

Work package 2: Local Area Energy Planning

1. Local Area Energy planning implications for Government, ESC report.
Sets out the links between local area planning and central government policies in some detail. As well as analysing the issues in terms relevant to HMT, BEIS, DCLG and DWP, it also makes identifies opportunities for greater policy impact and effective use of public resources.

2. Local Area Energy planning guidance, James Lang LaSalle report.
Provides an overview of the process and related statutory duties etc for those who may be involved in local area planning, especially local authority officers and representatives.

3. Newcastle Local Area Energy Planning Evidence Base.
A final compilation of evidence generated for the stakeholder group during the Newcastle study.

4. Bridgend Local Area Energy Planning Evidence Base, ESC report.
A final compilation of evidence generated for the stakeholder group during the Bridgend study.

5. Bury Local Area Energy Planning Evidence Base.
A final compilation of evidence generated for the stakeholder group during the Bury study.

6. Greater Manchester Spatial Plan Evidence Base.
Evidence produced by ESC and published by the GMCA in support of the GMSP.

In addition to these published outputs, each Local Authority was provided with some suggested elements of a local area energy plan, based on the evidence and engagements with local stakeholders. Each local authority will decide what plans and strategies to produce, informed in part by their work with ESC.

Work with the three local areas from SSH Phase 1 is informing the development of Smart Energy Plans as part of the SSH Phase 2 Programme. This involves identifying a range of near-term innovation and deployment projects in response to the challenge of decarbonising heat and wider energy system transformation.

The UK Research and Innovation “Prospering from the Energy Revolution” Programme involving the ESC is supporting the design of local, smart energy systems that are ready for roll out in the 2020s.

Work package 3: System Architecture

1. Tools for future energy systems, ETI Perspective.
Provides and introduction to the impact of internet technologies on the energy systems transition, both as a key enabler and also a disruptor. Links to other key publications.

2. Energy Systems Architecture Methodology: Enabling multi-vector market design, ESC report.
Introduces the high-level concepts of system architecture development on a multi-vector and multi-stakeholder basis.

3. Business Model Game, ESC report.
Provides a description of the BMG, various models developed using it, and also the issues involved in customer-facing business model innovation.

4. Business Model.
A downloadable version of the BMG and guidance on its use.

Further ETI material

1. Options, Actions, Choices: Updated.
Two plausible whole system scenarios for future UK energy systems, that provide context to the SSH programme.

It is not possible within a summary report to include every piece of work by others which has influenced and contributed to the SSH programme. ETI recognises its Members – BP, Caterpillar, EDF, Rolls-Royce and Shell, and Associate Hitachi, for the invaluable contributions they have made to ETI programmes and to the many project partners who have delivered critical elements of the outputs. There are a small number of references, relevant to the text, included in this Perspective. ETI Insights and project deliverables include much more extensive references to important contributions from others.

Further ESC material

In addition the ETI would like to recommend the outputs of two related programmes, undertaken by ESC with support from other stakeholders:

1. Fair Futures.
ESC is partnering with organisations from various sectors to develop a programme – Fair Futures – to better understand the issues faced by a range of vulnerable energy consumer groups. This will enable the identification of areas where commercial, governmental, community and householder needs and motivations could be aligned to provide more effective policies, products and services.

2. Future Power Systems Architecture.
The FPSA is a multi-stakeholder collaboration led by the Energy Systems Catapult and the Institution of Engineering and Technology. The FPSA is taking a holistic and whole-system approach to the evolution of its architecture – considering technical, governance, commercial and societal factors.

ABOUT THE AUTHOR

Andrew Haslett
FREng, BA, FIChemE, CEng – Chief Engineer – Energy Technologies Institute

Andrew Haslett is Chief Engineer at the ETI. He was the ETI's Strategy Development Director from 2008 – 2014. He is a Fellow of the Royal Academy of Engineering, the Institution of Chemical Engineers and the Royal Society for the encouragement of Arts, Manufactures and Commerce.

Additional contributors

Rebecca Sweeney
SSH Programme Manager – Energy Technologies Institute

Matt Lipson
Head of Consumer Insights – Energy Systems Catapult

Eric Brown
Innovation Director – Energy Systems Catapult

Richard Halsey
Innovation Business Leader – Energy Systems Catapult

Emma Harrison
Head of Systems Integration – Energy Systems Catapult

Daniel Mee
Energy Systems Architect – Energy Systems Catapult

Energy Technologies Institute
Charnwood Building
Holywell Way
Loughborough
LE11 3AQ

01509 202020
www.eti.co.uk
info@eti.co.uk
@the_ETI