Freedom Project
Interim findings

Short Paper
April 2018

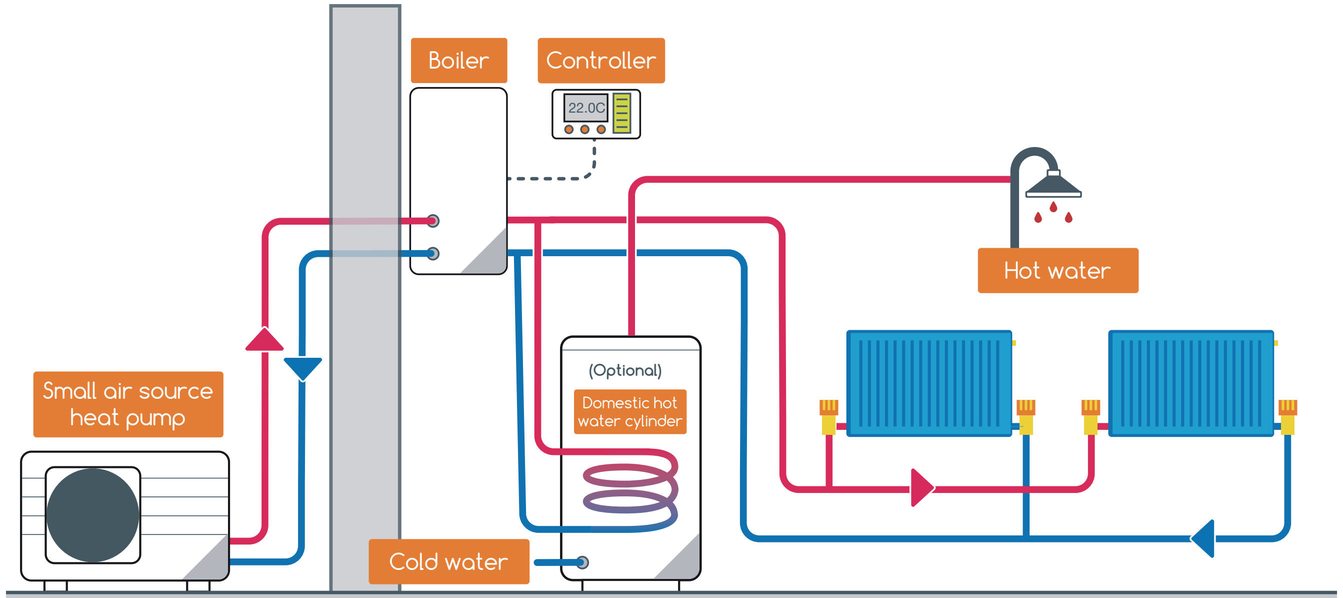
Contents

Introduction

Freedom

The Freedom Project is an industry first cross-sector collaboration project seeking to understand the potential role of multi-vector solutions to support the delivery of low cost, low carbon domestic heating.

Based in south Wales, the project is investigating the consumer, network and energy system implications of domestic smart controlled hybrid heating systems, which have the option of operating using a gas boiler or an air source heat pump.



An illustration of a hybrid heating system

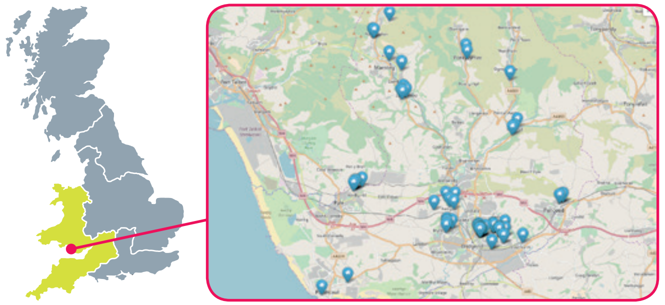
The project team

As an industry first, Distribution Network Operator (DNO) Western Power Distribution and Gas Distribution Network (GDN) Wales & West Utilities have formed a partnership using their respective Network Innovation Allowances (NIA) to invest with PassivSystems to deliver the Freedom Project. To support the delivery of this two-phased project, PassivSystems has appointed project partners Imperial College, Delta-ee and City University:

The project partners

Two phase project

Freedom is a £5.2m innovation project that has installed 75 hybrid heating systems in residential properties in Bridgend, south Wales, in 2017.



Map of Bridgend

PHASE 1

Phase 1 of the project produced forensic models from which hypotheses of system performance, detailed market assessments, and consumer research were derived.

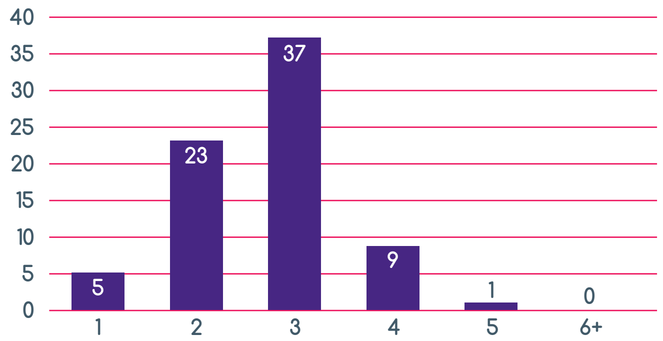
In addition, it delivered a four-home pilot installation, using three different manufacturers, to assess the selected hardware, installation contractors and project customer experience and engagement.

PHASE 2

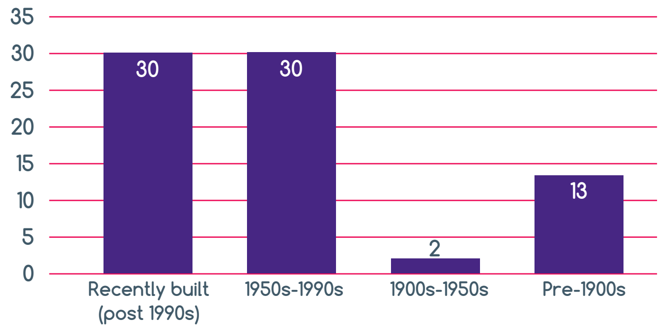
Phase 2 is currently field testing the hypotheses developed during Phase 1 in 75 homes, which are a mixture of social and private housing:

Property type

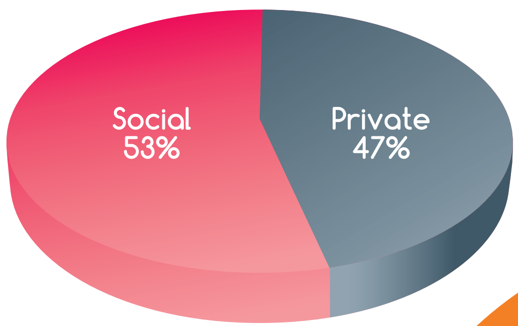
Number of bedrooms



Property age

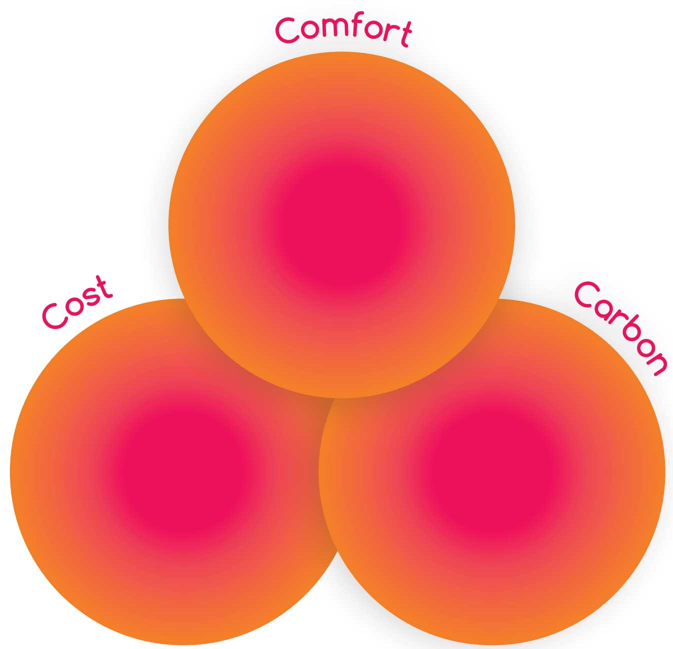


Private and social occupancy mix



Project aims

- Demonstrate the ability of the hybrid heating system to switch between gas and electric load to provide fuel arbitrage and highly flexible demand response services.
- Demonstrate the consumer, network, carbon and energy system benefits of deployment of hybrid heating systems with an aggregated demand response control system.
- Gain insights into the means of balancing the interests of the consumer, supplier, distribution and transmission network when seeking to derive value from the demand flexibility.
- Address all elements of the energy trilemma.



The energy trilemma for heat

Hybrid heating system installations

The programme started in October 2016, with the procurement of appliances and installer services being a high priority. The three heat pump manufacturers selected were Daikin, Samsung and MasterTherm, with each offering distinctive benefits. All three systems were carried forward into Phase 2 of the project. The decision to use three different hybrid systems was an additional cost but has provided much greater project learnings.

Now over halfway through the programme, the project has demonstrated that it is feasible to optimise smart hybrid controls on three different hybrid heating systems installed in a range of different house types (broadly representative of UK housing stock) using the existing wet heating systems and with no in-home disruption from additional insulation measures.

The project has also completed installations of three hybrid systems with a system boiler and hot water storage, three hybrid systems not on the gas grid (using Calor gas storage) and one property with a new heat pump retrofitted alongside an existing boiler as an example of a low cost hybridisation.

Daikin installation

The Daikin (5kw) hybrid heat pump is a fully integrated hybrid heating system and market leader

Samsung installation

The Samsung (5kw) heat pump and Worcester 30i boiler is a budget range hybrid heating system

MasterTherm installation

The MasterTherm heat pump (8kw) and Vaillant EcoTech boiler installation uses a high-end heat pump with an internet-enabled control box and a brushless DC compressor with zero starting current

Field trial hybrid heating system experiments

Over the course of the Freedom Project main field trial, a number of interventions are being set to change the operation of the hybrid heating system from their 'baseline' control strategy (minimum cost to consumer) to explore other scenarios and meet the research objectives of the project.

As a matter of course, homes are being moved back to the 'baseline' control strategy whenever possible, to avoid impact on consumer bills (as any intervention will increase consumer energy costs).

The interventions being delivered include:

- **Different fuel cost ratios** (ie using higher gas prices, including the price at LPG in off-gas grid homes, which is indicative of fuel switching with carbon taxes on fossil gas, BioSNG or hydrogen)
- **Fixed patterns** of time-varying electricity tariffs and restricted-consumption periods as a simple proxy of the smart grid representative of renewable generation intermittency
- **'Impulse' experiments** to look at the effects of highly simultaneous fuel switching on both electricity and gas networks
- **Forecast** electricity marginal carbon intensity[1] of generation
- **Aggregated demand management** to simulate avoiding the capacity limit of an electricity subnetwork.

1 Marginal carbon emissions: the carbon emissions produced by each additional unit of electricity generation

Optimised controls

Conventional control systems for hybrid heating systems usually program a transition between electricity and gas on the basis of the current external temperature. The systems calculate the external temperature at which the heat pump produces heat at the same price as the gas boiler, due to the coefficient-of-performance (COP) dropping at lower external temperatures.

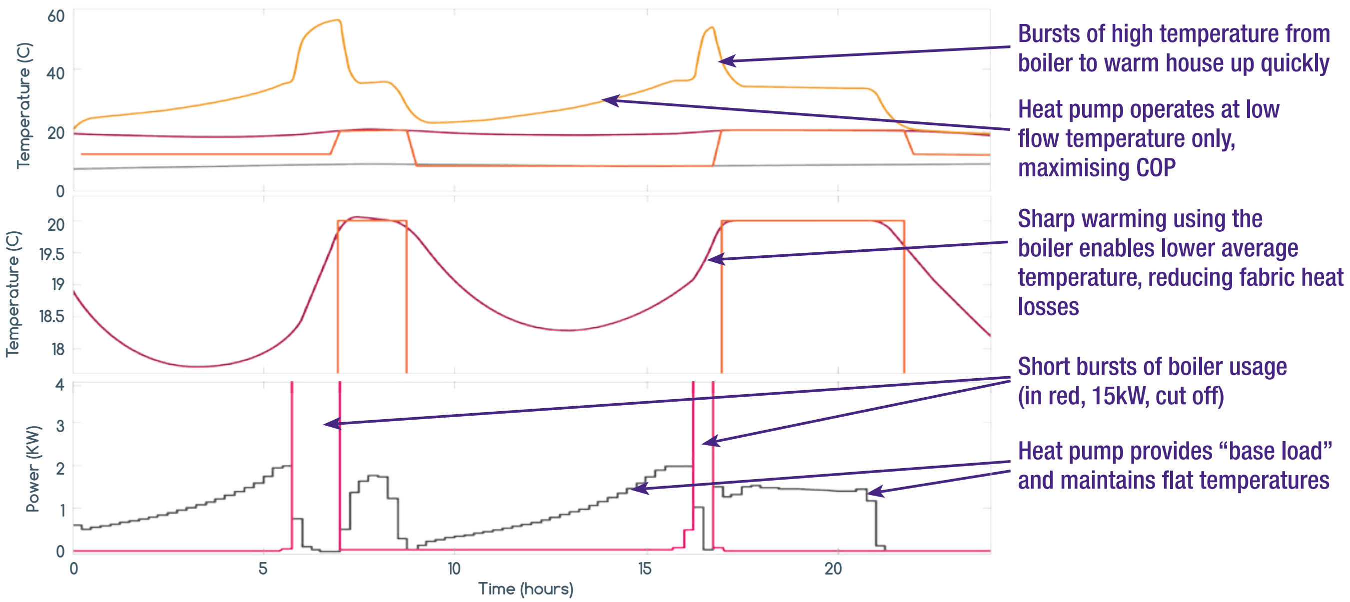
This is a natural extension of weather-compensated control, which assumes a static heat load. The Freedom Project is exploring whether there is a dynamical approach for hybrid heating systems that works better than the conventional 'external transition temperature' approach: the heating water temperature affects the COP as much as the external temperature. Smart control and the system 'learning' the best strategy for each house leads to much more complex but beneficial switching.

The Smart Control graphs, below, show the fully optimised predictive control solutions for a hybrid heating system for a scenario where electricity and gas are in close competition.

Our model assumes that the heat pump and boiler simply provide alternative sources of energy to heat up the water and space, without further detailed modelling of the hydraulics. We have assumed a gas:electricity price ratio of 1:3 and an empirical model for the COP of the heat pump; the predictive controller is programmed to minimise cost to the consumer.

A qualitative interpretation of the optimisation output is that the heat pump is being used to provide a baseload, keeping the house topped up with warmth with a low flow temperature, achieving a high COP; and the gas boiler provides boosts of high temperature warmth to get the house up to temperature. In warmer external conditions (not shown), the controller is able to use the heat pump on its own, and in colder conditions the boiler is needed to maintain the 20°C room temperature. In all cases the transitions are determined automatically without the need for an installer to set a transition temperature; the system just needs to know the fuel price ratio and the performance curve (COP) of the heat pump (and potentially an approximate boiler efficiency figure).

SMART CONTROL ILLUSTRATION



Graphs illustrating cost-optimised control of a hybrid system with a gas:electricity price ratio of 1:3, showing day-ahead predictions of heating water temperature (top), room temperature (middle), and power consumption (bottom, with electricity in black and gas in red)

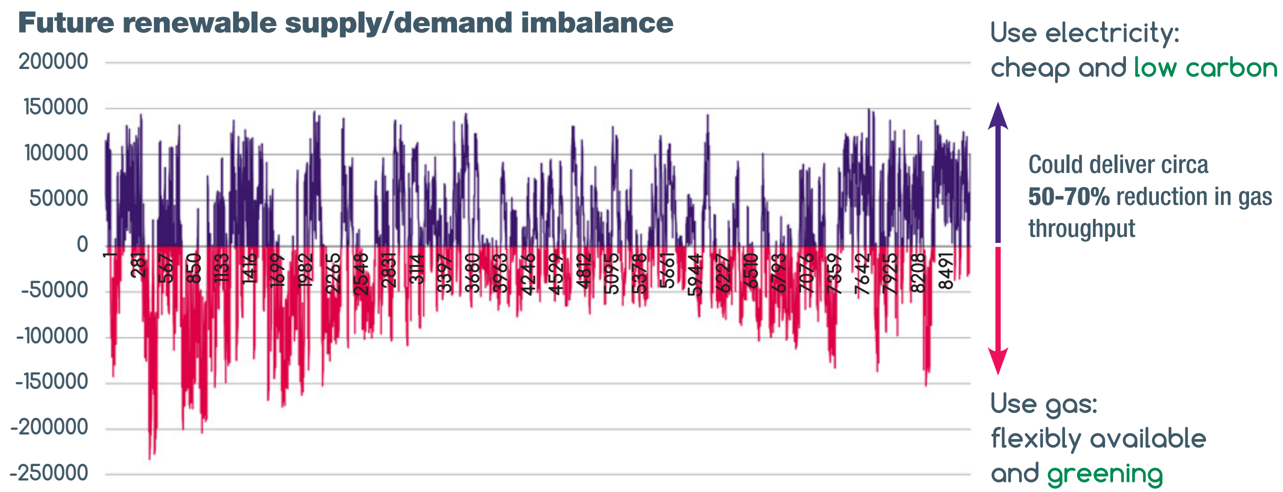
Switching fuel sources on availability of intermittent renewable generation

The Wales & West Utilities energy simulator has identified how the system could work in the future. The simulator has calculated a minimum 50% carbon reduction via an alternative path. This is based on using electricity for background heating when generation is both green and low cost, and gas the rest of the time.

Additionally, with hybrid heating systems using low-cost renewable electricity through the heat pump in the future and delivering demand side response services, the gas boiler and upstream gas network will be able to provide storage and flexibility for when the external temperatures are very cold, when there are electricity network constraints and when intermittent renewable electricity generation is unavailable. With at least 30% of domestic heat demand able to be met by renewable gases going forward, a total domestic heat decarbonisation pathway is emerging through a hybrid balance between two renewable energy vectors.

HYBRID HEATING SIMULATION

The graph below shows the supply-demand gap due to the intermittency issues associated with the renewable generation sources

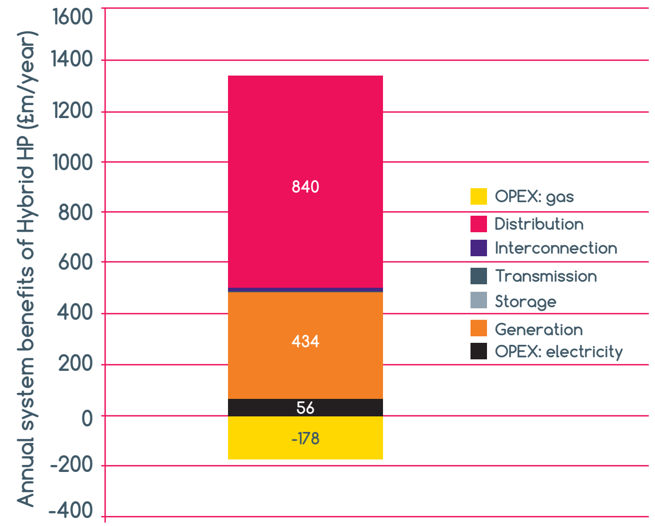


Switching fuel sources on electricity network capacity constraints

As part of a cost-efficient solution, the gas appliance in hybrid heating systems is used during peak electricity demand when there isn't capacity in the electricity system to meet heat demand. This enables the gas and electricity vectors to supply the entire heat demand by load shifting to gas when the electricity system is reaching peak capacity. This hybrid flexibility results in avoided costs in relation to increasing electricity generation capacity and electricity network reinforcement when compared to the electric-only scenario, where the entire heating demand would have to be met through electricity.

Hybrid switching signals based upon electricity network capacity show that gas would be used during the midweek evening electricity network peaks, yet not as often during the morning electricity network peaks or over weekends. This is because there is more electricity network capacity available for heat in the morning and on weekends.

Imperial College's modelling of hybrid heating system adoption indicates that the potential benefits of hybrid heating systems are considerable. Modelling the 2030 energy system, their analysis shows that an increased annual spend of £178 million on the gas system as a substitute to electricity in air source heat pump-only scenarios, the whole system is able to achieve gross savings in total cost of more than £1.3 billion per year.



Annual energy system savings using hybrids instead of ASHPs alone

An emerging customer proposition

The emerging proposition for heat as a service, which may be achievable to deliver by the mid-2020s, is showing that the potential combined value of fuel arbitrage, domestic demand side response and frequency response services could avoid initial capital outlay. This model requires a demand aggregator role to act on behalf of heat consumers and share the value from the benefit of flexibility of using two vectors and the storage in the gas network, with third party investors owning and maintaining heating assets.

The value between purchase of fuels and sale of heat could be grown further by reducing heat demand in the home, with the aggregator and investor incentivised to install insulation measures which pay back at no further cost to the consumer. The leakiest homes and those properties with higher occupancy and, therefore, higher heat demand would attract the quickest financial return from lowering demand in a heat service world.

Decarbonisation breakthrough

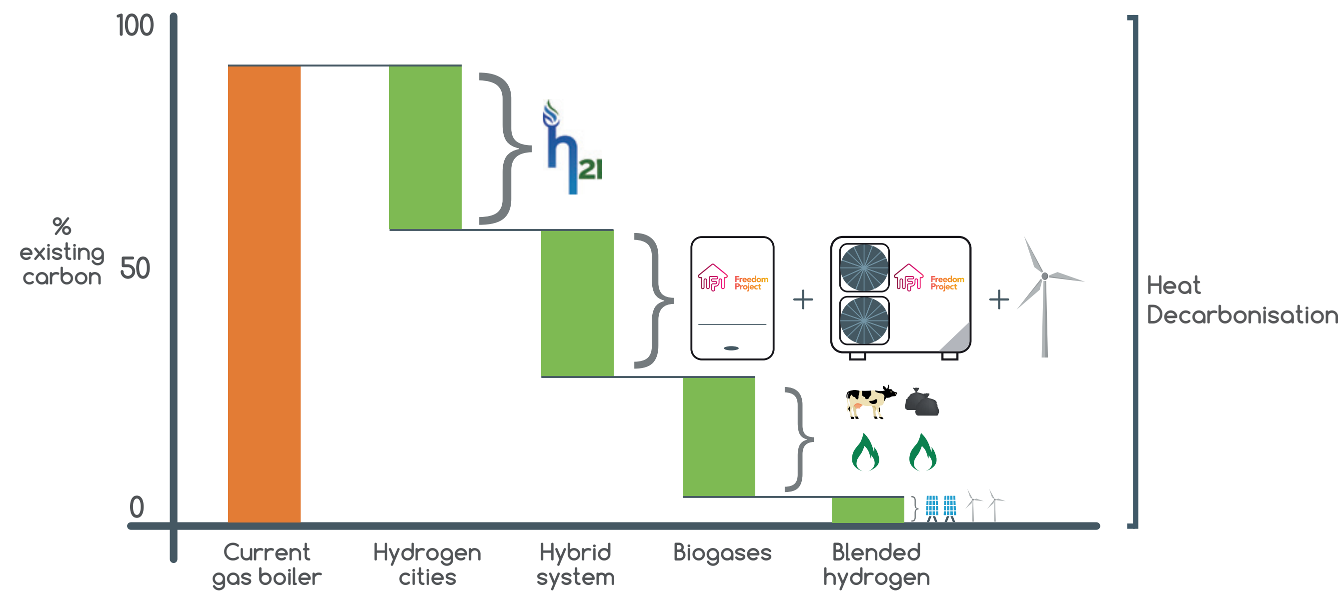
Not only is the evolving customer proposition attractive in the offering of lowest cost heat with minimal disruption, flexibility to smartly and remotely switch vectors on a variety of signals could enable a pathway to full domestic heat decarbonisation. This could be achieved through the balancing of renewable gas and electricity in an integrated energy system – which neither could achieve on their own. Using a fusion of heat decarbonisation technologies within a region has the potential to decarbonise heat at the lowest cost using the best of each technology.

The H21 project has demonstrated hydrogen gas can be transported, stored and used, using the existing infrastructure installed in the UK, the same way as natural gas, offering minimum disruption and cost compared to other low carbon alternatives. In addition, adoption of hydrogen would only require the consumer to convert their appliance, much like when the UK switched from town gas to natural gas in the late 1960s and early 1970s. Other alternatives will need new heating systems installed (ie replacing boilers and installing different radiators).

Biomethane is identical to the methane contained within natural gas, and is already playing a role within the UK energy system. The use of biomethane in the network does not require any modifications to appliances or how the gas is currently used.

BioSNG can be produced from black bin waste as demonstrated by Advanced Plasma Power and Progressive Energy in Swindon, opening up a large feedstock potential.

Hydrogen blends are being tested at Keele University (HyDeploy project), with a mix of 7% (by energy) expected to be acceptable.



An integrated approach to decarbonise domestic heat

The hybrid technology developed through this project becomes the catalyst to enable domestic heat decarbonisation at lowest cost

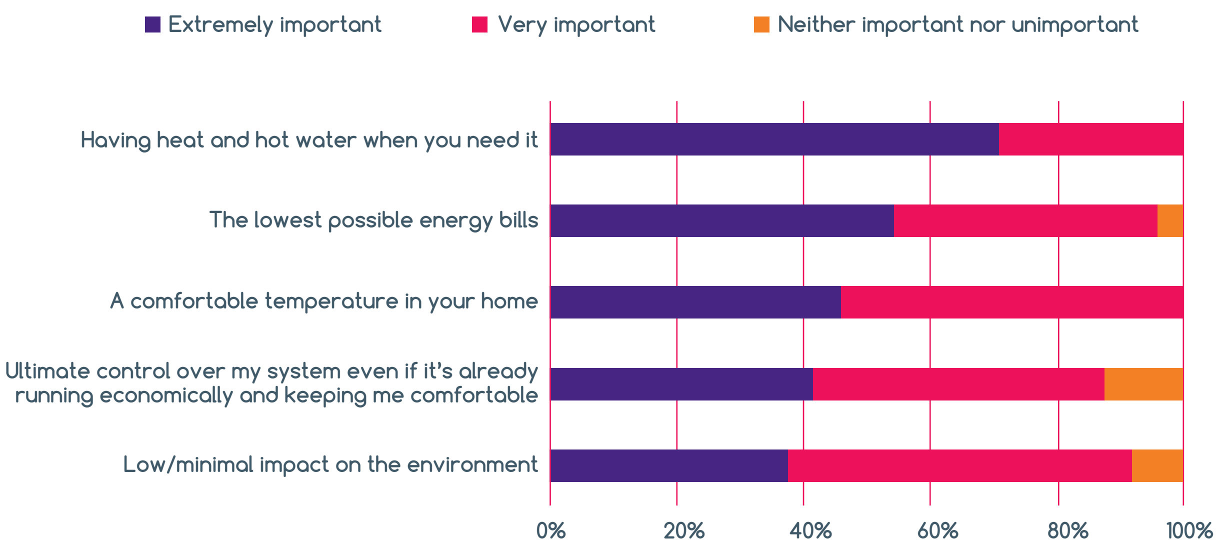
Customer experience

One of the biggest challenges of deploying any new heating technology is getting the end-users (ie householders) engaged with it and trusting that the system is working properly and to their advantage (ie keeping them warm while saving them money). Following on from Phase 1 of the project, Delta-ee undertook a pre-installation survey, with the questions focused on perceptions to hybrids and demand response pre-trial, as well as expectations for the hybrid heating system.

Surprisingly 12% of participants had what they considered 'good' or 'excellent' knowledge about hybrid heating systems prior to the trial. This was the same for heat pumps in general. The hybrid heating systems installed as part of the project were appealing to participants once they had been explained, with savings in running costs viewed as the biggest advantage. Nearly 90% of respondents found the idea of hybrid heating systems appealing or very appealing.

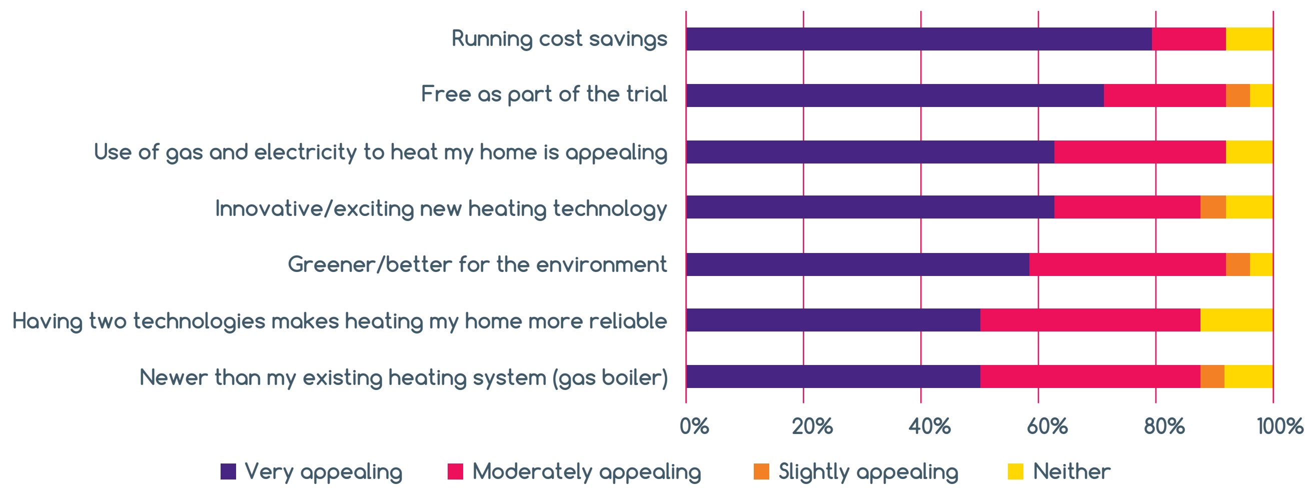
The supply of a hybrid heating system without trialists having to invest their own money in the equipment was a very appealing incentive. Some of our recent research has shown that initial capital cost is the key factor that influences a decision to change to an alternative heating solution, with 80% of consumers not being able or willing to pay[2].

WHAT ARE THE REASONS FOR CONSIDERING A HYBRID?



[2] Future of Energy & Investments in Gas Networks, Bridgend Phases 1-3 Summary Report, Wales & West Utilities, January 2016

WHAT IS IMPORTANT FOR THE CONSUMER?



Overall awareness of flexibility and demand response was higher than we might have expected, with 50% of triallists saying they had good knowledge of it, which is positive considering it is not a common offering at present in the UK. The majority of participants were not overly concerned about having a hybrid heating system installed, which shows that during the trial the systems were explained well to customers. Those that had concerns related to reliability, running costs and the availability of installers.

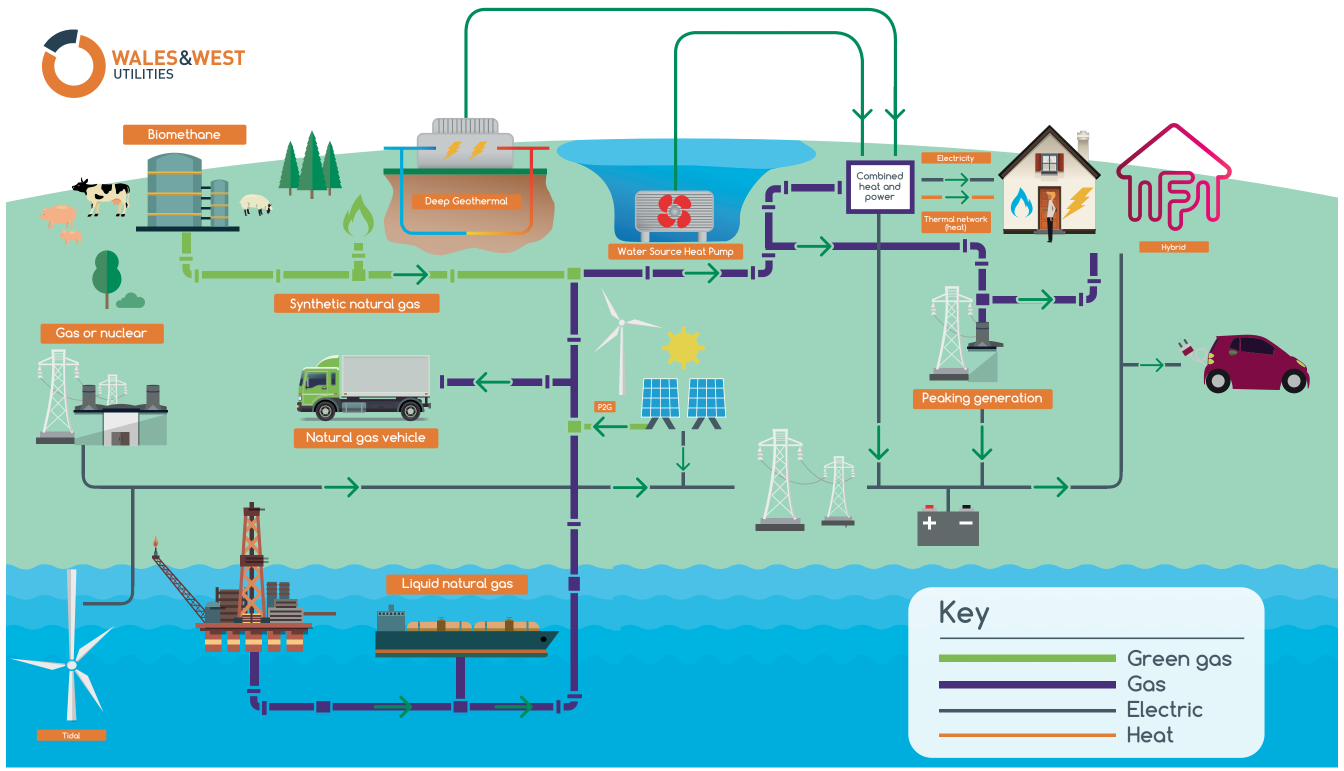
Hybrids in an integrated whole energy system

The global recognition of the challenges of climate change, in particular the ambitious reductions in carbon emissions proposed by the UK Government (ie 80% reduction relative to 1990 levels), are driving significant changes across the energy landscape. Significant progress is being made in decarbonising electricity generation and seeking low-carbon gas alternatives.

However in the UK, domestic heating remains largely unaffected by attempts to lower the carbon outputs, aside from the considerable progress made through increased boiler efficiency. Gas boilers are the predominant technology for the provision of domestic space heating and hot water in the UK with a market penetration of 80% of homes. In order to meet ambitious carbon reduction targets, our high dependency on fossil gas heating will need to reduce, with hybrids offering the flexible solution to make best use of renewable gas and electricity.

A high-resolution, spatial and temporal dynamic model has been developed to enable the holistic evaluation of the changing interactions between gas and electricity networks.

As the networks continue to integrate (see illustration below), variation of demand and supply on the electricity network will have immediate impacts on the gas network. For example, where more electric vehicles are charged with intermittently generated renewables, this creates larger demand swings on the electricity network, for example, affecting demand on the gas distribution system as gas peaking plants respond to maintain capacity on the electricity network.



Gas and electricity network integration

Key learnings so far

Smart controlled hybrid heating between an air source heat pump (ASHP) and a boiler running on natural gas offers lower cost and lower carbon domestic heat, when compared to electrified heat through ASHPs alone. The system avoids inefficient and costly use of peaking generation, with associated line losses, to power a heat pump. Burning gas in the home at 93% efficiency is more carbon efficient than incurring 6% electricity network transmission losses after burning fossil fuel at coal (34% efficient, 937 gCO2e/kWh) or gas peaking (28% efficient, 651 gCO2e/kWh) power stations.

When there is insufficient renewable electricity generation, when it is very cold and/or when there are capacity constraints in the electricity network, the heat load can shift across to the gas network, and vice-versa, to provide uncompromised heat, flexibly using the vast energy storage within the gas network (210TWh seasonally).

The addition of renewable gases to the network, such as hydrogen blends, biomethane or BioSNG, significantly improves the carbon reduction when the boiler operates and could achieve full decarbonisation of domestic heating.

The smart control panel enables switching between the two fuel sources and heating appliances driven by cost – supporting the decarbonisation of heat in an affordable way, with limited cost to the customer and limited behaviour change needed.

Imperial College's modelling of hybrid heating system adoption indicates that the potential benefits are considerable. Modelling the 2030 energy system, their analysis shows that an increased annual spend of £178 million on the gas system as a substitute to electricity in ASHP-only scenarios, the whole system is able to achieve gross savings in total cost of more than £1.3 billion per year.

Freedom could help deliver a future energy system that is affordable, secure and low carbon, while avoiding the need for costly and disruptive electricity network reinforcement, as well as in-home deep insulation retrofits and replacement of existing wet heat delivery systems.

Next steps

Aggregated controls

Continue running aggregated controls in all 75 homes using signals to switch between both appliances, using future fuel price ratios, tariffs, frequency response services, electricity network constraints and marginal carbon intensity of the electricity grid.

Hydrogen cities

The hybrid benefit to potential hydrogen cities will also be explored.

Follow-on projects

Develop potential follow-on projects, such as deeper exploration of viable pathways to market with heat as a service and demand side response, as well as the use of different appliances and technologies that also offer fuel vector switching benefits, such as using gas heat pumps in non-domestic hybrid systems and smart hybrid heat networks.

Wales & West House, Spooner Close, Celtic Springs, Coedkernew, Newport, NP10 8FZ
Visit our website: www.wwutilities.co.uk
Follow us on Twitter @wwutilities Like us on Facebook at facebook.com/wwutilities

RECYCLED
Paper made from recycled material
FSC® C022174