Department of Energy & Climate Change

RHI Evidence Report: Gas Driven Heat Pumps

Assessment of the Market, Renewable Heat Potential, Cost, Performance and Characteristics of Non-Domestic Gas Driven Heat Pumps (GDHPs).

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Executive summary

1. Introduction

We have carried out extensive research with the Gas Driven Heat Pump (GDHP) and wider heating and energy industries in the UK and Europe, and those involved with specific installations in the UK, to understand:

- The technology and technology potential across the UK building stock
- How well GDHP actually perform in-situ
- Attitudes of building services professionals including specifiers and installers
- Attitudes of end-users with experience of GDHP on their sites
- The reasons why GDHP have and have not been installed
- The ways in which the RHI may help to drive the GDHP market

2. Characterising the market & technology outlook

The GDHP market in Europe is immature, with sales of 5-10,000 units per year. In the UK, only two GDHP products are currently available through approximately 8 sales channels. Some other products are available in limited regions from a single installer. We estimate that current annual sales in the UK are unlikely to exceed 300 units / year.

We anticipate UK GDHP sales could grow to >1,000 / year by 2020 and 3,000 / year by 2030 in our Reference Scenario (with an RHI at a low rate – see Chapter 5), and >2,000 / year in 2020 and >5,000 / year in 2030 in our High Scenario (with an RHI at a higher rate – see Chapter 5).

Current GDHP technology:

Most of the installations in Europe are Gas Absorption systems (GAbHP), but there is also a growing market for Gas Engine Heat Pumps (GEnHP):

- **Gas Absorption Heat Pumps (GAbHP)** are mainly used for commercial heating in new build and retrofit in the current market.
- **Gas Engine Heat Pumps (GEnHP)** are mainly used for commercial heating and cooling in new build and retrofit where electricity supply capacity is limited.
- **Gas Adsorption Heat Pumps (GAdHP)** are currently mainly used for domestic heating so are out of scope of this report.
- Another group of solutions for the industrial sector exist, which tend to be unpackaged and bespoke systems. There is little evidence of significant adoption of GDHP in the industrial sector in the UK.

Future GDHP technology:

We do expect development and advancement of GDHP technology, resulting in efficiency gains, cost reduction, and greater suitability for European markets[1]. But we expect this change to be evolutionary rather than revolutionary. **The rate of GDHP development will depend on commercial decisions by the industry to invest in research and development (R&D) and industrialisation of production. These decisions depend on the industry having the confidence to invest - and policy makers have a key role in creating this confidence**. Opportunities include:

- Most developments for advancing efficiency will be incremental improvements to components, controls and integration with hot water storage tanks and other energy sources.
- Some developments will have a significant impact because they will make the job of the installer, and of other buildings service professionals, easier. For example, this can include the increased ease of installation through more plug and play products, and reducing servicing and maintenance needs through extending the minimum operating hours between servicing. This will lead to a reduction in installation costs, and so reduced upfront cost to the end-user.
- There is significant scope for cost reduction from GAbHP and GAdHP through the industrialisation of production - dependant on the technology making the leap from 1,000s of sales per year to 10,000s per year across Europe.
- Given the maturity of GEnHP in Asia, and the volumes at which they are already sold, there is less scope for cost reduction than with GAbHP, although there is potential for savings in the hydronic system designed for the European market.
- There is significant scope for cost reduction throughout the value chain as installer margins reduce with increased customer numbers and confidence, and as supply chains are consolidated and strengthened.

In what sectors are GDHP being installed – and where is the potential?

The sectors best suited to GDHP have high demand for heating and/or hot water and cooling, and have high required running hours. End-user sectors identified as creating particularly good propositions for GDHP include **hotels and restaurants, care homes, hospitals and industry** - all due to their high needs for heating, hot water and often cooling.

The sectors where GDHP have been installed in the UK differ from those identified as having greatest potential. Schools (which have relatively low demand for heating, hot water and cooling), along with universities, are by far the biggest sector for installed GDHP. While care homes and hospitals are also amongst the top existing sectors, installations in industry are non-existent. Many other sectors are well suited to GDHP, and installations in other parts of Europe have been proven successfully in, for example, offices, public buildings and multi-family homes. In the UK, there are very few installations in such sectors but the potential is there.

GDHP can be installed in new build and retrofit, although today new build dominates in the UK. The majority of UK installations are in the new build sector to help exceed building regulations or achieve BREEAM excellent ratings. GDHP have been installed in existing buildings in small numbers to date – though they have good potential.

[1] This view is derived from our primary research – interviews with manufacturers, developers, academia and independent experts with knowledge of on-going and planned R&D projects in GDHP.

3. Renewable and carbon saving credentials

Current credentials

From our data collection, it has been difficult to gather sufficiently large comparable data sets to fully analyse variances affecting performance of different types of GDHP in different applications. **Based on the available information and our primary research, our opinion is that GDHP are capable of achieving or exceeding the minimum SPF of 1.15 required to count as renewable. However, this will be highly dependent upon effective specification, installation and maintenance & control systems** (these issues are considered further in Chapter 1).

Based on this view, off-gas GDHP (running on LPG) can give in the order of 40-45% GHG savings compared to an oil boiler. On-gas GDHP can save 25-30% over a gas boiler.

In both on-gas and off-gas grid areas, the range of savings achievable even from a relatively low performing GDHP is significant.

GDHP credentials in the future

With incremental efficiency increases in GDHP, the CO_2 saving potential of GDHP will increase over time. Even based on a relatively modest rate of efficiency increase (0.75% increase in SPF per year), the CO_2 saving potential of off-gas increases to 45-50%, and of on-gas to 35-40% compared to the counterfactuals by 2030.

The GHG saving potential of GDHP compared to electric HP will decrease over time as the electricity grid decarbonises. However, there is still a significant window of opportunity, and **we believe that GDHP represent an attractive – and potentially lower cost - option for decarbonising a challenging sector**. Particularly in on-gas grid areas, electric HP struggle to compete on economics, and in both on and off-gas grid areas, limitations on the electricity grid can mean electric heat pumps are difficult and/or require costly grid upgrades.

4. Market drivers and barriers to deployment

One of the most important factors which will drive sustainable growth of the GDHP market (leading to the GDHP market being able to grow without incentives) is the GDHP industry having the confidence to invest in R&D, developing supply chains and marketing and awareness-raising for their GDHP. This confidence will come as a result of specific drivers becoming stronger, and specific barriers being overcome.

We highlight below the major market drivers, where ‘critical’ drivers are blue and influential drivers are white:

Driver	Importance in new build	Importance in retrofit
Limitations of electricity grid & excessive cost of grid upgrade driving gas as alternative	■	■
Meeting or exceeding building regulations	■	n/a
Achieving running cost savings	□	■
Recommendation from trusted building services professional or brand	■	■
Capturing available grants or incentive schemes	□	□
Promoting green credentials	□	□
Avoiding the need for two separate systems for heating / cooling	□	□
Availability of (local) after-sales support	□	□

We highlight the major market barriers, and how the RHI can help to overcome them:

Barrier	How RHI will help	
Lack of confidence from the industry to invest in developing the supply chain for GDHP	□	**Indirectly through sending a signal to the industry** that the government is committed to supporting the technology
Lack of awareness and/or in some cases poor perception of GDHP technology due to lack of information (and previous bad experiences)	□	Indirectly if combined with information dissemination & awareness-raising
Limited sales channels and routes to market create challenges for accessing the technology	□	Indirectly through building industry confidence to invest
Policy framework - this does not currently set a framework which places GDHP on a level playing field.	■	Directly
Specification - GDHP are not getting through the specification process so are not available as a choice	□	Indirectly if combined with information dissemination & awareness-raising – particularly targeted at specifiers
Upfront cost of technology	▨	Indirectly – especially if it allows 3rd party ownership

5. Conclusions

Our research indicates that government intervention is necessary in order to stimulate the GDHP market, and in order to reach a high growth scenario. There have been many challenges with this work, due to a lack of available data for GDHP performance, and patchy data on the UK commercial building stock. However, based on the completed research[2], **it is reasonable to conclude that GDHP are capable of exceeding the minimum 1.15 SPF**

[2] Consisting of analysis of the available field and test data, supplemented with expert opinion informed by a large number of interviews across the industry and end-users in the UK and the wider industry in Europe.

threshold required to be considered renewable, and that GDHP can contribute significantly to meeting UK emissions targets by making carbon savings relative to gas and oil boilers. Some market growth can occur without an RHI through marketing and awareness-raising, and some slow improvements to the economic proposition coming from the industry alone. In the short-term, an RHI will improve the economic proposition. In the longer term – and most critically – the RHI will give the industry the confidence to invest in developing the supply chain, and in R&D which will lead to efficiency increases and cost-reduction, setting the GDHP industry on course to being a sustainable industry without support:

- **The RHI must come hand in hand with a marketing & awareness-raising campaign** which reaches across the value chain.
- **Special attention should be paid to the building services professionals responsible for specifying** new heating/cooling systems in commercial buildings. This is the critical point in the value chain where a decision for a GDHP could be made - but in most cases is not.
- **The RHI design should ensure the possibility exists for 3rd party ownership** of renewable systems – to allow for alternative business models which can reduce upfront costs.

Limited available field data for GDHP has been a challenge for this project. Due to the lack of available comparable performance data, DECC may wish to consider carrying out or supporting a GDHP field trial in the UK in order to better understand in situ performance. It should also be considered to require performance monitoring with any RHI for GDHP, due to the extreme lack of available performance data in the UK.

Based on our research and data collection from the limited available data, and based on qualitative responses from industry experts, **it is the opinion of the research team that GDHP can achieve - and in some cases significantly exceed - the 1.15 SPF necessary to count as being renewable** (however, it is impossible to accurately determine the actual in-situ performance of GEnHP linked to Variable Refrigerant Flow (VRF[3]) systems which provide simultaneous heating and cooling).

There are significant risks that a GDHP RHI could result in perverse outcomes and/or gaming. In particular, there are risks associated with the specification of GDHP to achieve Part L compliance in a building which only achieves the minimum Fabric Energy Efficiency Standard (resulting in higher lifetime carbon emissions). Also, an RHI could incentivise the installation of GDHP as a subsidised way of avoiding electrical network reinforcement.

The industrial sector indicates significant potential, but may have to be considered separately to the commercial sector. In the industrial sector, the possible definitional constraints associated with Directive 2009/28/EC suggests that an alternative support mechanism might be more appropriate than the RHI.

[3] VRF provides an integrated approach to heating and cooling in medium to large buildings. The approach utilises waste heat produced by indoor units operating in a cooling mode to transfer heat to zones where heating is required. Heating & cooling is provided by utilising the same refrigerant within a sealed system.

Note regarding research methods and biased opinion

The majority of this report is based on primary research, made up mostly of interviews across the industry (including manufacturers, distributors, installers, specifiers, contractors, utilities and end-users). DECC has asked that we explain the extent to which we have experienced biased opinion from interviewees (e.g. over-estimating performance). We have managed the risk of receiving significantly biased opinion by 'sense-checking' all of our assumptions against as wide a range of experts as possible (including those with no reason to be biased, such as in academia). In any situation where we have suspected any bias, we have adjusted assumptions according to the wider opinion of all our interviewees.

1. Characterising Current Gas Driven Heat Pump Market

Key Messages

- **The Gas Driven Heat Pump (GDHP) market in Europe is immature**, with sales of 5-10,000 units per year.
- **In the UK, only non-domestic GDHP products are available through approximately 8 sales channels**. Some other products are available in limited regions from a single installer. Annual sales in the UK are not thought to exceed 300 units / year.
- **Most of the installations in Europe are Gas Absorption systems (GAbHPs), but there is also a growing market for Gas Engine Heat Pumps (GEnHPs),** which are well established in Asia. Gas Adsorption Heat Pumps (GAdHPs) are also emerging in Europe.
- **Gas Engine Heat Pumps** are mainly used for commercial heating and cooling in new build and retrofit where electricity supply capacity is limited. The GEnHPs are generally linked to a Variable Refrigerant Flow (VRF) system and / or Air Handling Units (AHUs) for distribution of heating & cooling (often also utilising heat recovery from the engine for hot water production). 800,000 GEnHPs are installed in Asia, but have only more recently come to Europe, where there is limited product availability and under-developed sales channels. The high level of market penetration of GDHPs in Japan is largely a consequence of very high maximum demand charges for electricity during the summer for cooling purposes (caused by an overloaded electricity network). This has resulted in many organisations installing gas fired air conditioning systems which provide operational cost savings and/or avoid exceeding maximum demand limits (i.e. the GDHPs are not generally installed for energy saving reasons, and are more for cooling). Approximately 1200 to 1500 GEnHPs have been installed in the UK since 2003.
- **Gas Absorption Heat Pumps** are mainly used for commercial heating in new build and retrofit in the current market. Within the next 1-2 years products will also emerge for domestic heating applications. The GAbHP concept is mature, and there is strong development from within Europe and growing sales, but still limited product availability.
- **Gas Adsorption Heat Pumps** are currently mainly used for domestic heating in the new build sector and there is little evidence of the technology being developed for the commercial sector – therefore they are not considered in detail in this report.
- **Gas Engine Heat Pumps and Gas Absorption Heat Pumps are both capable of providing heating, cooling and hot water**, but their design histories mean that the relative efficiencies vary:
  - GEnHPs have better cooling efficiencies than GAbHPs

- GAbHPs can generally produce hot water as standard whereas GEnHPs usually require an add-on hydronic module
- GEnHPs connected to VRF systems are capable of providing simultaneous heating and cooling (e.g. where one part of a building may require heating and another part cooling). At times when only heating is required the unit operates as a conventional air source heat pump but with heat distribution to terminal (cassette) units being via a refrigerant.

- It is important to recognise that **from an RHI perspective measuring the effective heat output of GEnHP VRF systems is particularly problematic**, since although the gas consumption of the engine can be readily measured, the proportion of gas used for heating and/or cooling cannot be determined (unless the system is designed to operate in a heating only mode)
- Upfront costs per kW for standard GEnHP and GAbHPs are comparable – but operation **and maintenance costs are higher for GEnHP.**
- **Another group of solutions for the industrial sector exist**, which tend to be unpackaged and bespoke systems. Market penetration in Europe is very low and there is no known activity in the UK, though the potential is high. Industrial heat pumps are a relatively mature technology. However, **there is little evidence of significant adoption of GDHPs in the industrial sector in the UK**. NB: The definition of renewable energy sources adopted in the EU Renewable Energy Sources (RES) Directive may prohibit the introduction of an RHI for most industrial applications (e.g. waste heat driven systems).

Introduction to GDHP Technology & Market

The Gas Driven Heat Pump (GDHP) market in Europe is predominantly made up of three solution types - Gas Engine Heat Pumps (GEnHP), Gas Absorption heat Pumps (GAbHP) and Gas Adsorption Heat Pumps (GAdHP). We also refer to industrial scale heat pumps - which tend to be bespoke unpackaged systems - although these have relatively limited market uptake.

Characterising current types of GDHP in (predominantly) the commercial sector

In the table below, we characterise for each of the three GDHP types:

	GEnHP	**GAbHP**	**GAdHP**
Technology characteristics	Can use low temperature heat source (ambient air) Predominantly VRF air/air systems, but air/water emerging (usually requiring add-on hydrobox) Can produce high flow temperatures (but hydronic system not standard solution) Option to recover heat from engine for additional hot/cooled water needs	Can use low temperature heat source (ambient air) Most commonly hydronic systems (brine/water and air/water) but can also be air/air or water/water. Solar thermal integration possible. Can produce high flow temperatures (>60 °C)	Current products require high temperature heat source (solar thermal / ground-loops) Products on market are hydronic systems (ground/water or solar thermal) Current products designed for flow temperature of <45 °C.

	GEnHP	GAbHP	GAdHP
Capacity range (heating)	~20 – 100s of kW (installed as modular units)	~30 - 100s of kW (installed as modular units))	<10 kW
Performance range *(for existing products based on manufacturer material, measured in LHV – NOT FINAL DATA)*	Heating: 120-160% Cooling: 120-140% NB: hot water usually requires add-on	Heating: 120-160% Cooling: <100% NB: hot water usually standard	Heating: 120-140% Cooling: n/a NB: hot water usually standard
Installation / maintenance	Requires annual safety check & oil change.. Major overhaul/service every 10-20,000 running hours. Installation by refrigeration engineer plus Gas Safe registered engineer.	Annual gas safety checks but little other maintenance requirements Installation by Gas Safe registered engineer/ boiler installer with manufacturer training	No moving parts so very limited maintenance Installation by Gas Safe registered engineer/ boiler installer
Applications	Typically designed as air-based systems for heating/cooling, usually requiring add-on for hot water production. Traditionally more cooling than heating-led, but can be both - heating led more common in Europe	Typically designed for hydronic heat distribution (radiators) European products generally heating-led but can be both	Typically designed for hydronic heat distribution (underfloor / fan coils) Current products generally heating-led
Operating parameters	Relatively wide due to low temperature heat source requirement & high flow temperature achievable (if using heat recovery for hot water)	Relatively wide due to low temperature heat source requirement & high flow temperature achievable	Current products relatively limited due to high temperature heat source requirement & relatively low flow temperature system designed for (there is scope for new adsorption products to widen this though)

	GEnHP	GAbHP	GAdHP
System topologies	Can be installed alone as single units or up to 10s as modular units Hydronic modules and additional hot water tanks can be added to enable hot water production Can be installed combined with back-up gas boiler	Can be installed alone as single units or up to 10s as modular of units Can be integrated with solar thermal system Can be installed for air or ground source Can be installed combined with back-up gas boiler & hot water tanks (usually the case in cascade systems) and/or chillers	Usually installed alone as single unit – modular configuration may be technically possible Systems currently on market designed for use with solar thermal or ground-loops as heat source – generally requiring separate hot water tank
End-user sectors where currently installed	Wide range of commercial building and a limited number of industrial applications	Predominantly commercial e.g. schools, offices, hotels, multi-family homes	Single-family homes (currently out of scope)
Level of commercialisation (all numbers here are a Delta-ee view based on interviews with industry experts in the UK and Europe – including manufacturers, utilities and independent research institutes).	Mature product with around 800,000 installed in total and 10,000s installed per year in Japan. Just 100s / year installed in Europe from 4-6 manufacturers.	10s of 1,000s installed in Europe (GasTerra's GDHP book suggests as high as 45,000, though the biggest manufacturer has installed 10,000 so the sources of the other sales need to be clarified). Annual sales in the range of low 1,000s per year.	Residential scale version available since 2010 but only 2-3 products commercially available in Europe, predominantly in Germany, with low 100s installed in total. No commercial-scale products currently available.
Importance in UK	Limited sales channels in UK, with most active sales channels for Panasonic GEnHP (formerly Sanyo). Total installed numbers unlikely to exceed 200.	Low 100s GAbHPs installed in UK, all from Robur - via own sales channels (4 distributors), and via BDR Thermea (Baxi) and Bosch (packaged with Baxi/Bosch own gas burner and controls)	Currently not sold in the UK

Table 1: Summary of GDHP product and availability in the UK - commercial sector

Source: Delta-ee Primary Research – interviews with a range of industry experts in the UK and Europe

Types of heat pump by heat source

Whether gas driven or electric, heat pumps can be categorised in terms of the heat source (e.g. they capture heat from the air, from the ground, or from water), and the heat delivery method in the building (air or water).

Air-source heat pumps can be differentiated by the delivery method:

- An air source heat pump with a water heat delivery method can be described as an ‘air to water’ heat pump, often abbreviated air/water.
- An air-source heat pump with an air based heat distribution system can be described as an air to air heat pump (air/air).

Ground source heat pumps can be differentiated by the way that they capture heat from the ground, which is determined by the fluid which circulates within the system (brine or groundwater):

- **Brine/water** heat pumps are typically “closed loop” systems where *brine* (a mix of water and antifreeze) is continuously circulated through a closed loop between the ground and the heat pump. This is the typical type of “ground-source” heat pump found in the UK, for both electric and gas-driven heat pumps.
- **Water/water** heat pumps usually use “open loop” collectors, where *groundwater* is circulated through the pipes, via the heat pump, and discharged back to the source[4].

Gas engine heat pumps are typically air/air (a/a) or air/water (a/w) i.e. the heat source is always air, heat distribution can be air-based or hydronic.

Gas absorption heat pumps are typically air/water (a/w) or brine/water (b/w), and sometimes water/water (w/w) i.e. the heat source can be air, or ground (with brine or water systems), and the heat distribution is mostly hydronic.

It is also possible to integrate **solar thermal** with gas driven heat pumps – typically where there is hydronic heat distribution:

- In the case of some gas adsorption heat pumps (excluded from this study because they are only available on a domestic scale at present), the solar thermal is acting as the primary heat source, and the system could therefore be considered “solar-source”.
- But in most cases with commercial scale gas driven heat pumps, solar thermal is an add-on which provides a secondary heat source to a system already using air or ground loops as the primary heat source. The solar thermal is typically integrated in a simple way via the hot water tank.
- It is conceivable in the future than more products will emerge where solar thermal is more integrated and acting more as a primary heat source. There is a lot of work on solar-based cooling using sorption cycles, which is out of scope of this study.

[4] Water/water heat pumps can also use surface water from e.g. a lake as a heat source – in which case they are categorised as “water-source” heat pumps. Water-source heat pumps are very uncommon in the UK, and there are no known installations of a water-source gas heat pump (so where we refer to w/w GDHP in this report we refer to the groundwater type, which is ground-source).

Heat pumps in the industrial sector

Technology characteristics:

- Closed-Cycle Mechanical Heat Pumps: Conventional closed-cycle heat pump utilising a compressor and refrigerant working fluid. The compressor can be driven by any mechanical drive, including; electric motor, gas reciprocating engine, gas or steam turbine etc.
- Open-Cycle Mechanical Vapour Compression (MVC) Heat Pumps (NB: out of scope with this review): a mechanical compressor (typically a Root's Blower) is used to increase the pressure of waste vapour. The working fluid is generally water vapour. MVC heat pumps are considered to be open cycle because the working fluid is a process stream. Most common mechanical drives are utilised for MVC heat-pumps, including electric motors, steam turbines, gas or diesel engines, and gas turbines. Often used in distilling, process concentration, solvent recovery etc.
- Open-Cycle Thermocompression Heat Pumps: Utilises the energy in high-pressure motive steam to increase the pressure of waste vapor using a jet-ejector device. Typically used in evaporators, the working fluid is steam. As with the MVC Heat Pumps, thermocompression heat pumps are open cycle and are out of scope with this review (NB: in-scope systems are; ground source, to water; air to air and air to water and solar thermal, to water).
- Waste heat driven closed-cycle absorption & adsorption heat pumps

Applications & benefits:

A review of industrial heat pumps undertaken by the International Energy Agency Heat Pump Programme (Annex 21)[5] established that when compared with heat pumps installed in domestic and non-domestic buildings, industrial heat pumps can, in many cases, provide a number of advantages, including:

- High COPs, as a consequence of small temperature lifts (i.e. the difference between evaporator & condenser temperature in many industrial applications is small)
- Extended hours of operation (typically over 5000/year)
- Excellent Return on Investment
- Heat source and heat sink often occur simultaneously avoiding the need for buffer storage of heat

Appendix B provides a summary of the key industrial processes and relevant heat pump types

Level of commercialisation

Despite these potential benefits, the number of industrial heat pumps installed to-date remains very low compared with the number of technically and economically viable opportunities (see Appendix B). Industrial heat pumps have been implemented in only a very limited number of applications (e.g. timber drying, maltings, food processing, chemical and pulp & paper evaporation and for distillation).

The IEA Annex 21 report "Industrial Heat Pumps" identified the following as the key reasons of poor heat pump adoption by industry:

- Lack of knowledge of the potential processing benefits
- Lack of experience or familiarity with industrial heat pump technology
- Lack of combined process integration and heat pump technology experience or knowledge

[5] Industrial Heat Pumps Experiences, Potential and Global Environmental Benefits. IEA HPP Annex 21 April 1995 Report No. HPP-AN21-1

The report noted that "some early industrial heat pump installations were poorly designed, installed and/or operated and these have created some negative perceptions about the technology and its potential benefits".

Although the GDHP RHI review identified a number of conventional heat pumps operational at UK industrial sites, no gas driven systems were located.

Large bespoke systems, engineered from discrete components (i.e. gas engine, compressor, heat exchangers etc.) have been trialled (most notably in the 1980s) but with limited success (see Section 4 Market Drivers & Barriers for further details).

Large bespoke systems are utilized in the process sector, however, these are out-of-scope with this study, since they either utilize waste heat and/or are open cycle systems.

Sector specific industrial heat pump applications are discussed in Chapter 3.

GDHP Products Available in Europe / Globally

We provide an introduction to the main GDHP products currently on the market for commercial applications, and those under development which may be on market by 2020, in Appendix E. We consider GEnHP and GAbHP but not GAdHP because there are no products of commercial scale today – nor any expected to be available in the next 2-3 years given the lack of current R&D activity. We provide full details of available products in Appendix E. A summary is provided here:

- The only GAbHP available in the UK is from Robur
- Climatewell and E-Sorp may have some GAbHP products available in the UK (either themselves or through a partner) in the longer term (but on a post-3 year timescale)..
- Panasonic is the only GEnHP available directly in the UK (i.e. from Panasonic UK).
- Aisin has a single installer in the UK through which a GEnHP can be sourced.
- Mitsubishi Heavy Industries have some legacy GEnHP installations but no longer have UK sales channels
- Yanmar and Tedom both manufacture GEnHPs but are not available in the UK to date (they may be within 3 years).

We present some further product information for the three selected key products which have currently the most availability in the UK, including efficiency, performance, capacity, and cost can be found in AppendixH.

- Robur
- Panasonic
- Aisin

GDHP Current Performance

It is critical for DECC to understand the realistic range of performances achieved by GDHP in the field, because the performance determines the renewable contribution which GDHP can make to meeting targets. We summarise here the range of performances expected based on quantitative data, and in addition, some qualitative information from interviews with end-users, to add colour to this picture of in situ performance.

Quantitative performance data

The purpose of the data collection and aggregated data set (summarised in Appendix D) is to provide a clearer and more comparable picture of how GDHPs perform and how this performance varies with factors such as GDHP type, system boundaries, applications, demand patterns, end-users and climate. This is not straightforward given that there is a range of sources of information which use a variety of methodologies, and a variety of ways of recording performance (e.g. gas utilisation efficiency (GUE), primary energy ratio (PER), using higher heating value (HHV) or lower heating value (LHV)). The 4 main data points that have been used in the analysis of GAbHP performance data have come from installations in France, Germany and Italy. There is uncertainty related to translating these results directly to the UK. Given that two of the data points were in areas with more severe winter conditions than most of the UK (in Germany and Northern Italy), there is a possibility that GDHPs in the UK would in fact perform better than they do in the places where the field tests were carried out.

As explained in Appendix D, the data collected had many gaps, uncertainties, and other characteristics making meaningful comparison very difficult. Based on the data we have seen combined with our existing knowledge and conversations, our opinion is that GDHP clearly can meet the minimum 1.15 SPF required to be counted as renewable according to the RES Directive. In many cases we believe GDHP can significantly exceed 1.15.

Qualitative

End-users are generally not able to provide us with detailed performance data, and rarely know all the details of the installations which are necessary to make realistic comparisons of performance. It is important to note that it is not possible to determine the SPF of GEnHp's in the field if connected to a VRF system (since the proportion of heating, cooling & heat recovery provided cannot be determined). What is critical to the end-user is essentially that the GDHP lowers the energy bill, and does not break down. While this evidence does not help to provide clear evidence of the renewable credentials of GDHP, our conversations indicate that end-users who do have GDHP are satisfied, and do not feel "cheated" by false performance claims.

Highlights of quotes from interviews:

"The Gas Engine Heat Pump is reliable – it's just like a car engine"

"The Gas Heat Pump is brilliant"

"We do not know the exact SPF but we know it is good because our energy bills are lower"

"I don't need to monitor it as long as it works, that's all that matters – and it has worked so far"

"We know GDHPs work so we don't need to test them further – there are 1,000s installed in Europe. The technology has already proven itself"

GDHP Current Costs

We present the approximate break-down of costs based on data we were able to collect from industry professions in the UK (supplemented with some additional information from Europe). This data feeds into our payback modelling as part of the upfront and on-going running costs (i.e. including technology cost, system costs, installation costs, auxiliaries costs, and servicing and maintenance costs). Cost data is very sensitive data to companies so we have based this on only a limited data set. Further, a significant amount of information gathered from end-users is difficult to use because end-users are unable to give details on what the costs are for (e.g. gas consumption and/or maintenance cost / unit or per system?). We have focused as far as possible on prices in the UK.

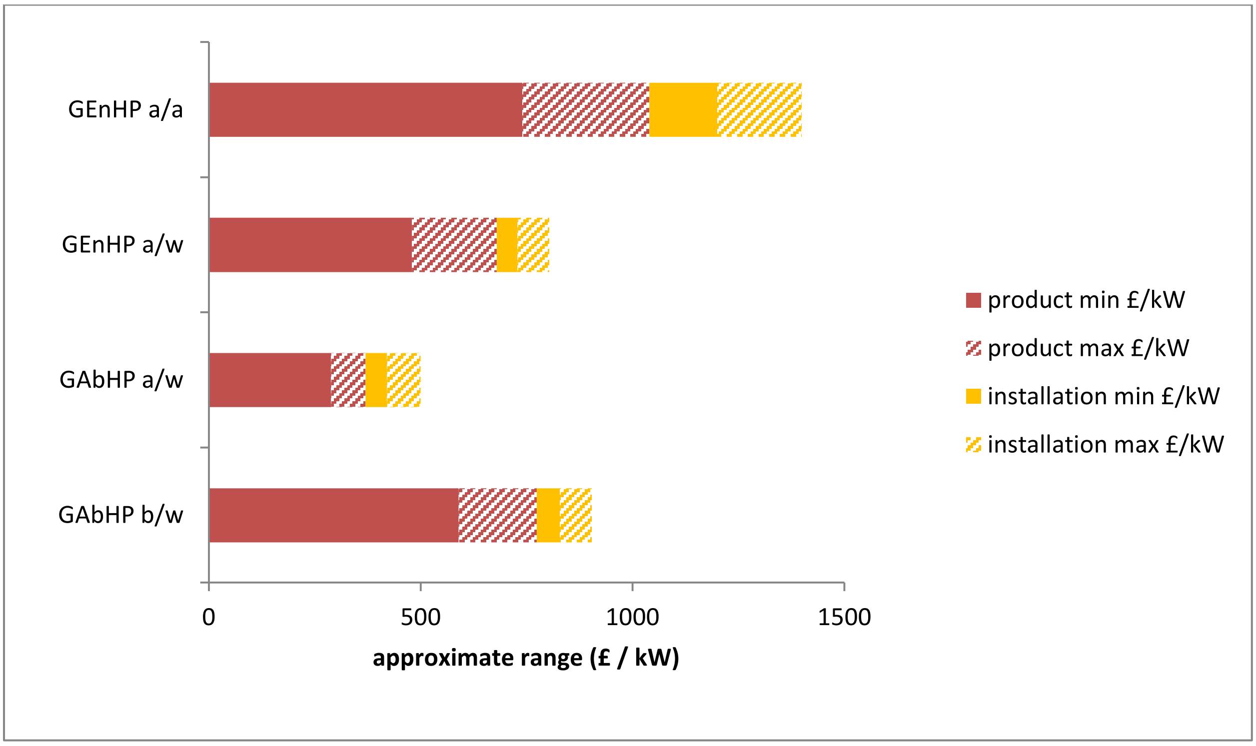

Figure 1: Approximate price break-downs for GEnHP a/w, a/a and GAbHP a/w, b/w

Source: Delta-ee primary research with installers, distributors and end-users in the UK, with some supplementary information from Europe, as presented in the Aggregated Data files. GAbHP w/w is not included in this figure because no data was available for the UK – and we are not aware of any w/w installations in the UK.

Observations on cost data:

- GDHP fully installed costs in the UK lie in the range of £350-£1400 / kW, with GEnHP (a/a) in the UK generally at the higher end of the cost range and GAbHP (a/w) at the lower end. This is mainly due to the relatively high costs for the installation of the heat distribution system, which for multi-split a/a heat pumps is an integral part of the HP system and has therefore been considered in the capital expenditure of this system type. (NB: The costs for the installation of a wet heat distribution system have not been considered for GAbHPs and a/w GEnHPs)
- When comparing the costs of GEnHPs (a/w), which consist of the outdoor unit and a supplementary heat exchanger, to only the outdoor units of GEnHPs (a/a), the a/a systems are less expensive. The price premium for an a/w system compared to an a/a outdoor unit is approximately 30% in absolute numbers. When comparing the relative costs per kW of these two types, this rises to approximately 30-45%, as GEnHPs (a/w) have slightly lower capacities than GEnHPs (a/a).
- GAbHP (b/w) are expected to be higher cost than GAbHP (a/w), due to the cost of borehole heat exchangers, which can more than double the product cost.
- Maintenance costs are more significant for GEnHP than for GAbHP.
- For GAbHP our research indicates that maintenance costs are in the range of £7-10 per kW per year (figure derived from interviews across the industry suggesting maintenance costs of £250-350 / year for a single unit).

- For GEnHP, the maintenance cost is dependent on the time interval between required services. Based on 10,000 running hours – which users indicated equated to every 2-3 years – the costs are expected to be in the order of £1,500 per service or £30-100 per kW per year depending on the system capacity.

GDHP Current Renewable Credentials

Do GDHP count as renewable under RES Directive?

Below we present the relevant parts of the EU-law which determines the required criteria that GDHPs have to meet in order to be considered as renewable. The calculation methodology for how much renewable energy they actually produce is in the RES-Directive, Annex VII, complemented by the European Commission's Decision on calculating renewable energy from heat pumps.

RES-Directive:

The official identifier of this document is 2009/28/EC it has been published in the EC OJ L 140/16-62. The document in the Annex is the latest consolidated version, as accessed on 14 May 2014 (EUR-Lex Document 02009L0028-20130701).

The relevant parts are article 5(4) and Annex VII.

COM Decision on calculating RE from HPs:

The official identifier of this document is 2013/114/EU, it has been published in the EU OJ L 62/27-35.

The most important part is article 3.3.The key text reads:

> 3.3. **Minimum performance of heat pumps to be considered as renewable energy under the Directive**
>
> In accordance with Annex VII to the Directive, Member States shall ensure that only heat-pumps with a SPF above 1.15 * 1/η are taken into account.
>
> […]
>
> For heat pumps that are driven by thermal energy (either directly, or through the combustion of fuels), the power system efficiency (η) is equal to 1. For such heat pumps the minimum SPF (SPER net) is 1.15 for the purposes of being considered as renewable energy under the Directive.
>
> […]

The document also provides default values which are to be used when sufficient datasets allowing Member States to define their own improved estimates are unavailable. For GDHPs the default values to be used are to be found in the Annex of the Commission's Decision, Table 2, as cited below:

Table 2

Default values for H_{HP} and SPF ($SPER_{net}$) for heat pumps driven by thermal energy

		Climate conditions					
		Warmer climate		Average climate		Colder climate	
Heat Pump Energy source:	Energy source and distribution medium	H_{HP}	SPF ($SPER_{net}$)	H_{HP}	SPF ($SPER_{net}$)	H_{HP}	SPF ($SPER_{net}$)
Aerothermal energy	Air-Air	1 200	1,2	1 770	1,2	1 970	1,15
	Air-Water	1 170	1,2	1 640	1,2	1 710	1,15
	Air-Air (reversible)	480	1,2	710	1,2	1 970	1,15
	Air-Water (reversible)	470	1,2	660	1,2	1 710	1,15
	Exhaust Air-Air	760	1,2	660	1,2	600	1,15
	Exhaust Air-Water	760	1,2	660	1,2	600	1,15
Geothermal energy	Ground-Air	1 340	1,4	2 070	1,4	2 470	1,4
	Ground-Water	1 340	1,6	2 070	1,6	2 470	1,6
Hydrothermal heat	Water-Air	1 340	1,4	2 070	1,4	2 470	1,4
	Water-Water	1 340	1,6	2 070	1,6	2 470	1,6

The default values set out in Tables 1 and 2 above are typical for the segment of heat pumps with a SPF above the minimum threshold, meaning that heat pumps with SPF below 2,5 have not been taken into consideration when the typical values have been established ([6]).

Given the current lack of data in general and the lack of data from the UK in particular, we consider it at the current stage impossible to use other values than the defaults, as "… improved estimations […] should be based on accurate assumptions, representative samples of sufficient size, resulting in a significantly improved estimate of renewable energy from heat pumps" (Annex, Article 3.12).

GDHPs are also included in the EU's Eco-Label. The ecological criteria which GDHPs have to meet in order to be awarded with the Eco-Label can be found in the Commission Decision 2007/742/EC

Which standards exist for GDHPs?

There is currently only a European standard for GAbHPs and GAdHPs, EN 12309, which is currently being overhauled (publication is expected later in 2014). The standard has been significantly enlarged compared to its original version from 2000. It now not only covers the measurement of rated efficiencies at static set points, but also includes a calculation methodology for assessing the seasonal primary energy ratio (SPER) of the systems.

On European Level there is currently no standard for GEnHPs available. Working Group 3 of the Technical Committee 299 of the European Committee for Standardization (CEN/TC 299/WG 3 – Gas-fired endothermic engine heat pumps) is currently working on a standard for these systems, but the publication date is currently unclear.

On an international level there is the Japanese standard JIS B8627:2006, but this standard only refers to air-to-air gas engine heat pumps. Air-to-water GEnHPs currently do not have their own European or international standard.

Do current products reach this 1.15 – and what are the implications for CO_2 savings?

The outcomes of our data collection indicates that, where GDHP are specified, installed, maintained and controlled correctly, they can certainly reach an SPF of 1.15 – and can significantly exceed this level in most cases. The data we have collected is not complete enough in order to draw meaningful conclusions as to how much the specific SPF levels vary with different types of GDHP (GAbHP or GEnHP), or in different sectors (new build / retrofit). Further details are in Appendix D.

Based on the data collection, our existing knowledge and extensive primary research within this project, we estimate the performance range for GDHPs properly installed and specified to be between an SPF of 1.15 and 1.58. The lower range of SPFs may be expected in the more challenging retrofit sector, while in new build the SPF may be higher. However, **it should be noted that where GDHPs have not been installed according to manufacturer specifications, or where installation has not been completed correctly, GDHPs may perform significantly below the 1.15 level, particularly if loads are intermittent and/or seasonal.** An example of this is at the site of a GDHP installed by a UK utility on one of its own sites. The site had very low heat demand and was recognised as sub-optimal for a GDHP of the available capacity. The installation was completed purely as a proof of concept and not as an economic or carbon saving exercise. The utility is confident that the GDHP would perform well if heat demands were sufficient. Similar experiences can be found when looking more widely across installations of electric heat pumps – all heat pumps' performances are very sensitive (more so than standard boilers) to factors such as accurate sizing and installation practice.

Based on the range of figures derived from our research for properly installed / specified systems, we calculate the GHG saving potential in the on-gas and off-gas grid sectors for GDHP running on natural gas (replacing Gas Condensing Boilers - GCB) and GDHP running on LPG (replacing oil boilers).

As can be seen in Figure 2, based on the current modelling, off-gas GDHP can save in the order of 40-45% GHG emissions compared to an oil boiler. On-gas GDHP can save 25-30% over a gas condensing boiler (GCB).

In both on and off-gas grid areas, the range of savings achievable even from a relatively low performing GDHP is significant.

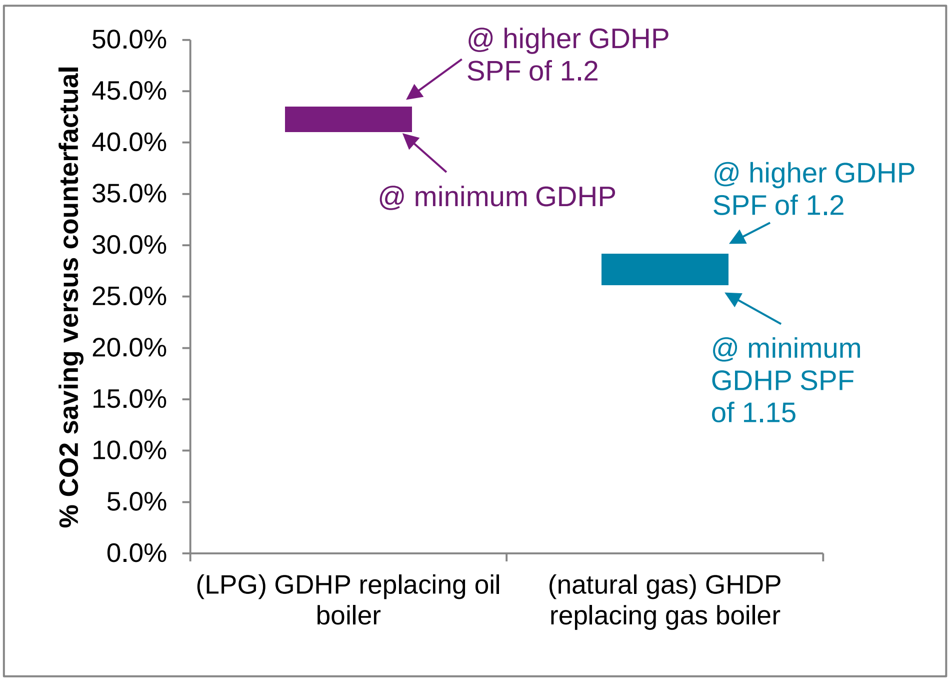

Figure 2: CO2 saving potential of GDHP

Source: Delta-ee modelling, primary research, and DECC (for carbon intensity figures). This is based on a carbon factor of 0.1841 for natural gas (kgCO2e/kWh), of 0.2688 for oil and of 0.2145 for LPG. It is based on annual efficiencies of 0.85 for oil or gas boilers and a range from 1.15 to 1.2 for GDHP (the same range for LPG or natural gas).

2. GDHP Technology Outlook

Key Messages

- Based on our research[6], we do expect development and advancement of GDHP technology, resulting in efficiency gains, cost reduction, and greater suitability for European markets. But we expect this change to be evolutionary rather than revolutionary.
- The technical potential for advancement of GDHPs is large, but will depend on commercial decisions by the industry to invest in R&D and industrialisation of production. These decisions depend on the industry having the confidence to invest - which policy makers have a role in creating.
- We see some potential for new design concepts emerging between now and 2020 which will widen the suitability for European and UK markets (e.g. the evolution of GEnHPs with water based distribution, scaling down of GAbHPs to <20 kW).
- Most developments advancing efficiency will be incremental improvements to components, controls and integration with water tanks and other energy sources.
- Some developments will have a significant impact because they will make the installer (and other buildings service professional)'s job easier. For example, increased ease of installation through more plug and play products, and reducing servicing and maintenance needs through extending the minimum operating hours between servicing.
- There is significant scope for cost reduction from GAbHPs and GAdHPs through industrialisation of the production - dependant on the technology making the leap from 1,000s per year to 10s of 1,000s per year across Europe.
- Given the maturity of GEnHPs in Asia, and the volumes at which they are already sold, there is less scope for cost reduction here, although savings are possible in the hydronic systems preferred in European applications.
- There is significant scope for cost reduction throughout the value chain as installers margins reduce with increased customers and confidence, and as supply chains are consolidated and strengthened. This is particularly challenging in the UK where sales channels are so under developed. This, in combination with the reduced product cost, will ultimately result in a lower installed cost to the customer. Upfront cost is one of the strongest barriers to GDHP deployment, so this potential for cost reduction is good news.

[6] Assertion based on interviews with manufacturers, academia, utilities and industry experts regarding existing & planned R&D projects.

Technology outlook for each GDHP type

Summary

In the table below we focus on the three main technologies within scope - GEnHP, GAbHP and GAdHP, and discuss the main technology developments expected towards 2020.

Development	Gas Engine HP	Gas Absorption	Gas Adsorption
Design concepts	GEnHP a mature technology, with general consensus amongst manufacturers on design concepts - so unlikely to be significant conceptual developments. Key developments may include: Trigeneration systems - incorporating power generation More solutions with integrated hydrobox for air/water solutions (most existing products require “add-on” hydrobox) More compact dimensions More products offering 3-pipe systems for simultaneous heating and cooling	GAbHP a relatively mature technology though there is still scope for efficiency gains and likely to be further design concept consolidation (though more evolution than revolution): Scaling down of larger system to smaller version <20 kW. More compact dimensions Advancements in control system for integration with boiler / other energy sources Reduction of noise emissions “Combi” GAbHP without need for hot water tanks (technically possible – and would have significant benefits in space reduction - though no work on this at present)	GAdHP is immature with significant scope for consolidation of design and optimisation of system. Widening operating parameters to use lower temperature heat source e.g. air Scaling up to >10 kW a possibility, but unlikely to see commercial products by 2020 given lack of activity today.
Efficiency	Incremental efficiency increases via: Advanced compressors and other components, and advanced control systems (e.g. enabling more efficient integration with boilers, chillers) Improvements in part load operation Optimising integration with hydronic system	Incremental efficiency increases via: Advanced control, optimised components Improvements in part load operation	Incremental efficiency increases via advanced control and optimised components. More significant increase in (seasonal) efficiencies achievable if new working pairs can be found which enable higher flow temperatures or use of lower heat source temperatures. Current work on ammonia – carbon which can widen operating parameters (restrictions are capital cost and size rather than technology). Ammonia / salt advanced cycles offer significantly higher COPs (>2[7]) but need proving in lab. Definitely not available 2020 although could be proven in 2 or 3 years

[7] According to academic expert in GDHP development

Installation & maintenance	Increased running hours between required servicing intervals (from ~10,000 hours to >30,000 hours)	More 'plug & play' systems e.g. easier to connect with boiler, solar thermal or other source. Use of alternative working fluids which could be perceived as safer than the generally used ammonia and suitable for indoor installation (e.g. on-going work on ethyl alcohol)	More 'plug & play' concepts
Noise	Potential for limited reduction in noise because the product is already mature and there is a limit to how much noise reduction can come from a gas engine.	Currently an area of some on-going research around e.g. reducing noise from fans and pumps. But incremental rather than revolutionary improvements expected.	Already very quiet because there are no moving parts, so limited scope for improvement
Product Cost	Little scope for cost reduction because GEnHP already mass produced for Asian market selling 10s of 1,000s per year.	Large scope for cost reduction through economies of scale (shift from low 1,000s to 10s of 1,000s per year), which would enable e.g. sourcing cheaper components, industrialising the production process.	Significant scope for cost reduction through economies of scale - whole market is only 100s per year.
Use with LPG/Biogas	Most can already run on LPG. No signs of development of biogas capability though no specific technical barriers.	Some can already run on LPG, though not all (there are no technical barriers). No signs of development of biogas capability though no specific technical barriers.	No product set up for use with LPG or biomass, but no technical reason why it cannot be developed.
Impact of developments	Significantly increasing running hours between servicing intervals could create strong growth - it reduces costs and reduces the scale of the challenge for manufacturers to set up servicing networks in new markets (currently a core barrier to European market growth).	Cost reduction of product and installation (via more industrialised production and more plug & play products) will be the most important technology development factor in driving the GAbHP market. Reduction in noise emissions could open opportunities in e.g. more dense urban sectors	Limited signs of adsorption systems emerging on commercial scale so will not be core market - but widening of operating parameters would create the most growth.

Table 2: Summary of anticipated technology developments to 2020

Source: Delta-ee primary research through interviews with academia, research institutes, manufacturers and other independent experts

Industrial gas driven heat pumps -Technology outlook

Industrial gas driven heat pumps are generally designed specifically for the application. The technology is mature and no major technological developments are anticipated associated with reciprocating gas engines, heat exchangers, compressors or other components. There are several research & development projects associated with micro/small scale gas turbines, which if successful could have implications for industrial gas fired systems. The majority of innovation is likely to be associated with industrial heat pumps are outside the scope of this study e.g.

open cycle vapour compression or waste heat driven systems). See Appendix B for further details.

Potential for efficiency improvements

There is scope for efficiency gains to be made over the next years to 2020 and beyond for GDHP - but the rate of improvement is dependent on the rate of increase in R&D spending by manufacturers - which is a commercial rather than technical decision. Current R&D into GDHP is orders of magnitude less than for electric HPs - there are many opportunities for incremental improvements and larger step change improvements. The factor limiting current R&D is not technical, but commercial - efficiency improvements can be made *if* the gas heat pump industry becomes much larger and attracts investment.

We present below our expectation of the efficiency advancements possible to 2030 (based on the Reference Scenario in our modelling - the explanation is in the following section).

			2014	2020	2030
GEnHP	a/a	SPF	1.30	1.34	1.41
		SPF hot water	1.00	1.03	1.08
		SEER[8]	1.20	1.24	1.30
GEnHP	a/w	SPF hi temp	1.10	1.17	1.29
		SPF lo temp	1.30	1.38	1.52
		SPF hot water	1.00	1.06	1.17
		SEER	1.20	1.27	1.41
GAbHP	a/w	SPF hi temp	1.10	1.17	1.29
		SPF lo temp	1.30	1.38	1.52
		SPF hot water	1.10	1.17	1.29
		SEER	0.55	0.58	0.64
GAbHP	b/w	SPF hi temp	1.20	1.27	1.41
		SPF lo temp	1.40	1.49	1.64
		SPF hot water	1.20	1.27	1.41
		SEER	0.50	0.53	0.59
GAbHP	w/w	SPF hi temp	1.20	1.27	1.41
		SPF lo temp	1.40	1.49	1.64
		SPF hot water	1.20	1.27	1.41
		SEER	0.50	0.53	0.59

Table 3: Advancements in efficiency anticipated by 2020 and 2030 for each type of GDHP (all recorded in HHV) – REFERENCE SCENARIO

Source: Delta-ee view in our Reference Scenario (see Chapter 5), informed by interviews across the industry, and sense-checked with experts. These numbers are used only as indicative figures for modelling.

[8] SEER = Seasonal Energy Efficiency Ratio – cooling output divided by gas input during cooling season

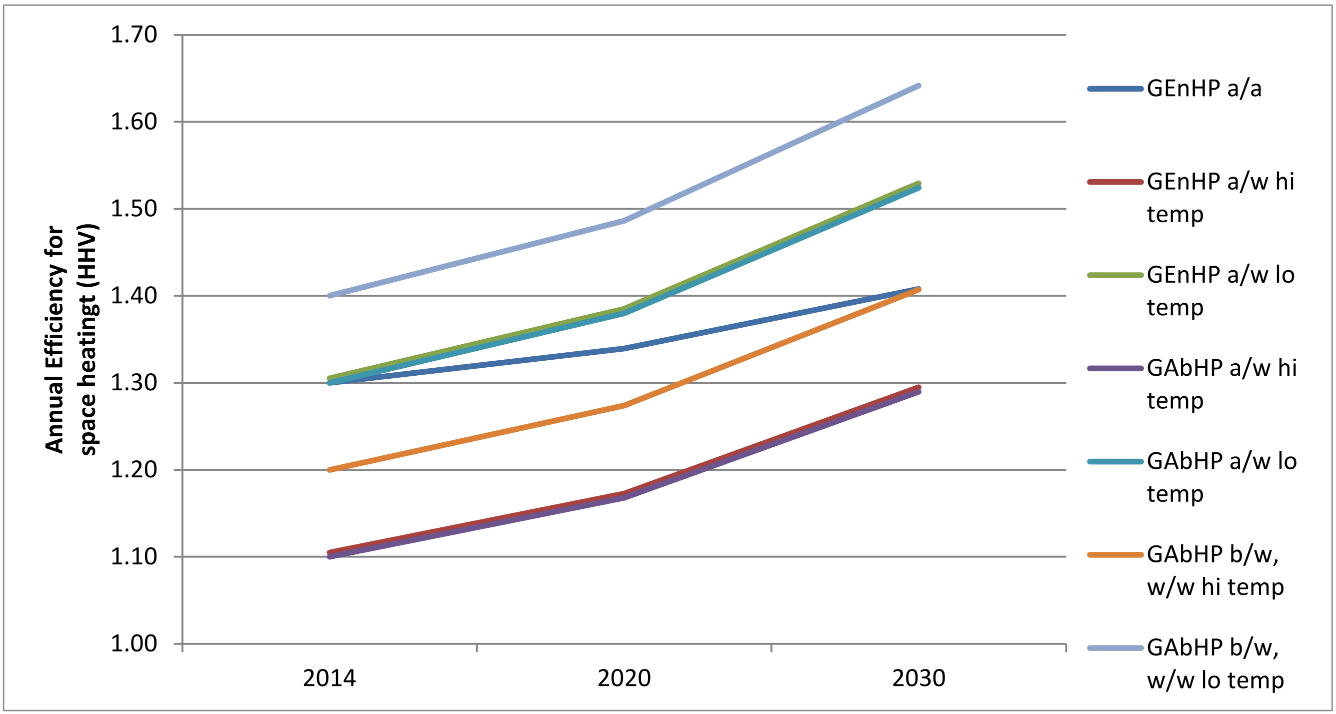

Figure 3: Graphical representation of advancements in (space heating only) efficiency anticipated by 2020 and 2030 for each type of GDHP (all recorded in HHV) – REFERENCE SCENARIO

Source: Delta-ee view in our Reference Scenario (see Chapter 5), informed by interviews across the industry, and sense-checked with experts. These numbers are used only as indicative figures for modelling

Where could efficiency improvements come from?

There are several factors which may influence future efficiency increases in GDHP, all contributing to the anticipated efficiency increases shown in the above Figure and Table. These factors are identified based on discussions with the industry (including manufacturers, academia, utilities and other industry experts), and can each be said to contribute to incremental efficiency increases. One single factor is not specifically identified which could lead to a step-change in efficiency, but it is possible that a major break-through could be made in any of these factors which could potentially lead to step-changes in efficiency. We highlight the main factors below:

R&D on "working pair" (for GAb and GAdHP systems)

- **Increase heat transfer efficiency through R&D into adsorbents** – could bring improvements to adsorption heat pumps. Vaillant / Viessmann use zeolite with water refrigerant, while Sorption Energy is working with active carbon and ammonia and believes it can yield better results. On-going R&D on this topic is likely to lead to the discovery of new adsorbent refrigerant pairs with improved heat transfer[9].
- **Widen operating parameters through use of different refrigerant/sorbent pairs**: (i) the heat source temperature which can be used is limited by the refrigerant used e.g. if water is used as a refrigerant (e.g. Vaillant/Viessmann products), given that the minimum

[9] Based on primary research informed by academic expert in GDHP – e.g. there is considerable R&D activity on the bonding of adsorbent powders to heat exchangers, consolidated and composite adsorbents, all of which have the potential to dramatically improve heat transfer. There is also much interest in new zeolites and MOFs (Metal Organic Frameworks), mainly intended for use with water as a refrigerant that might give larger concentration swings and hence higher COPs although the main focus is on air conditioning systems at present.

temperature it can be boiled in the evaporator is a few degrees above 0°C, the low temperature heat source must be at a higher temperature still. This use of water therefore rules out an air source heat pump. A second-generation Viessmann development will use ethanol in an air source absorption system (ii) The upper limit of (flow) temperature output achievable depends on the thermal stability of the refrigerant and on its interaction with the sorbent (either liquid or solid). The zeolite water combinations used by Vaillant/Viessmann do not show sufficient affinity to reach high output temperatures but are chosen for other reasons such as requiring a lower heat input temperature from the gas flame. Ammonia with either water absorbent or active carbon adsorbent has sufficient affinity to generate heat output at 60 C or higher. The choice of refrigerant in either adsorption or absorption cycles is very limited if a high COP is needed. The requirement is simply for a very high latent heat and this in turn requires a small polar molecule. Water, ammonia and alcohols are the only practical refrigerants. Historically sulphur dioxide was used but has unacceptable toxicity. Where the opportunities occur are with improved sorbents for these refrigerants that allow a closer approach to ideal theoretical COPs. This will open up significantly more market opportunities.

System design, operation and control:

- **Use of advanced sorption cycles to reach higher flow temperatures (Ab and Ad sorption):** Double-effect and multiple sorbent cycles offer the possibility of dramatically increased efficiency, increased output temperature or some combination of the two. However, they would also be more complex, more costly and physically larger.
- **Optimisation of hydrobox integration (a/w GEnHPs):** The GEnHPs sold in Japan in the range of several 100,000s are typically air/air systems, but water-based systems (which are essentially the same as the air/air system but with an add-on hydrobox and additional heat exchanger) are sold in smaller numbers and are emerging as a greater requirement in Europe. There is room to improve efficiency as this integration and control becomes more advanced.
- **Optimised integration with boiler, solar thermal**:
- **Minimising losses in cascade systems (all GDHP types):** There are losses associated with cascading several systems together - advanced control may bring incremental improvements here.

Potential for cost reduction

Cost reduction of GDHP will be possible to 2020 and beyond, but the rate of cost-reduction is proportional to the rate of market development. There are no inherently expensive components / materials in a GDHP – but (in Europe and particularly in the UK) supply chains are poorly developed, production volumes are small, system engineering is not optimized, and installer experience is low. Learning rate theory suggests 10-20% product cost reduction could be achieved with every doubling of production volumes. As such, making the switch from 1,000s of installations in Europe per year to 10s of 1,000s per year could enable a step change in GDHP costs across the value chain, from production to installation and maintenance, as discussed below. Our view of cost reduction potential for GDHP is outlined in Appendix C.

Where could the cost-reduction come from?

Sourcing cheaper components (Mainly GAbHP and GAdHP): While selling in low GDHP sales volumes, using lower cost OEM suppliers is not possible for some major components (for example, copper or brass valves, heat exchangers etc - standard in other systems - cannot be used with ammonia, so GDHP manufacturers using ammonia must develop or acquire their own bespoke versions at a higher price). As the number of GDHP players on the market increases, using lower cost OEMs for standard components (as for electric HP today) will become easier.

Increasing market competition (all types of GDHP): As new entrants enter the market and existing players ramp up activities, growing competition between manufacturers will drive cost reduction. A wild card is that another type of player - e.g. a utility - begins marketing and/or selling GDHP on a wide scale, or employ new business models such as heat contracting, which could create a step change in cost.

Industrialisation of production (mainly GAbHP and GAdHPs): The GEnHPs which sell in 10s of 1,000s per year in Asia have the advantage of already having industrialised production and therefore lower costs. However, many existing GDHPs made in Europe are effectively still handmade, with production capacities of 100s to low 1,000s per year. Industrialisation / automation in the production process will allow significant cost reduction.

Reducing distribution/import costs: Increased development and consolidation of (currently limited) sales channels in Europe could bring costs down.

Reducing installer margins (all types of GDHP): Today, installer margins are relatively high, but there is scope for reduction as follows:

Status today - why is the installer margin high?	Status in 2020 - why will the margin come down?
Installers install only a small number of systems so need to cover their costs	More installations per year - costs can be lower
They are covering the potential costs of having to return to the site to fix problems	They are more experienced and therefore more confident in their ability to Install without problems occurring later, and manufacturers have made the systems easier to install (more plug & play)
There is little or no market competition	There will be more competition, so installers will have to become cost-competitive
The installer is covering costs of the GDHP installation training course (and potentially the refresher courses) they have to attend, often outside the UK	Training courses will be more readily available in the local area (reducing e.g. travel costs), and because more installations will be made, there will be less requirement for additional refresher courses.

Table 4: Summary of anticipated installer margin reductions to 2020

Source: Delta-ee primary research with installers, distributors and manufacturers in the GVDHP and wider heating industry

How will GDHP renewable and cost saving credentials change over time?

What factors affect the GDHP proposition?

Advancements in GDHP performance will of course have a profound impact on the renewable credentials, carbon saving potential and running cost savings potential of GDHP – but there are several factors affecting the nature and rate of this change. Below we present some sensitivity analysis of the impact of these factors.

GDHP development: Dependent on the rate of technology development and commercialisation

Indications are that because gas heat pumps are relatively new to the market[10], there is still significant potential for cost-reduction in the manufacturing process, and efficiency gains to be made as the technology evolves. These developments will help move gas heat pumps beyond a niche product for early innovators. The question is now how quickly these developments can happen, and how much will be spent on R&D. This is dependent on a strong policy framework which gives the industry the confidence to invest

Rate of (upfront) cost reduction of GDHP technology

- The faster GDHP technology costs come down (particularly relative to competing technologies), the better the economic proposition will be (i.e. paybacks will come down).

Rate of efficiency increase in gas heat pumps (relative to competing technologies)

- Overall efficiency improvements to GDHP will reduce running costs and increase carbon savings – and the renewable contribution
- Efficiency improvements which widen the operating parameters of GDHP (for example, allowing them to use lower temperature heat sources or produce higher flow temperatures), increase opportunities in retrofit applications, maximising the size of the potential GDHP market, and therefore increasing the renewable contribution

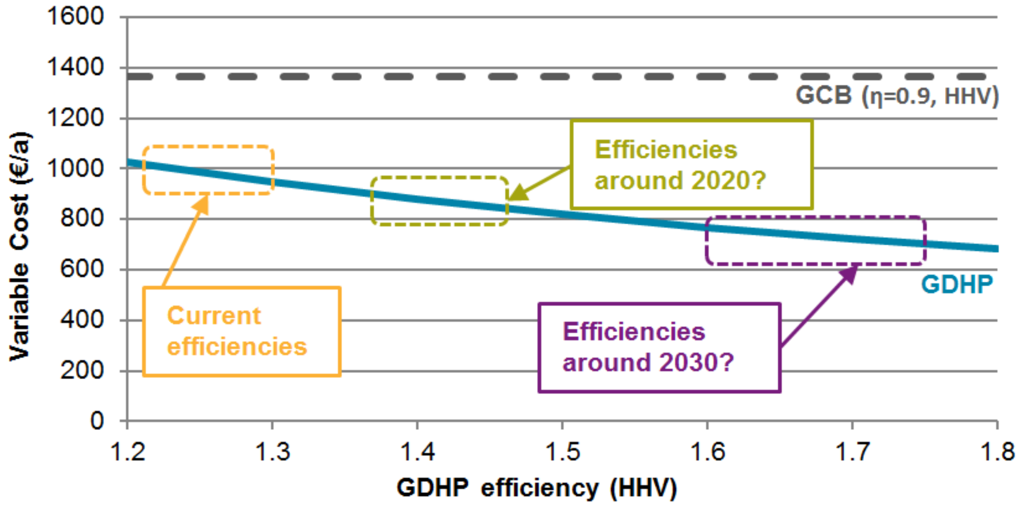

Figure 4: Indicative magnitude of running cost developments for a GDHP as efficiencies increase

Source: Delta-ee Heat Pump Research Service Gas Heat Pump Report – based on interviews with industry experts

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[10] This is particularly true for GAbHPs – for GEnHPs the situation is different because of their extensive uptake in Asia, but they are new to the European market

Trends in the wider energy market: Dependent on macro-scale political and economic factors

Electricity and gas prices are expected to rise, and in the UK, the infrastructure costs associated with upgrading existing electricity networks could mean an increasing divergence of prices, with electricity prices rising faster – giving a stronger GDHP economic proposition. But conversely, as grid carbon reduces, the GDHP carbon saving credentials reduces against electric HP.

Gas and electricity price trajectories

- A divergence between gas prices and electricity prices (i.e. electricity prices rise faster than gas prices) will strengthen the position of gas technologies – including GDHP - relative to electric HPs.
- But converging prices will weaken the position of gas technologies versus electric HPs.
- It is likely that the UK will move further to the left in Figure 5 below, with electricity prices rising further than gas, which would improve GDHP economics versus electric heat pumps[11].

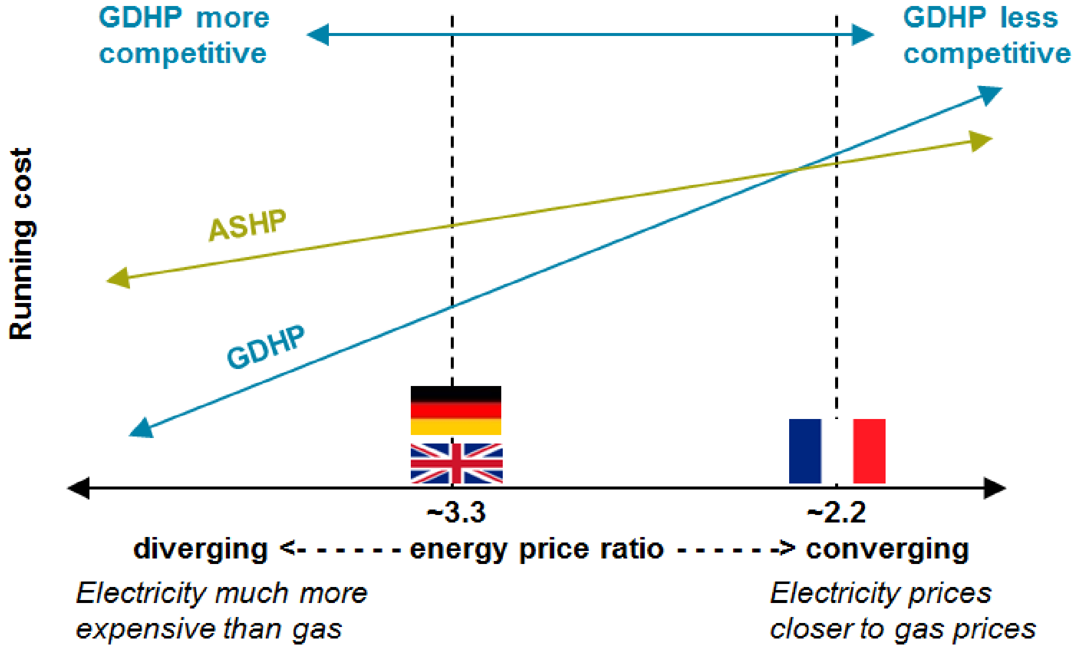


Figure 5: The changing proposition for GDHP versus electric HP with evolving gas and electricity price

Source: Delta-ee Heat Pump Research Service Gas Heat Pump Report – based on interviews with industry experts

[11] We include some comparison to electric heat pumps as requested by DECC – though in most cases we do not consider electric heat pumps to be the main competition to GDHP.

Rate of grid carbon reduction

Today GDHP can generally outperform or equal most electric heat pumps in terms of carbon reduction potential in on-gas grid areas in the UK – but this will change with time:

- As grid carbon reduces, the competitive position of GDHP weakens – so the rate of grid carbon reduction will define the length of the window of opportunity
- If developments are made regarding decarbonisation of the gas network, the window for GDHP will again be lengthened – but for the purpose of this analysis, DECC is assuming no gas grid decarbonisation.

Figure 6 illustrates the impact of grid decarbonisation on the proposition for GDHP compared to electric heat pumps (ASHP) and gas condensing boilers (GCB). As the grid decarbonises the carbon saving potential of GDHP reduces relative to electric HP. However, the shift from “lower efficiency GDHP” to “higher efficiency GDHP” is representative of the magnitude of efficiency increase which could be possible between now and 2030, as illustrated in figure 6 – which in turn increases the window of opportunity for GDHP.

It should be noted here that in the longer term, electric heat pumps will have higher carbon saving potential than GDHP. However, one of the strongest drivers of GDHP installs to date is the fact that the electricity grid is too weak or requires significant costly investment to support electric heat pumps. So GDHP may not save the greatest carbon but may be a lower cost way of achieving some carbon savings.

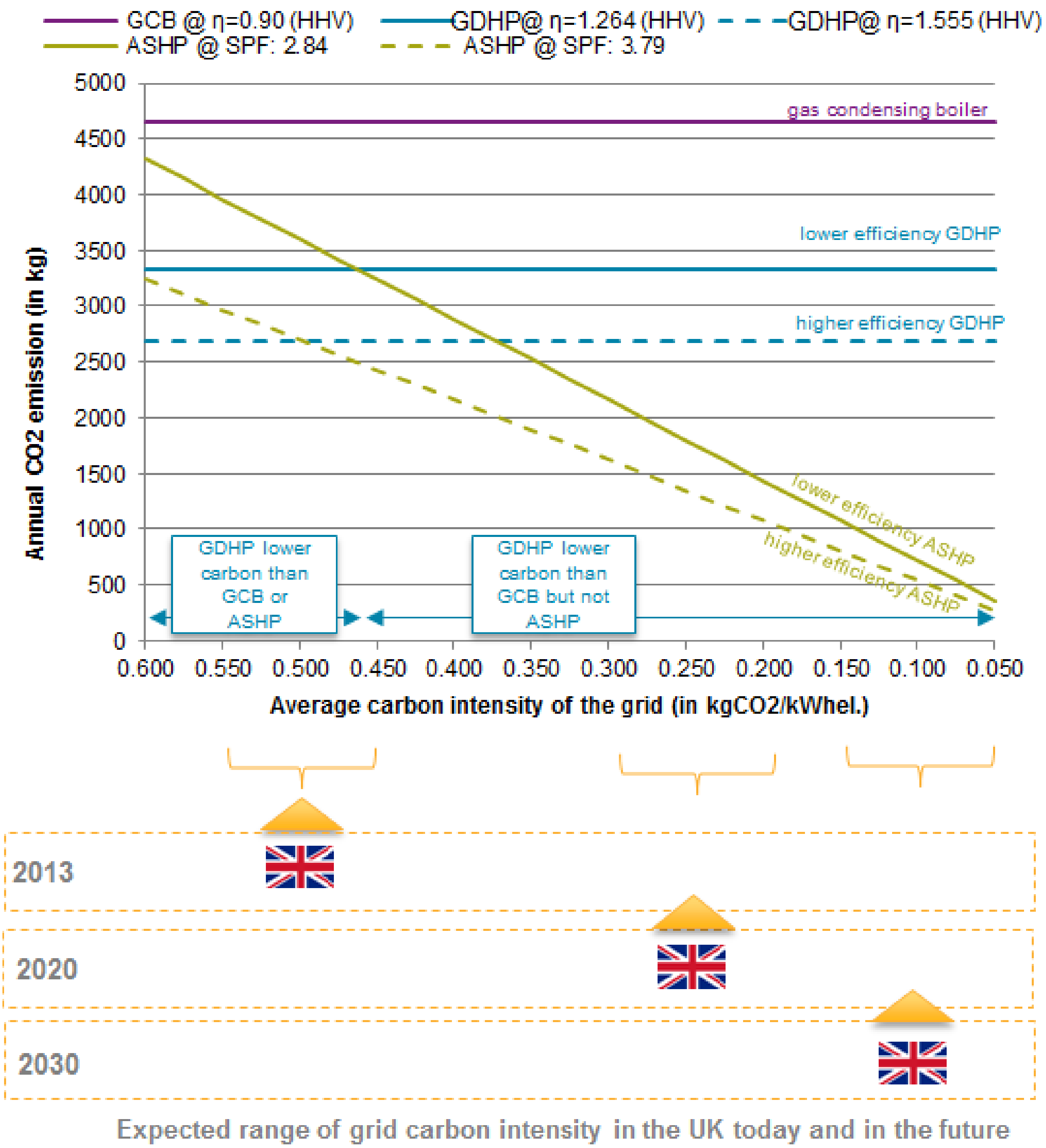


Figure 6: Annual CO2 emissions from gas boilers, electric heat pumps and gas heat pumps

Source: Delta-ee Heat Pump Research Service Gas Heat Pump Report (based on smaller scale GDHP). Emissions factors for UK are indicative of the future direction of grid carbon, as discussed in Appendix C..

Significant CO_2 savings can be made against gas and oil boilers with GDHP:

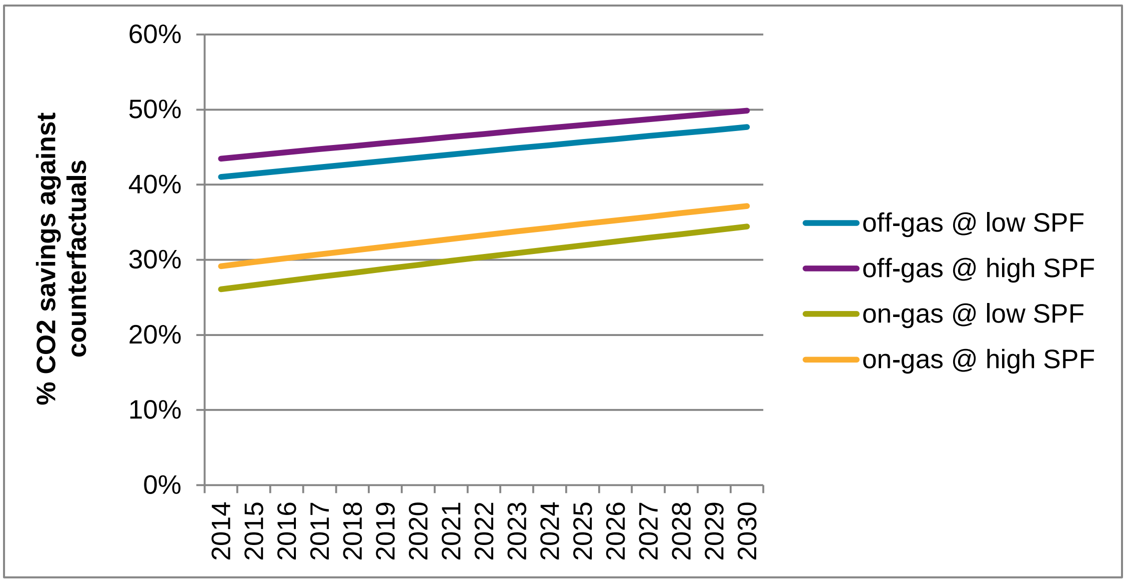


Figure 7: CO2 savings of GDHP versus counterfactuals on-gas and off-gas, with SPF range from 1.15-1.2

Source: Delta-ee modelling & primary research (the saving for GDHP on-gas is calculated relative to the on-gas counterfactual = gas condensing boiler; the saving for GDHP off-gas is calculated relative to the off-gas counterfactual = oil boiler; GDHP SPF increases 0.75% / year[12]. See Appendix C for assumptions on emissions factors of different fuels and efficiency advancements over time)

[12] 0.75% / year efficiency increase is derived from conversations with industry experts on the potential for efficiency increases to 2020 and to 2030. The end points for efficiency at 202 and 2030 were tested with several industry experts in the UK and Europe, and the annual efficiency increase derived from assuming a straight line for efficiency increase from 2014-2020 and 2020-2030.

3. Sectors and Use Cases

Key Messages

- **The sectors best suited to GDHP have high demand for heating and / or hot water and cooling, and have high required running hours**.
- End-user sectors identified as creating particularly good proposition for GDHP include **hotels and restaurants, care homes, hospitals and industry -** all due to their high needs for heating, hot water and often cooling.
- **The sectors where GDHP have been installed in the UK differ from those identified as having greatest potential**. Schools (which have relatively low demand for heating, hot water and cooling), along with universities are by far the biggest sector for installed GDHP. While care homes and hospitals are also amongst the top existing sectors, industry is non-existent.
- **Many other sectors are well suited to GDHP**. Installations in other parts of Europe have been proven successfully in e.g. offices, public buildings and multi-family homes. In the UK, there are very few installations in such sectors but the potential is there.
- **The majority of UK installations are in the new build sector.** The primary reason for specification is associated with sites where the electrical supply is limited and cooling is required. In a small number of sites GDHPs have been specified, for e.g., to achieve Part L compliance and/or BREEAM ratings, and retrofit is mainly restricted to major refurbishment projects. This is due to the high upfront cost and the lack of awareness of the technology amongst specifiers on such projects (explored in Chapter 5).
- **GDHP have been installed in existing buildings in small numbers** to date. They have good potential as retrofit solutions because of their ability to reach high flow temperatures (which some competing renewable technologies struggle with). Air-source systems are likely to dominate in existing buildings because of their lower cost and easier installation. The main barrier in retrofit to date is low awareness of GDHP.
- **Different GDHPs have different 'sweet spots' in the market:** GAbHPs are generally best suited to sectors which are heating and hot water led, whereas GEnHPs are generally suited to sectors which are heating and cooling led and/or where there is a limitation in electricity supply capacity. However, both technologies can and have been deployed in a wide range of sectors and applications.
- **There is significant potential to achieve substantial carbon/energy savings in industry**[13] by stimulating demand for heat pumps, however, most of the relevant industrial heat pump technology types fall outside the scope of this review (i.e. they are not GDHPs)
- In the course of our research with end-users, installers and contractors who had direct involvement in GDHP projects in the UK, the general message was that **once a GDHP had been chosen and installed, it tended to work and there had been largely positive experiences**.
- **The main challenge for the GDHP market is for GDHP to get to the stage of being**

[13] As indicated by past studies identified in Chapter 1

specified for commercial projects. In most cases, it does not reach this stage.

GDHP Suitability

Criteria determining end-user sector suitability for GDHP

Our research with industry experts involved in the current GDHP market has identified the following generic criteria as most important in influencing the suitability of (different types of) GHDP to different sectors of the building stock:

Generic requirements across building stock:

1. High end-user kWh demand for hot water / heating / cooling - advantageous to have a need for simultaneous heating or hot water and cooling
2. High required running hours (at least 3,000 hours / year)

Further site specific factors strengthening the case for GDHP:

1. Availability of a suitable heat source for a GDHP (space for ground loops, possibility to install outside unit for ambient air, space for solar thermal, availability of waste heat etc)
2. Restrictions / high costs associated with strengthening the electricity grid to accommodate electric systems of air conditioning and heating - is prohibitive ("can be 10s of £1,000s" based on interviews with specifiers and installers) - so use of gas is preferred

Categorising sectors by generic requirements

Here we define three broad groups within which different end-user sectors can be generally categorised. The 'high demand' and 'low demand' sectors refer to links to the categories of the same name in the modelling in Chapter 5.

Sectors	Demand requirements	Implications for GDHP
Group 1 (high demand)	High sanitary hot water (SHW) and high space heating demand (or industrial / process heating), plus (potentially simultaneous) cooling needs. Demand is for a high number of running hours throughout the year (i.e. likely demand throughout day and night).	Ideal requirements for an economically positive GDHP because of high running hours, and avoiding the need for 2 separate heating and cooling systems. NB: there are a wide range of industrial applications where there are simultaneous demands for heating and cooling.
Group 2 (high demand)	Demand for both SHW and heating (but demand for at least one of these not as high as in Group 1),, plus some cooling needs. Demand is for a high number of running hours throughout the year (i.e. likely demand through day and night).	Good requirements for GDHP as in Group 1 (but running cost savings may be lower because of lower overall demand for space heating and/or hot water relative to Group 1).
Group 3 (low demand)	Limited space heating and cooling demand with little hot water demand. Demand may be for a limited number of running hours throughout the year (e.g. with summer breaks / no evening or night time demand). NB: buildings constructed to post-2014 Part L will generally be in this category	GDHP can technically make sense but economics may be marginal because of low required running hours

Table 5: Grouping end-user sectors by demand type, and implications for GDHP

Source: Delta-ee primary research – interviews with installers, specifiers, end=users and other industry experts

Segmenting the commercial building stock by suitability for GDHP

End-user sectors are investigated according to type and level of demand, and categorised in the 3 groups as identified in Table 9. This will enable some conclusions to be drawn regarding the suitability of each sector to GDHP. Where the sector has a * associated with it in the table, we have considered it in our commercial building stock analysis. The analysis presented below relates to the existing building stock. New/future buildings constructed to post-2014 Part L standards are likely to require minimal space heating.

sector	**Demand**			**Running hours >3,000/yr?**	**Summary**	**Category**
	heating	cooling	hot water			
Office*	high	yes	low	marginal?	Space heating & cooling, little SHW	3 - low demand
Wholesale trade*	high	yes	low	yes	Space heating & cooling, little SHW	3 - low demand
Hotel / restaurant *	high	yes	high	yes	Space heating, SHW, cooling	1 - high demand
Health* – care homes	high	yes	high	yes	Space heating, SHW, cooling	1 - high demand
Health* - hospitals	high	yes	high	yes	Space heating, SHW, cooling	1 - high demand
Education* - Universities	high	No	low	yes	Space heating dominates	3 - low demand
Education* - Schools	high	yes	low	marginal?	Space heating dominates	3 - low demand
Multi-family homes	high	No	high	yes	Space heating & some SHW, no cooling	2 - high demand
Leisure (sports halls, pools)	high	no	high	yes	SHW dominates, cooling needs & some heating	2 - high demand
Museums . galleries	high	yes	low	marginal?	Space heating & cooling, little SHW	3 - low demand
Industry[14]	high	yes	high	yes	Space or process heating and/or cooling (and/or SHW)*	1 - high demand

Table 6: Assessing end-user sectors by type and amount of demand requirements

[14] NB: Industrial heat pumps are generally custom designed / engineered to be integrated with the process heating & cooling demands. Heat pump specification is bespoke and packaged systems are only occasionally used (as modular units).

Source: Delta-ee primary research - – interviews with installers, specifiers, end-users and other industry experts, combined with the limited data available from NDEEM and the Display Energy Certificate Register

Where are GDHP currently deployed?

Which end-user sectors?

We provide an overview of the main sectors where GDHP are being deployed in the UK today. The two sectors consistently mentioned by interviewees were schools and care homes, though there have been a wide range of installations in many types of building. The figures below are approximate and for the UK only.

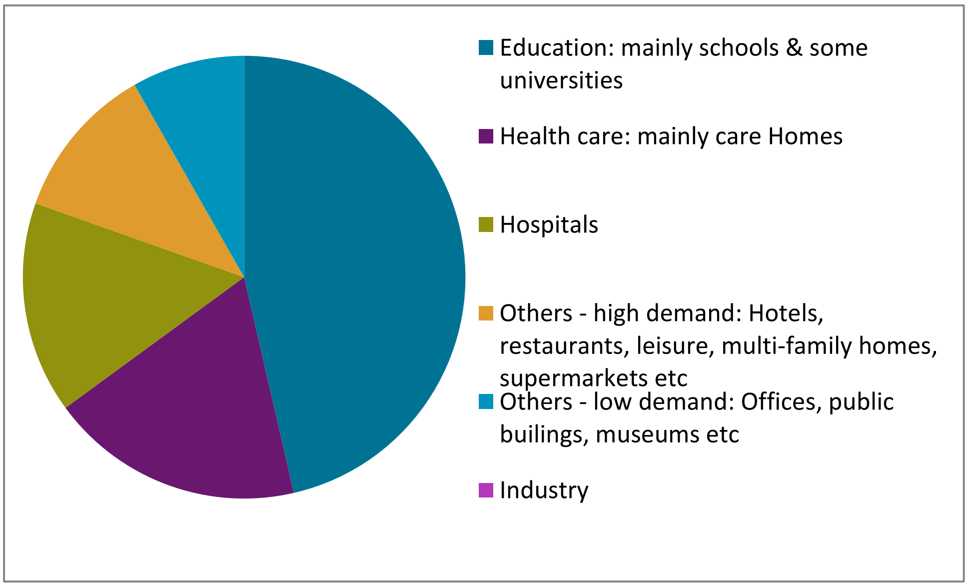


Figure 8: Approximate share of GDHP installations in different end-user sectors in the UK

Source: Delta-ee primary research (interviews with installers and UK industry experts). Here we provide a single % for each sector – we have chosen a central % based on the range of %s derived from our interviews.

Why are these sectors the most popular for GDHP in the UK today?

Sector	% of UK GDHP installations	Type of GDHP	Sector-specific drivers: Why have GDHP been installed in this sector?
Education	close to 50%	Mainly GAbHP primarily for heating, but also some examples of GEnHP linked to VRF systems to primarily provide cooling	Availability of financing under “Building schools for the future” programme (now ended) GDHP installations in the UK tend to be in new build, ‘high end Academies’ and ‘eco-schools’ where having the best products with the latest technology and green credentials is a strong driver. In some cases GDHP have not been installed in schools because of a particularly high heat/cool demand or good economics, but because of a requirement for the greenest / most efficient technology.
Care homes	10-20%	Mainly GAbHP primarily	Typically installed in ‘high end’ new build care homes

		for heating and hot water	where having the best products with the latest technology and green credentials is a strong driver. Lowering running costs are a driver because of very high heating demand
Hospitals	10-20%	GEnHPs for heating / cooling with heat recovery for hot water; GAbHP for hot water plus heating or chiller type for hot water plus cooling	Hospitals have a constant year-round base-load need for hot water, as well as heating and cooling needs, making a strong case for GDHP.
Others - high demand	10-15%	Mainly GAbHP where heating is the primary demand, and GEnHP where cooling demand also significant	
Others - low demand	5-10%	GEnHP and GAbHP	
Industry	0%	Custom engineered systems	Studies undertaken by the US DOE and the IEA (and by the UK Energy Efficiency Office in the 1980s) have identified considerable carbon abatement potential associated with industrial heat pumps. However, installations of GDHPs in the UK are currently very low/non-existent.

Table 7: Exploring characteristics of each of the main sectors for GDHP, and sector-specific reasons why GDHP have been chosen

Source: Delta-ee primary research –interviews with installers, specifiers, end-users and other industry experts

NB: Market drivers and barriers are covered further in Chapter 4.

Note regarding industrial GDHP applications: No current UK installations found

Access to the UK government Energy Conservation Demonstration Project grant Scheme (and design support) in the 1980s resulted in considerable interest in industrial GDHP applications. A number of trials were installed, with independent monitoring & evaluation undertaken.

It is understood that most of the systems were decommissioned within about 5 years of installation as a consequence of poor performance, poor reliability and high maintenance cost. With the exception of the Mitsubishi Heavy Industries (MHI) gas engine driven system installed at GSK Weybridge (which is understood to be in the process of being de-commissioned), the GDHP RHI review has not identified any UK industrial applications.

Large industrial heat pumps are utilised in the process sector. However these are out-of scope with the current study, since they are either open cycle systems (Mechanical Vapour Compression) or waste heat driven absorption systems.

Imperial College undertook a research for DECC (published 2013) summarising the evidence associated with decarbonisation of heat in industry[15] . The report identified the following sectors as offering potential for heat pumps:

- Pulp & Paper sector
  - "A Swedish study on the utilisation of excess heat in the pulp and paper industry found there was potential for the use of mechanical and adsorption heat pumps with a payback of 1.7 to 2.7 years"
- Food & Drink Sector
  - The report states "Significant technical potential exists for decarbonisation in the food and drink sector to 2050, particularly from the application of dielectric heating technologies, CHP and heat pumps".

Are GDHP installed in new build or retrofit?

GDHP are installed in both new build and existing buildings. The potential in retrofit is a consequence of the ability of GDHPs to reach high flow temperatures, which can be a challenge for many other renewable technologies. While efficiencies do drop at higher flow temperatures, this differential is less pronounced than with electric heat pumps, for example.

- **New Build, >60% of current UK installations:** In the UK, based on current experience (as indicated by our primary research), new build is the most common sector for GDHP, where they are typically installed in order to comply with Building Regulations Part L (or to gain BREEAM credits). In new build there can be a combination of ground-source (typically brine/water), which are often preferred for the higher efficiencies achievable, though there are associated costs, air/water and air/air systems. NB: Future revisions to Part L are likely to result in buildings having minimal space heating demand. Low space heating load will reduce the economic case/return on investment associated with heat pumps (of all types) and could reduce market take-up in the new-build sector. However, new buildings (or industrial process applications) with a significant hot water requirement could provide a sufficient load to justify a GDHP.
- **Existing buildings, <40% of current UK installations, most of which are major refurbishments:** For existing buildings, most GDHP installed have been as part of a major refurbishment, where the whole building is being overhauled, likely including replacement of existing heat distribution systems, installing underfloor heating and improving insulation. In existing buildings, given space restrictions and costs associated with ground loops, air/water (where there is an existing hydronic system) and air/air systems where there is an existing dry heat distribution system) are more common.

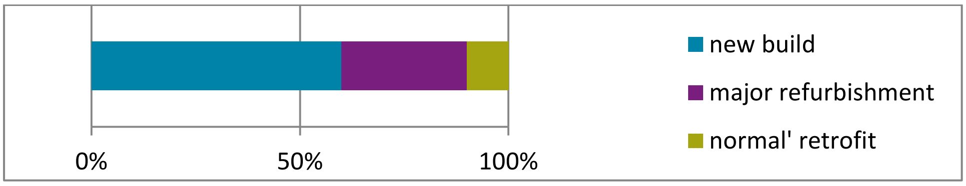


Figure 9: Approximate share of GDHP installations in different sectors in the UK

Source: Delta-ee primary research – interviews with installers, specifiers, end=users and other industry experts

[15] Decarbonisation of heat in industry A review of the research evidence Report for the Department of Energy & Climate Change, Ricardo-AEA/R/ED58571 Issue 1 Date 31/07/2013

Which type of GDHP for which sector? GAbHP vs GEnHP

GAbHP and GEnHP are both installed in the UK, but GAbHP currently dominates. This is largely because it has a greater number of sales channels and availability of products than GEnHP.

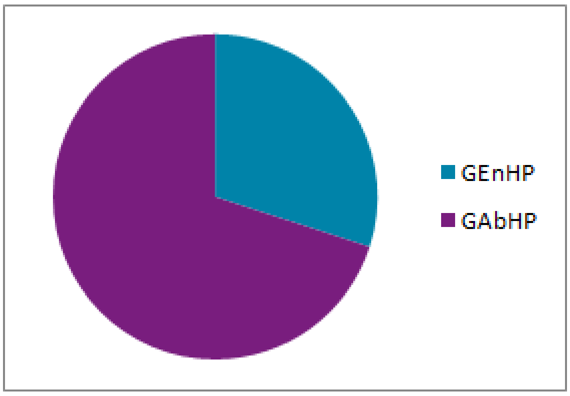


Figure 10: Indicative proportion of GEnHP versus GAbHP installed annually in the UK today

Source: Delta-ee primary research – interviews with installers, specifiers, end=users and other industry experts

GAbHP and GEnHP can both be installed in a wide range of end-user sectors, but the technologies have different characteristics and relative efficiencies for meeting different types of demand. Based on existing installations of both GEnHP and GAbHP in Europe, and based on interviews with industry experts in the UK and Europe, we can characterise the suitability of the different types as follows in Table 13. Note that there is some cross-over between sectors and GDHP types - every site will have its own demand characteristics and system design options:

GDHP type	Technology characteristics influencing suitability in different sectors	Typical end-user sectors
GAbHP - heating and hot water led	Current technology is designed for hydronic systems and has been optimised for meeting relatively high heating and hot water demands. Cooling is possible, but efficiencies are relatively low in systems designed for heating (e.g. compared to GEnHP). GAbHP can be adapted for better cooling efficiencies but generally this means loss of some heating efficiency. Ground-source (b/w) GAbHP would need very large ground array when used for cooling in reverse cycle, so any GAbHP for cooling would be air/water.	**Sectors with high heating and hot water demand** e.g. care homes, hospitals, industrial processes (where there is a need for warm water for washing, cleaning etc), hotels.
GEnHP - heating and cooling led	Technology has a history in cooling applications and has a track record of providing air-based heating / cooling - often simultaneously. GEnHPs generally designed for optimum cooling efficiency. To design for heating, have to buy an additional refrigerant/water interface system, or use refrigerant based heat emitters - at an additional cost. Hot water can also be produced with heat recovery, but this is generally not designed to cover 100% of hot water demand.	**Sectors with a need for cooling and heating, but where hot water demand may not be so high** e.g. offices, supermarkets. Also sectors where there could be a need for simultaneous heating and cooling (and another system can cover base load for hot water) e.g. hospitals, hotels.

Table 8: Suitability of different types of GDHP to different applications and sectors

Source: Delta-ee primary research – interviews with installers, specifiers, end=users and other industry experts

To illustrate the above we present examples of the end-user sectors in which two major European players are installing: Robur (GAbHP) and Aisin (GEnHP). It is notable that Robur installs its largest numbers of GAbHPs in sectors with high hot water and heating needs (with some cooling demand) e.g. industry, hotels and leisure. In contrast, the biggest numbers for Aisin's GEnHPs are in a sector with heating and cooling needs but low hot water demand (offices).

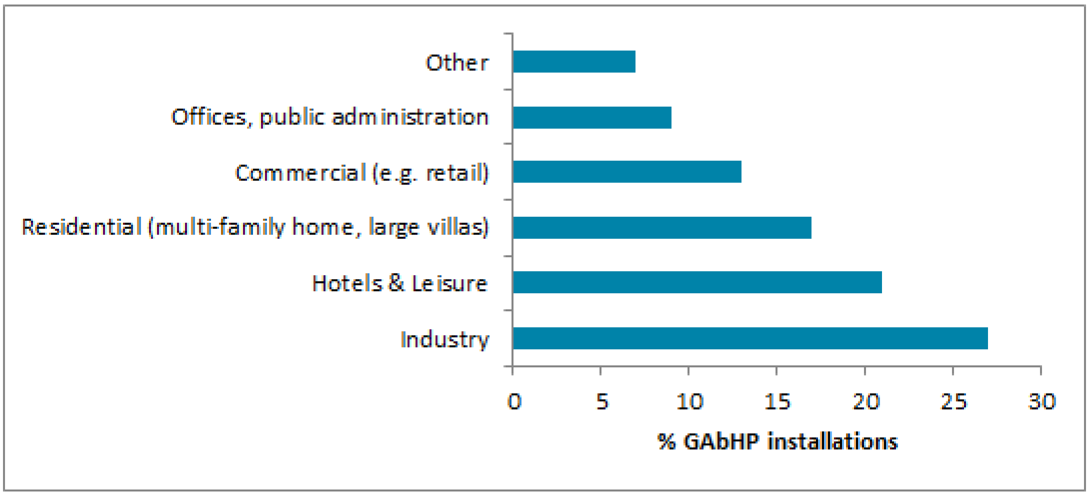


Figure 11: Share of Robur GAbHP installations in different end-user sectors in Italy

Source: Robur

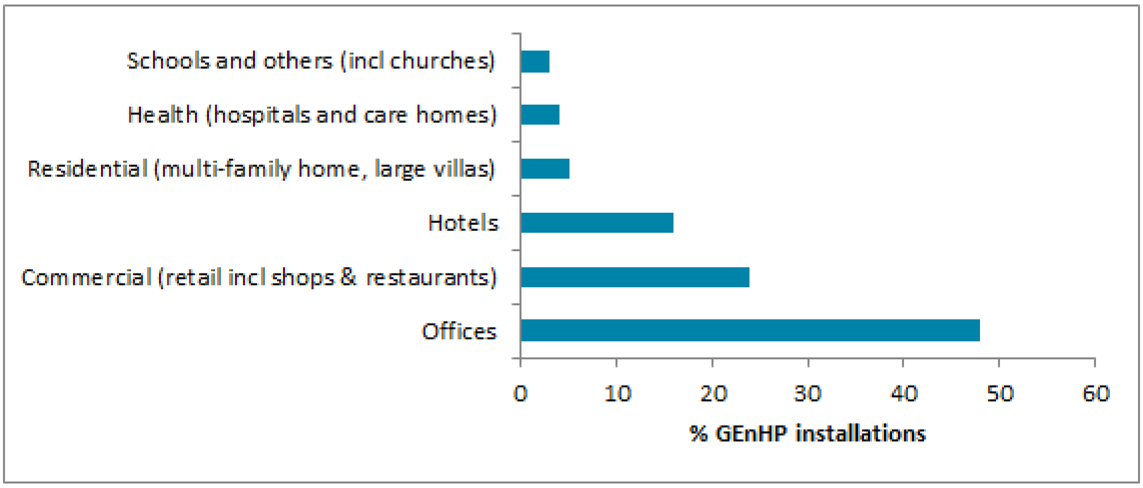


Figure 12: Share of Aisin GEnHP installations in different end-user sectors in Europe

Source: Tecnocasa

Use case examples are presented in Appendix F. We present a series of use case examples to illustrate the discussion above, taken from three important sectors for GDHP in the UK today: education, hospitals and hotels.

4. Market Drivers & Barriers

Key Messages

We identify the key drivers for GDHP in the UK as follows:

- The two critical drivers – and most common reasons for GDHP being installed in the UK in both new build and retrofit are the **limitations of the electricity grid**, and the end-user / developer receiving **recommendations for a GDHP from a trusted company**.
- Additionally, **running cost savings** are critical in retrofit, and **meeting or exceeding building regulations** is critical in new build.

Driver	Importance in new build	Importance in retrofit
Limitations of electricity grid & excessive cost of grid upgrade driving gas as alternative	■	■
Meeting or exceeding building regulations	■	n/a
Achieving running cost savings	□	■
Recommendation from trusted building services professional or brand	■	■
Capturing available grants or incentive schemes	□	□
Promoting green credentials	□	□
Avoiding the need for 2 separate systems for heating / cooling	□	□
Availability of (local) after-sales support	□	□

Key ■ CRITICAL DRIVER: Without this, the decision to choose a GDHP would not be made □ INFLUENTIAL DRIVER: If one of the critical drivers is in place, these support the decision for a GDHP

Table 9: Critical and influential drivers which have led to installation of GDHPs in the UK

Source: Primary research with end-users, installers, specifiers manufacturers and other building services professionals

There remain significant barriers to GDHP uptake in the UK. These barriers are particularly prevalent in the existing building sector, where the additional driver of exceeding building regulations or achieving a higher BREEAM rating does not exist:

Barrier	How RHI will help
Lack of confidence from the industry to invest in developing the supply chain for GDHP	**Indirectly through sending a signal to the industry** that the government is committed to supporting the technology
Lack of awareness and/or in some cases poor perception of GDHP technology due to lack of information (and previous bad experiences)	**Indirectly if combined with information dissemination & awareness-raising:** The financial benefit of the RHI will not overcome this barrier, but GDHPs inclusion in the scheme will raise GDHPs profile
Limited sales channels and routes to market create challenges for accessing the technology	**Indirectly through building industry confidence to invest:** The recognition of GDHPs in the RHI indicates the government's long-term policy support, which will help give the industry the confidence it needs to invest in expanding the supply chain
Policy framework - this does not currently set a framework which places GDHPs on an even playing field.	**Directly**: Inclusion of GDHP in the RHI would give a clear indication of the government's support for GDHP alongside competing technologies such as biomass, electric heat pumps
GDHPs are not getting through the specification process so are not available as a choice	**Indirectly if combined with information dissemination & awareness-raising:** Specifiers have limited – if any – experience with or knowledge of GDHPs real potential – inclusion in the RHI may increase general awareness and may increase direct requests from customers
Upfront cost of technology	**Indirectly – especially if it allows 3rd party ownership:** The RHI does not tackle the upfront cost challenge but by reducing payback times it creates a better economic proposition, and also opens the opportunity for alternative business models which reduce upfront cost and risk to end-users

Table 10: Barriers to installation of GDHPs in the UK

Source: Primary research with end-users, installers, specifiers manufacturers and other building services professionals

Recommendations

- **The RHI will go some way to overcoming some barriers** by making the economic proposition more positive. However, an RHI alone will not overcome other barriers.
- **The RHI must come hand-in-hand with a marketing & awareness-raising campaign** which reaches across the value chain.
- **Manufacturers will invest in advancements to the technology and supply chain** once they have the confidence that policy makers are serious about supporting GDHP on a level playing field with other renewables, and once marketing and awareness-raising start to increase customer and installer pull for the technology.
- **Special attention should be paid to the building services professionals responsible for specifying new heating/cooling systems in commercial buildings**. This is the critical point in the value chain where a decision for a GDHP could be made - but in most cases is not.
- **The RHI design should ensure the possibility exists for 3rd party ownership of renewable systems** – to allow for alternative business models which can reduce upfront costs.

Why have GDHPs been deployed so far in the UK?

There are a variety of different drivers which have contributed to the choice of GDHP in existing installations in the UK and further afield, some of which sector-specific reasons have been explored in Chapter 3. We summarise the most important overall drivers below:

Driver	Importance in the UK	Rating - new build	Rating - retrofit
Limitations of electricity grid pushing decision for gas and away from electricity. Compared to the option of a single electric system for heating and cooling, a GDHP avoids the often prohibitive costs of upgrading the electrical grid to cope. It makes more economic sense to use gas, especially where there is already a gas connection.	**Potentially one of the most important reasons for GDHP installations in the UK** where the single-phase electricity supply is a challenge for electric systems. The cost in the UK to strengthen the grid to go to full electric system of air conditioning & heating can be "10s of £1,000s" for one site[16]. Across the whole UK, GDHP have significantly lower grid impact than electric systems (chillers, aircon) which are commonly used in the commercial sector.	critical	critical
Meeting or exceeding building regulations (we explore further in Market Barriers chapter).	**One of the strongest drivers for GDHP to date - and a reason for the skew towards new build:** "Achieving Part L compliance and/or BREEAM credits" is cited as the most important driver for installation in many of the existing GDHP installations. UK GDHP installations have typically achieved BREEAM 'excellent' or 'good' ratings.	critical	n/a
Capturing available grants or incentive schemes	**An important driver in some UK sectors to date, but not a driver of sustainable growth**. For example, many GDHPs were installed in schools in the UK as part of the 'Building Schools for the Future' programme.	influence	influence
Promoting green credentials	**A driver in the UK for many existing GDHP installations, which are in 'high-end' establishments.** These sectors are most likely to invest in expensive kit, and could be seen as 'innovators', tending to be more green-leaning. For the mass market, the green argument will not be the most critical factor.	influence	influence
Running cost savings	**A critical driver particularly in the retrofit sector**, where a core reason for changing the heating (/cooling) system is to achieve running cost savings against the existing system.	influence	critical

[16] Based on interviews with specifiers and installers

Avoiding the need for 2 separate systems to heat and cool - GDHP can provide both.	**An advantage for GDHP in the commercial sector**: Although the upfront cost of a GDHP is still high, the avoidance of 2 separate heating / cooling systems has been cited as a driver in the UK because a single GDHP has lower maintenance requirements than a 2 separate systems - less hassle and cheaper to run.	influence	influence
Recommendation for a GDHP to the end-user / architect from a trusted building services professional (or trusted brand)	**This is a critical factor for GDHP in an emerging market like the UK:** The key decision-maker for a GDHP is not typically the end-user or architect, but the contractor or installer (or an industrial process consultant/specialist). Particularly given the low awareness and trust of GDHP in the UK, the recommendation (or not) of a trusted consultant and/or contractor is critical in determining the decision for GDHP. Some end-users cited that decisions were based solely on the recommendation of their trusted consultant/contractor. NB: most industrial heat pumps are specified by specialist consultants/process energy contractors	critical	critical
Availability of after-sales support for installers / contractors	**Would increase market confidence on GDHP if it was widely available in the UK:** Cited as a driver for e.g. the installation of Robur systems in its native Italy.	influence	influence

Table 11: Market drivers for GDHP and importance of drivers in the UK context

Source: Primary research with end-users, installers, specifiers manufacturers and other building services professionals

Selected views from primary research: Perception of GDHP – why they have been installed?

"An LPG GDHP was the only option because of the limited electricity supply we had in this remote area" [end-user]

The GDHP "ticks the green box with planners" [end-user]

"Nearly all GDHP we have installed have been installed in order to achieve Part L compliance or BREEAM credits" [GDHP supplier]

Identifying Critical Points: The key actors in the decision process for a GDHP

The decision to install a GDHP is very rarely driven by the customer. The specifier has potentially the most influential role in the product choice because they are responsible for providing the initial system options to meet a site's needs. The contractor is also critical because they are the main interface with the installer and have to provide necessary support (sometimes the contractor and installer are one company, or can be responsible for commissioning the final installation). Raising awareness of and provision of information about GDHP technology and potential across the value chain, including the customers, specifiers, contractors and installers is crucial to ensuring GDHP are considered at any site.

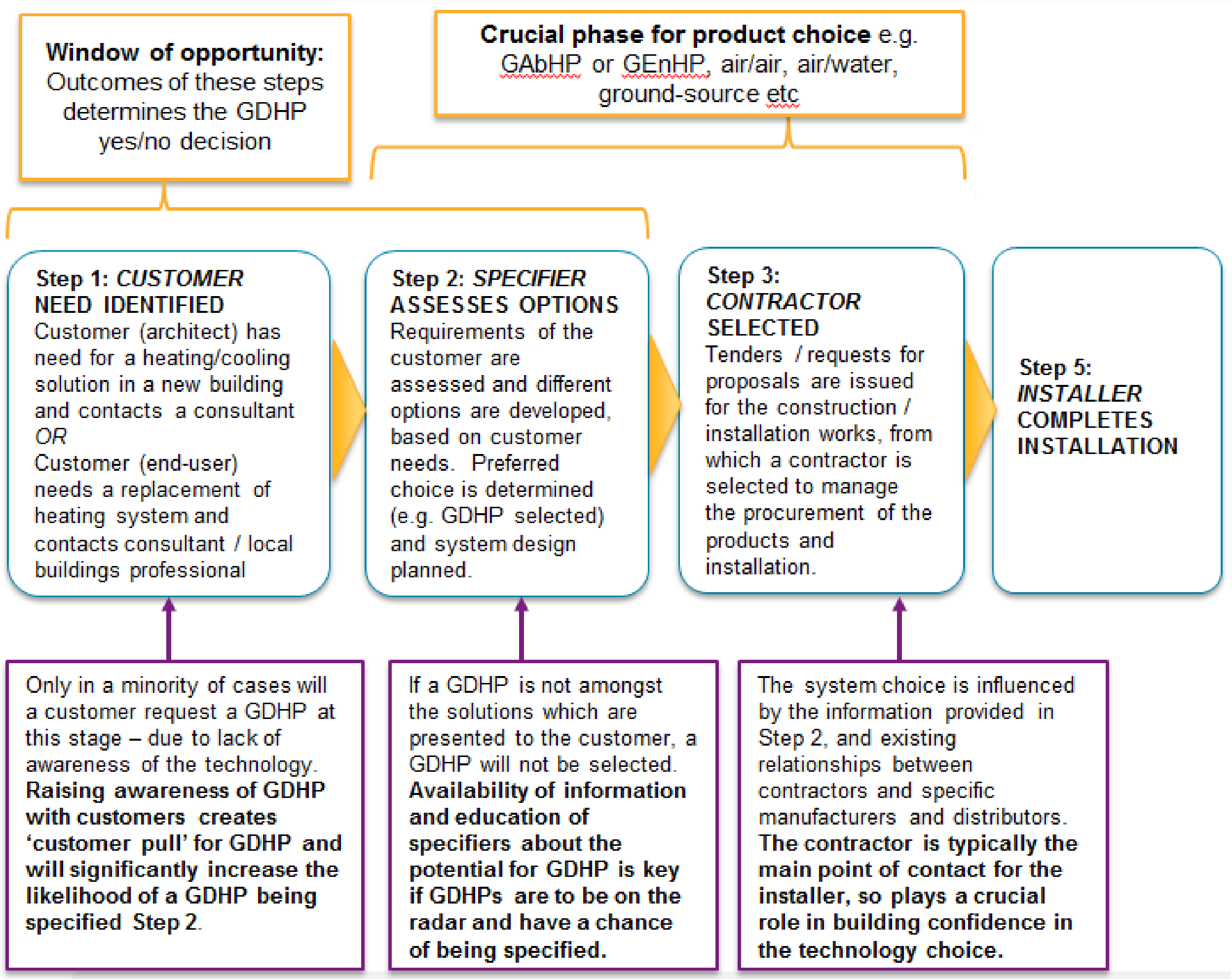


Figure 13: The typical role of the customer, specifier, contractor and installer in the decision making process regarding a new or replacement heating/cooling system in the UK

Source: Primary research with end-users, installers, specifiers manufacturers and other building services professionals

Main barriers

There are a number of barriers which must be overcome if we are to see significant uptake of GDHP within the UK. The most obvious is the increased capital cost of a GDHP system compared to conventional heating technologies like condensing boilers. Yet a general lack of awareness of the technology, and resistance among some vendors to offering novel technologies alongside their traditional product ranges, is further undermining the potential of the technology.

This section highlights the main barriers to widespread adoption of GDHP technologies within the UK, introduces suggestions on how these barriers could be overcome as well as considering how effective the introduction of an RHI could be in eliminating, or minimising, these barriers.

Gas-driven heat pumps face several strong barriers, each of which is explored in more detail below:

- **Upfront cost of technology:** GDHPs are significantly more expensive than incumbent technologies. This proves to be a significant barrier for the technology and one of the biggest reasons why GDHPs are not more prevalent (though this is also the case for other renewable technologies - the upfront cost of a GDHP is equivalent to a comparable biomass system, for example).
- **Policy & regulatory framework:** GDHPs are likely to need a more favourable policy and regulatory framework in order to compete 'on a level playing field' with conventional technologies (such as gas boilers) and incentivised technologies (such as biomass boilers - which have been driven by the commercial RHI to date).
- **Low Awareness and poor technology perception:** GDHPs need greater exposure across the value chain, including end-users, installers, specifiers, contractors and other building professionals, if we are to witness significantly increased sales in the future. There is a perception in some quarters that GDHPs should not be considered 'renewable' and there is less confidence in the reliability of a technology that is not widespread. Both perceptions should be conciliated if GDHPs are to achieve more than a niche market penetration.
- **Sales channels & routes to market:** Development of sales channels and installation / maintenance networks is a critical issue for GDHPs to overcome in the UK market, where they are currently limited.

Upfront cost of technology

Upfront cost is consistently highlighted as the single biggest barrier to market entry for new technologies. This is certainly the case for GDHP technologies which are generally priced much higher than the incumbent heating/cooling technologies (though not necessarily above the price of alternative renewable/low carbon technologies). On average a GDHP costs between £550 and £800 per kW, whereas a gas condensing boiler costs on average £95 to £105 per kW (see Appendix C for details of cost assumptions and expected evolution). Until costs are reduced, GDHP will remain a niche product for affluent market sectors. This barrier is most relevant for the emerging GDHP technologies – absorption and adsorption - both of which have significant progress to be made in order to bring costs down. Yet, it is still a challenge for all types of GDHP: "These units are not cheap… " and "… very expensive compared to conventional solutions" (Quotes from research calls with end-users)

How can this be overcome?

In order for the upfront technology cost to come down, first GDHPs must establish an increasing share of the non-domestic market and commence a journey towards market maturity. Until such a time when GDHPs are widely available, with industrialised production lines, and more established and consolidated sales channels and service & maintenance arrangements in place, GDHP products are likely to remain prohibitively expensive for the majority of potential customers. Over time, as sales of GDHP products increase, it is likely that the cost of the technology would come down as 'economies of scale' trends take hold (see Chapter 2 for the outlook cost reduction potential for GDHP).

How could the RHI help?

While an RHI which rewards generation of renewable heat would not reduce the upfront cost of GDHP technologies initially, it would go some way to improving the economic viability of the technology from the perspective of the end customer. It is highly likely that the introduction of an RHI would stimulate the market for GDHPs, creating the investment for manufacturers to invest in technology R&D, industrialisation of production, development of sales channels and servicing and maintenance networks. If implemented alongside a marketing and awareness raising campaign, this will result in sales increasing sharply - which in turn would lead to upfront costs coming down. Further, an RHI is likely to create more confidence for the wider industry to create financing packages and ESCo models, for example, which take the upfront cost and technology risk away from the end-user.

Policy & regulatory framework

In order for GDHP products to be seriously considered as a viable option within the non-domestic sector, the technology must be 'on a level playing field' with competing technologies. At this relatively early stage of their market emergence in the UK, if GDHP are to reach their potential market, they need to be recognised and given fair treatment relative to other technologies, for example, based on their relative primary energy efficiencies and carbon saving potential. As it stands today, the policy and regulatory framework remains a significant barrier for GDHP to overcome.

How can this be overcome?

Policy should aim to put all commercial renewable heating technologies on an even playing field rather than over-incentivising one, which can skew the market.

How could the RHI help?

If the RHI was structured in such a way that GDHP technologies were given comparable treatment to other technologies already listed within the non-domestic RHI, it is likely that the UK would witness a significant upturn in GDHP unit sales.

Low Awareness & technology perception

Lack of awareness and/or in some cases poor perception of GDHP technology due to lack of information (and previous bad experiences) is pervasive across the value chain - from the end-user (who is not requesting GDHP) to the installer (who is not confident to install GDHP) to the contractor (who does not know where to go to source a GDHP), to the specifier (who will not specify GDHPs).

Selected views from primary research: Perception of GDHP – why have they not been installed?

Among specifiers, GDHP is occasionally viewed as a 'risky' technology as it is less established within the UK market. A specifier commented *"Why would we choose an unknown technology when we can more quickly design a boiler solution which we know works?"*

Within some established boiler vendors, GDHP is viewed among some sales staff as *a "very disruptive, expensive technology which distracts from their core business of selling boilers".*

And even amongst end-users who have installed a GDHP there is still some fear of the unknown *"The GDHP works now, but we do have worries about future problems, as the system is complex"*

Further, there is a **legacy of mistrust in the industrial sector following a number of unsuccessful GDHP demonstrations in the 1980s, undertaken in the malting & textile sectors.** This concern is pervasive amongst process engineering consultants, specifiers and installers (and some end-users) regarding poor reliability, lack of operational savings and high maintenance cost associated with the industrial GDHP demonstration schemes installed in the 1980s. The UK Energy Efficiency Office published a number of reports and Case Studies associated with the following trials:

- Gas driven heat pump in a textile works at Vitatex Ltd, Slough (1982)
- Demonstration of a large gas engine-driven heat pump for industrial process use at Associated British Maltsters Limited, Newark (1981)
- Gas driven heat pump in a maltings (same company as above but a second, larger installation) (1982)
- Heat recovery by steam turbine driven heat pump "The Marfleet Refining Company Ltd (1982)
- Heat recovery by heat pumps in a dairy Midland Counties Dairy Ltd (1981)

It is important that the shortcomings of these schemes are fully understood and disseminated, so that the next generation of industrial scale GDHPs are designed, installed to operate effectively.

There are a number of factors which contribute to GDHP product awareness levels remaining very low:

- Some vendors appear not to be proactively marketing the technology to their customers. The larger vendors (e.g. the boiler companies) who offer GDHP products do so as an aside to their more main-stream offerings – typically conventional boilers and/or cooling technologies. In most cases, it appears that vendors only engage in sales of GDHP products if there is first a 'customer pull' for the technology – whether from an energy saving perspective or other motives.

- Within the UK, there are few products available on the market today. This contributes to a lack of competition and less 'market push'.

Where there is awareness, the way GDHP is perceived within industry is a challenge to be overcome. In some quarters, GDHP is not perceived to be a renewable energy technology as they require natural gas as a fuel. This view continues to undermine the environmental benefits GDHP technologies exhibit over conventional solutions. Further, there are perceived concerns over the use of ammonia as a working fluid – explored in the text box on the next page – which again reflects a lack of information.

How could the RHI help?

The RHI would almost certainly add weight to the credibility of the technology, and establish a market which would, in all probability and over time, diminish negative perceptions of the technology within the heating industry.

A cross-industry marketing and awareness raising campaign which engages both industry bodies such as the Heat Pump Association, utilities, and associations representing installers, contractors and other building services professionals, is critical to raising the profile of GDHP amongst potential specifiers and customers of GDHP products. Demonstration and dissemination of results from well-designed, installed and operated installations should occur. Consideration should be given by DECC to making the RHI conditional upon recipients monitoring and publically sharing the performance and return on investment - which can feed into information dissemination. In addition, developing a consistent vision for GDHP which can be shared across the industry, identifying the end goal, and defining measures required to achieve this goal is also necessary.

Safety concerns about the toxicity of Ammonia

The use of ammonia as a working fluid (as in some absorption or adsorption systems) has been cited as a potential safety concern for GDHP because of its toxicity. This issue is more of a challenge in terms of 'perception' than in real safety issues, based on experience in the heat pump and refrigeration industry which show that the risk from ammonia leaks from GDHP is not significant:

- GDHPs are generally pre-charged and hermetically sealed at the factory, so the installer does not typically have to handle the ammonia (installation is the most likely time for refrigerant leakage).
- GDHPs assessed in this report are for outdoor installation and often on roves, far away from any end-users – so there is no chance of leakage inside buildings.
- Ammonia is in fact used in many systems commonly used every day such as fridges in hotel rooms – the real risk of toxic leaks here is incredibly low based on the years of successful experience.
- Ammonia is well tested and used in larger electric heat pump installations, with no real problems.
- Even in the very unlikely case of an ammonia leak, ammonia can be detected through smell long before it becomes a health risk – which makes it far less dangerous to end-users than carbon monoxide or other leaks from a standard gas boiler.

The challenge for the industry is to reduce the *perceived* risks associated with ammonia leakage through information dissemination.

Development of sales channels and routes-to-market

Even where a GDHP is sought, it is still relatively difficult to source one, due to low product availability (only 2-3 products have UK sales channels, based on outcomes of our interviews across the UK GDHP and heating industry), and the limited availability of installers (one contractor suggested that there were "no more than 6 installers in the UK able to install a Gas Absorption Heat Pump - and the figure is much less for Gas Engine Heat Pumps").

The creation of sales channels and established routes-to-market is a key challenge which needs to be addressed if and when GDHP are to become a mature product offering. Currently, conventional heating suppliers are not actively driving sales of GDHP (even if they offer GDHP products as an aside to their mainstream offerings). This can partly be attributed to sales personnel not having the necessary experience when it comes to selling the product (for example, highlighting the attributes of a more expensive, yet more efficient alternative to their usual offerings), and also the significant challenge in training traditional heating installers to be able to install GDHP. Currently, as the market for GDHP is so small in the UK, there is no clear rationale for conventional heating suppliers to disrupt their existing activities (normally centred around boilers) to accommodate parallel sales channels for GDHP. It is generally accepted among heating companies that GDHP activities will increase in time, but that it will be a 'steep learning curve' and one which suppliers don't wish to take on until there are stronger drivers in place.

"Our commercial heating installation company is so busy installing boilers on a day to day basis that they have limited time to try to sell Gas Heat Pumps" - UK Utility

The current lack of an established, nation-wide maintenance network to provide back-up support and servicing for GDHP is a real challenge for the technology - particularly for GEnHPs which have higher maintenance requirements than GAbHPs. Without this, it is less clear how the technology can reach a mass market, so up-skilling installers in GDHP maintenance, and manufacturer support with developing distribution partnerships within regions, is key to achieving a mature GDHP market.

How can this be overcome?

These challenges will likely be overcome when customer demand for GDHP increases to a level where vendors view the size of the opportunity as sufficiently large to warrant the development of sales channels dedicated to the technology. Furthermore, the establishment of installer training schemes and GDHP distribution partnerships in regions throughout the UK would likely help with issues of maintenance and routes-to-market, respectively.

How could the RHI help?

The establishment of an RHI for GDHP would – in all likelihood – kick-start the industry, with sales channels, installer networks and maintenance teams quite quickly set up to meet the inevitable growing demand from customers.

What are the commercial implications of the F-Gas Directive for GDHPs?

The EU F-gas regulations will result in a reduction of emissions from fluorinated greenhouse gases (F-gases), including HFCs, by two-thirds of 2012 levels by 2030 and ban the use of F-gases in some new equipment (where viable climate-friendly alternatives are readily available).

GAbHps generally utilise natural working fluids such as ammonia and water (whose use will not be restricted by the F-Gas Regulation). As a consequence GAbHPs may benefit from the phase-out of F-gases, potentially being selected as an option rather than an electric heat pump / air conditioning system which is more likely to use F-gases.

Conversely, GEnHps coupled to VRF systems currently utilise F-gases and it is unclear what replacement working fluids will be adopted and/or the impact the F-gas phase-out will have on GEnHp VRF SPF.

The F-gas regulations may stimulate the early replacement of some existing refrigeration and heat pump systems with non-F gas containing equipment – however, the extent that this will occur and/or impact upon the demand for GDHP's cannot be predicted.

5. Future Outlook: Scenarios for GDHP market growth

Key messages

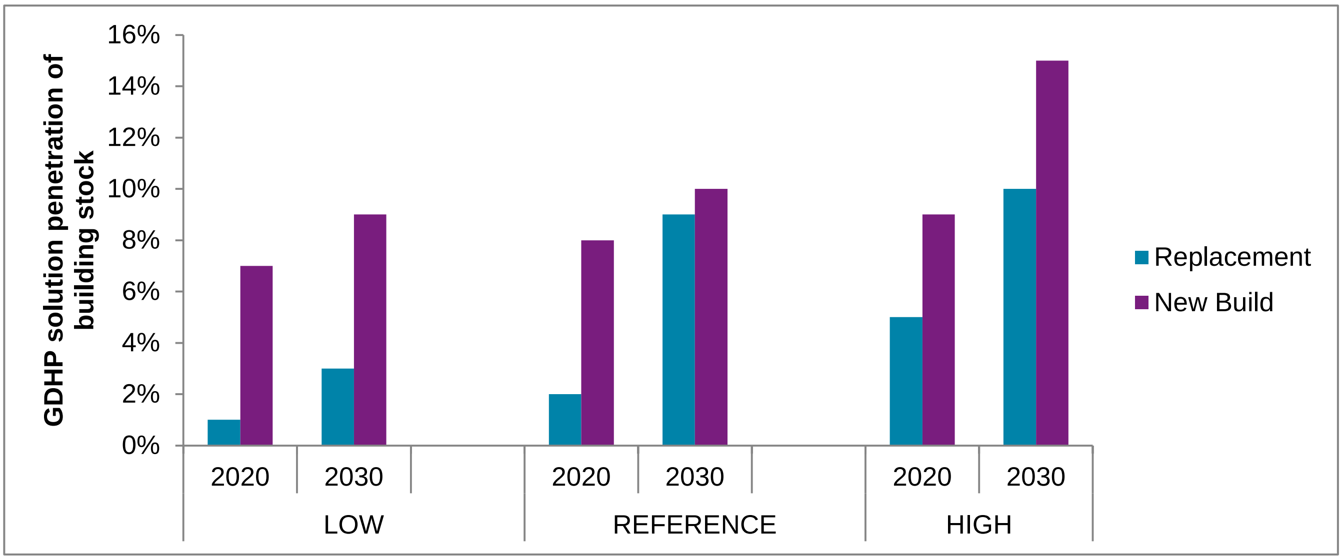
There is significant opportunity for GDHPs to exploit a share of both the new build and existing building market, and therefore significantly contribute to the decarbonisation of the non-domestic building sector. The total addressable market is relatively small – around 40,000 heating systems / year in the replacement sector and ~600 new builds per year, which means the total numbers of GDHP likely to be deployed are relatively small (when compared with numbers in the residential sector) - however, the potential emissions savings are high:

- There are limitations on the electrical capacity which can be added to the existing grid without costly grid upgrades by the end-user / developer, which is a prevalent issue particularly in the UK due in part to the single phase supply. The prohibitive costs of the electrical upgrade are a primary driver for existing GDHP installation. In the long-term, GDHP represent a strong opportunity to minimise electrical grid impact.
- GDHP have an advantage over other technologies because of their ability to provide heating, cooling and hot water with a single system.
- Our initial modelling suggests that GDHP can already provide a strong economic proposition in some sectors, with paybacks under 5 years achievable, particularly in off-gas applications (using LPG).
- There is a significant opportunity for GDHP to be deployed across a wide range of end-user sectors, with the best opportunities lying in those sectors with the greatest demand requirements. The majority of current installations in the UK are in only in a small number of sectors (e.g. schools, care homes, hospitals), but experience from Europe highlights the potential for successful application in many more sectors which have thus far been penetrated only to a limited extent in the UK (e.g. multi-family homes, offices, industry). The reasons that GDHP are not deployed significantly in these sectors in the UK is not because the UK is unsuitable, but rather because of the market barriers identified in Chapter 4.
- The industrial sector offers considerable scope for the adoption of heat pumps, however, the market is likely to remain very small unless DECC broadens the definition of RHI eligible systems to include; waste (and possibly biomass) heat driven systems and open cycle/vapour compression systems (i.e. an industrial heat pump RHI should not be limited to GDHPs as currently defined by DECC).
- The EU RES Directive (2009/28/EC) limits the definition of energy captured by heat pumps to be considered as renewable energy to “aerothermal, geothermal or hydrothermal” sources. Clarification is required from DECC and the European Commission, since a literal interpretation of the current definition of a renewable energy source, could severely limit the potential offered within the industrial sector associated

with waste heat recovery and/or opportunities for very high COP open cycle/vapour compression systems (and waste driven systems).

We have modelled three scenarios for GDHP market uptake in this chapter. Please note that the outcomes are based on limited available data[17], and are combined with expert views informed by and tested with our extensive network across the industry. Further work should be done to fill in the data gaps – particularly as identified in Appendix D – if strong conclusions are to be drawn from the data.

- In the low scenario, GDHP sales per year increase from ~300 per year in 2014, to 650 per year by 2020 and to 1,500 per year by 2030.
- In the reference scenario, GDHP sales per year increase from ~300 per year in 2014, to 1,200 per year by 2020 and to 2,700 per year by 2030.
- In the high scenario, GDHP sales per year increase from ~300 per year in 2014, to 2,500 per year by 2020 and to 5,500 per year by 2030.
- We present below how these numbers translate into penetration of the heating market in new build and replacement in each scenario:



The key factors affecting the uptake rates in each scenario

Figure 15: GDHP penetration of heating market

Source: Delta-ee modelling – see Appendix C for modelling assumptions and information sources

The key factors affecting the uptake rate in each scenario are:

- Existence of an RHI
- Level of awareness of GDHP
- Perception of GDHP

[17] The gaps lie particularly around performance data for GEnHPs which was available only in very limited supply (including no real field test data). Further, building stock data pertaining to heat demand in different sectors is also relatively limited.

- Level of choice for an alternative system
- Treatment of GDHP in future building regulations
- Level of supply chain development (including scaling up of production facilities)
- Level of R&D in technology development

Methodology for developing GHDP Deployment Scenarios

As requested by DECC, the extensive description and discussion of how the deployment scenarios were calculated is provided at the end of this document in Appendix G.

GDHP deployment scenarios

Based on the analysis of market uptake rates based on firstly economics and secondly the influence of 'soft' factors, we have developed three broad Scenarios for market uptake. We provide a description below to illustrate what each Scenario looks like. The descriptions are not comprehensive but are intended to paint a picture of the type of activities and status which may be expected.

	Low Scenario	**Reference Scenario**	**High Scenario**
Economic inputs			
RHI	None	RHI at 1.2p / kWh	RHI at 1.2p / kWh
Upfront cost reduction	Low (rates as detailed in Table 8)	Reference (rates as detailed in Table 8)	High (rates as detailed in Table 8)
Efficiency increase	Low (rates as detailed in Figure 3)	Reference (rates as detailed in Figure 3)	High (rates as detailed in Figure 3)
Soft factors (see Table 26)			

	Low Scenario	**Reference Scenario**	**High Scenario**
Awareness	Marketing / awareness-raising led almost only by GDHP industry, limited involvement from heating/utility industry or government. By 2020: Stays at today's low level – only innovators. By 2030, limited increase but primarily amongst innovators and some early adopters.	Marketing / awareness-raising by heating industry, utilities & government – not necessarily all telling same message By 2020: >30% of building service professionals have heard of GDHP, >10% understand them & there is some limited customer awareness. By 2030: >50% of building service professionals have heard of GDHP, >30% understand them & increasing customer awareness leading to some requests for info on GDHP	Marketing / awareness-raising by heating industry, utilities & government – united message By 2020: All building service professionals have at least heard of GDHP, many understand the proposition. Increasing customer awareness leading to customer requests By 2030: All building service professionals understand the GDHP proposition, many customer requests
Perception	Information about GDHP is limited and not enough from impartial sources By 2020: Mistrust pervades as today, many have the perception of expensive, unreliable untested technology By 2030: Improvement from 2020 through increased knowledge of limited number if installs	Information dissemination from trusted e.g. government and utility sources, based on limited currently available data By 2020: Mistrust amongst some but technology increasingly proving itself, mis-trust is balanced by positive view in some sectors By 2030: Mistrust amongst some but technology increasingly proving itself, mistrust is balanced by positive view in most sectors	Strong information dissemination campaign providing e.g. GDHP trial data or many case-studies proving performance. By 2020: GDHP accepted as a viable technology as an alternative to traditional or other renewable systems in many sectors By 2030: GDHP preferred trusted solution in some sectors and recognised as viable in most sectors

	Low Scenario	Reference Scenario	High Scenario
Level of choice for alternative system	By 2020: As today - wide choice of lower cost, more trusted alternatives in most sectors By 2030: Possibility that new competing technologies are emerging which reduce the GDHP opportunity	By 2020: GDHP increasingly seen as one of the stronger options or one of few options By 2030: Possibility that new competing technologies are emerging which reduce the GDHP opportunity	By 2020: Many sectors have very limited choice and GDHP is one of few choices and/or GDHP outperforms or is lower cost than most alternatives By 2030: Possibility that new competing technologies are emerging which reduce the GDHP opportunity
Treatment of GDHP in future building regulations	By 2020: GDHP only installed in a limited number of new buildings, not a requirement to meet regulations By 2030: Under stronger regulations GDHP don't qualify for building regulations	By 2020: GDHP amongst the choices of technology to meet or exceed building regulations By 2030: GDHP amongst choices – possibility of emerging technologies competing more strongly reducing the opportunity	By 2020: GDHP may be only or one of very few solutions which can meet regulations By 2030: Regulation stronger, though possibility that new competing technologies are emerging which reduce the GDHP opportunity
Level of supply chain development	Limited investment in developing supply chain By 2020: <10 sales channels for GDHP (as today) By 2030: not much growth from 2020	RHI gives industry confidence to invest in some supply chain developments By 2020: Supply chain can support doubling or more of sales from today in some parts of the UK / for some GDHP technologies (10s of sales channels) By 2030: Supply chain can support significant growth across a large part of the UK (i.e. >100 sales channels)	RHI gives industry confidence to invest in significant supply chain developments & industrialisation of production By 2020: Supply chain can support order of magnitude market growth in some parts of the country / with some technologies (>100 sales channels) By 2030: Fully established with 100s of sales channels
Market characteristics			

	Low Scenario	Reference Scenario	High Scenario
Type of GDHP	By 2020: Today's trend continues – only 2 or 3 available products, with GAbHP from one supplier dominating By 2030: Some limited expansion of GEnHP activities	By 2020: >5 products available in UK, GAbHP (sold through boiler companies, utilities and own brands) plus GEnHP (sold through own brands, possibly utilities). Emergence on small scale of some new concepts but commercialisation by 2020 unlikely By 2030: More choice of products with more different GAbHP manufacturers on market & more Asian GEnHP companies in Europe. Some biogas products likely. New concepts commercialised	By 2020: 5-10 products available, including existing products plus new players in GAbHP; more Asian GEnHPs targeting Europe & UK with cheaper a/w systems; commercialisation of some new concepts; R&D in biogas By 2030: Wide range of products available in UK; biogas options commercially available

Table 12: Outline of characteristics of each GDHP market uptake Scenario

Source: Delta-ee analysis based on primary research – interviews across the GDHP and wider heating industry in the UK and Europe, to understand how well and how quickly market barriers have been addressed in other sectors and countries.

Notes regarding the modelled Scenarios

We present the uptake graphs in the following section.

- The modelled Scenarios refer to market uptake for GDHP primarily for heating. While cooling is outside the scope of the Renewable Heat Incentive, it should be considered that the ability of GDHPs to produce cooling is often a strong driver for GDHP installation. If we included GDHP with more of a cooling focus, the total numbers are likely to be higher.
- The number of GDHPs presented in the Scenario graphs in the Figures below refer to the total number of GDHP *units* installed, including each individual GDHP which may be installed at any single site.
- The Summary graph below represents the penetration of GDHP *solutions* at replacement / new build sites at which GDHP are deployed, where a cascaded set of several GDHP at one site counts as one 'solution'.

Summary: Penetration of heating market in each scenario

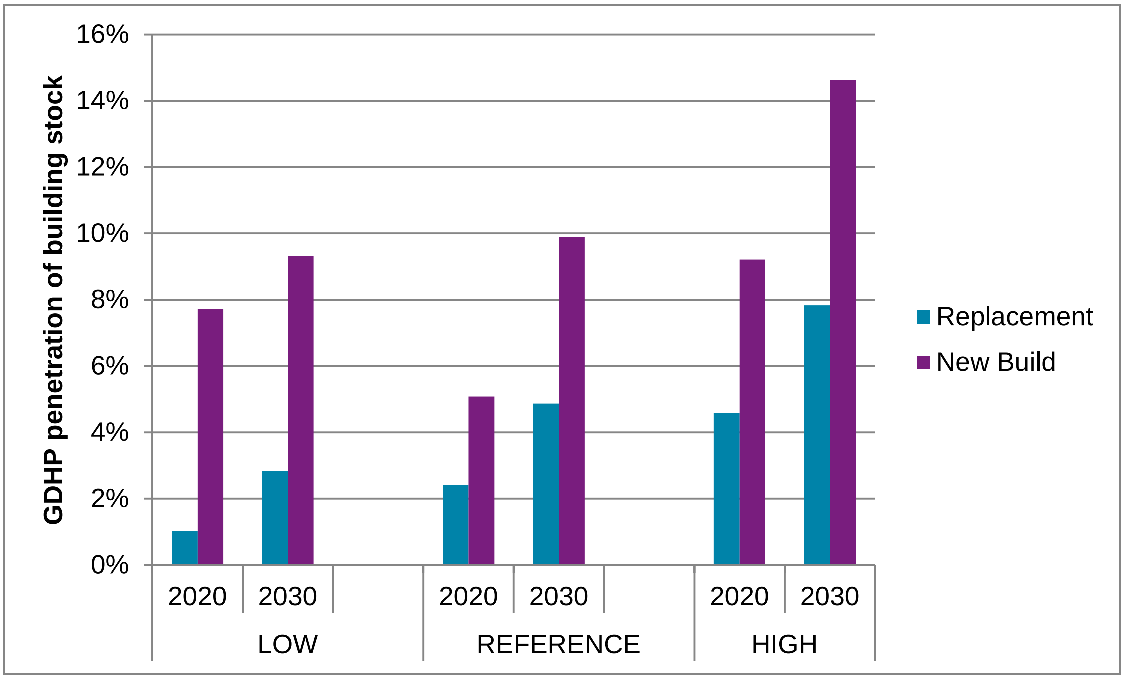


Figure 16: GDHP solution penetration of building stock

Source: Delta-ee modelling – see Appendix C

Low GDHP Uptake Scenario: Business as usual

No RHI, significant market barriers, low awareness

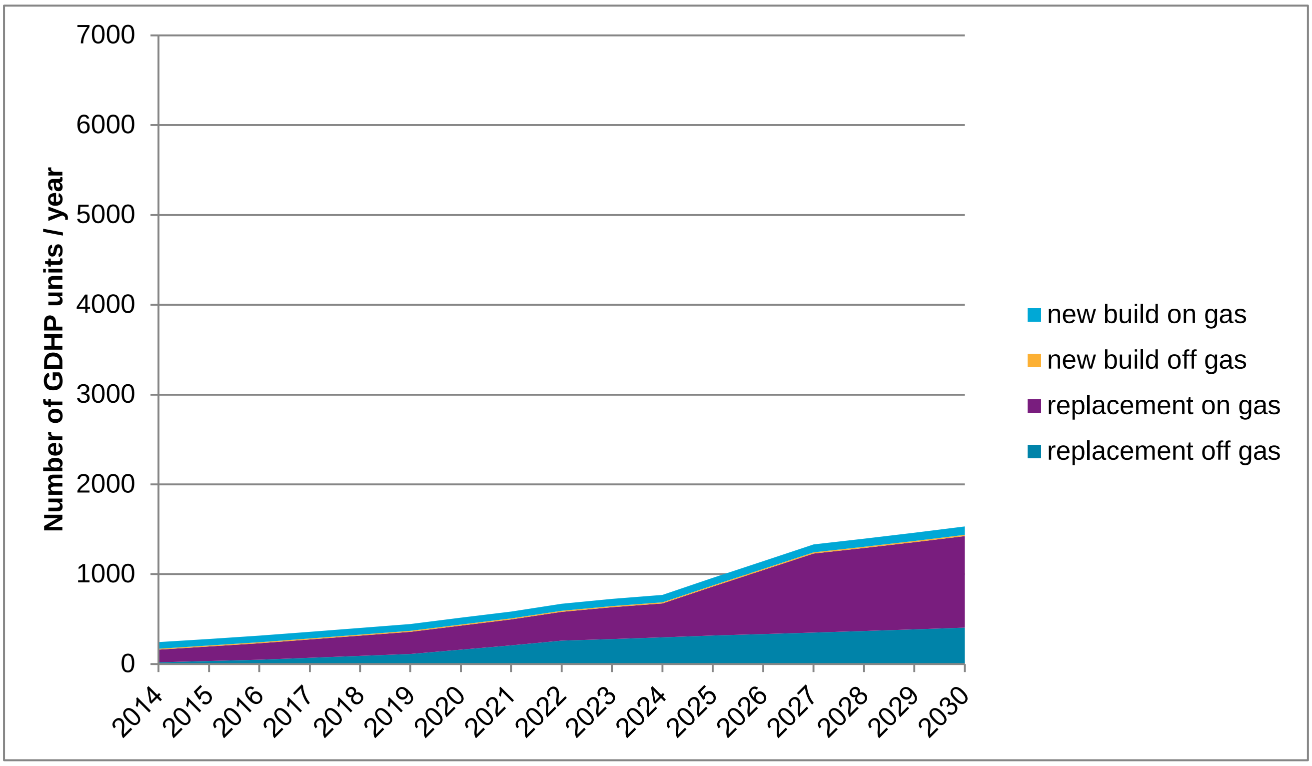


Figure 17: Low Scenario

Source: Delta-ee modelling (see Appendix C for assumptions)

	2014	2020	2030
Replacement	<1% (160 units)	1% (428 units)	3% (1,424 units)
New Build	<5% (80 units)	7% (80 units)	9% (108 units)

Table 13: Approximate penetration of heating market in Low Scenario (% of sites with GDHP solutions – combined on-gas and off-gas)

Source: Delta-ee modelling (see Appendix C for assumptions)

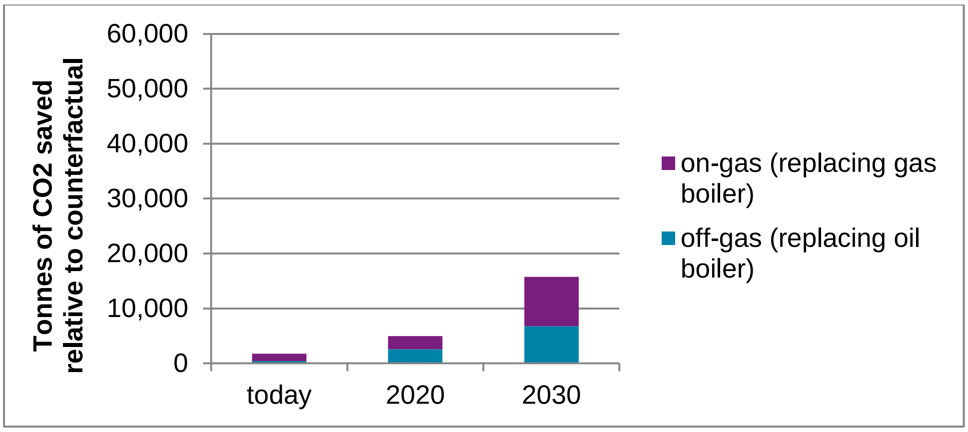


Figure 18: Renewable contribution associated with Low Scenario

Source: Delta-ee modelling (see Appendix C for assumptions including carbon factors of different fuels)

Reference Scenario: Moderate Growth

With RHI, some barriers remove, increasing market awareness

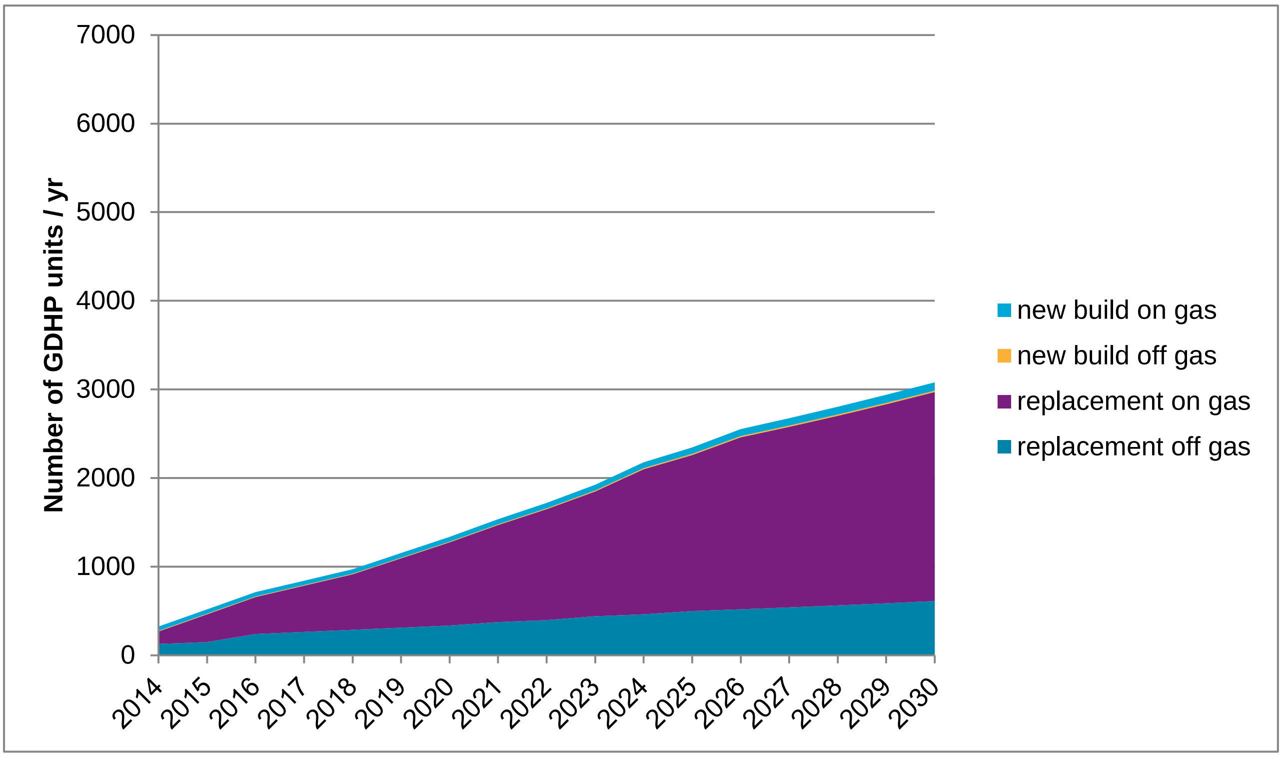


Figure 19: Reference Scenario

Source: Delta-ee modelling (see Appendix C for assumptions)

	2014	2020	2030
Replacement	<1% (160 units)	2% (1,275 units)	5% (2,971 units)
New Build	<5% (80 units)	8% (90 units)	10% (118 units)

Table 14: Approximate penetration of heating market in Reference Scenario (% of sites with GDHP solutions – combined on-gas and off-gas)

Source: Delta-ee modelling (see Appendix C for assumptions)

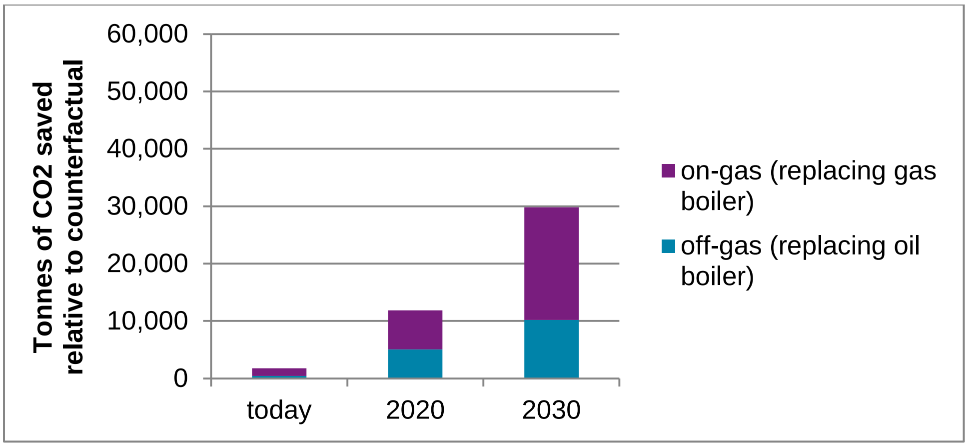


Figure 20: Renewable contribution associated with Ref Scenario

Source: Delta-ee modelling (see Appendix C for assumptions including carbon factors of different fuels)

High Scenario: Strong Growth

With RHI, many barriers remove, high market awareness

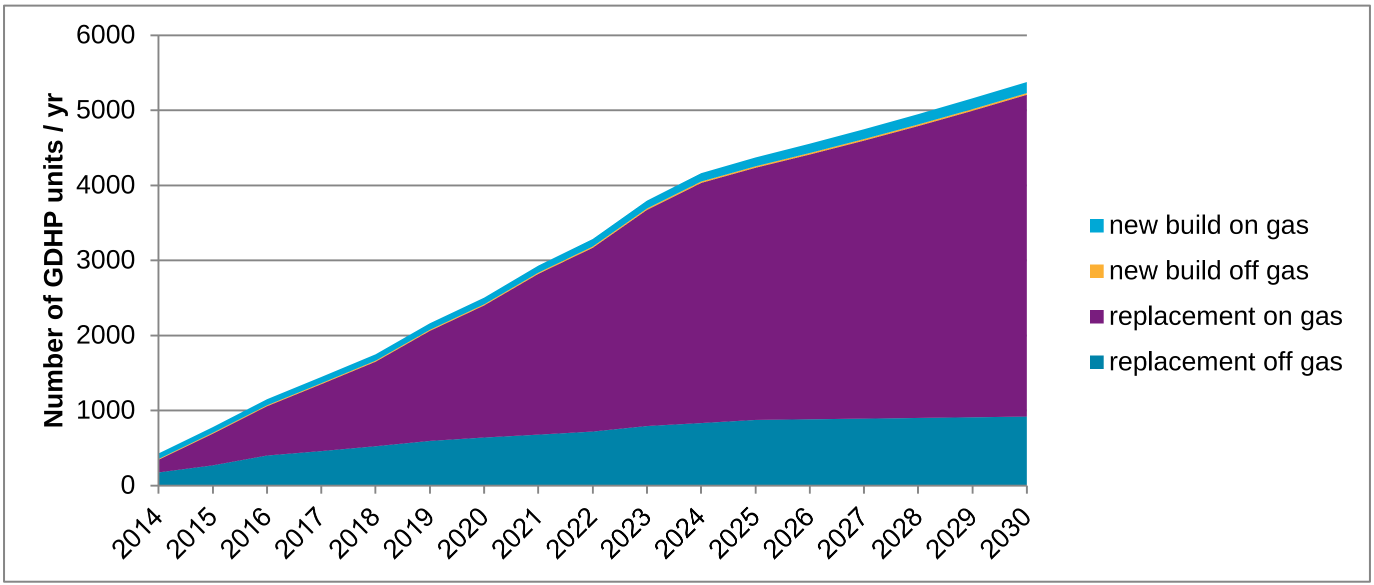


Figure 21: High Scenario

Source: Delta-ee modelling (see Appendix C for assumptions)

	2014	2020	2030
Replacement	<1% (160 units)	5% (2,400 units)	8% (5,207 units)
New Build	<5% (80 units)	9% (103 units)	15% (169 units)

Table 15: Approximate penetration of heating market in Reference Scenario (% of sites with GDHP solutions – combined on-gas and off-gas)

Source: Delta-ee modelling (see Appendix C for assumptions)

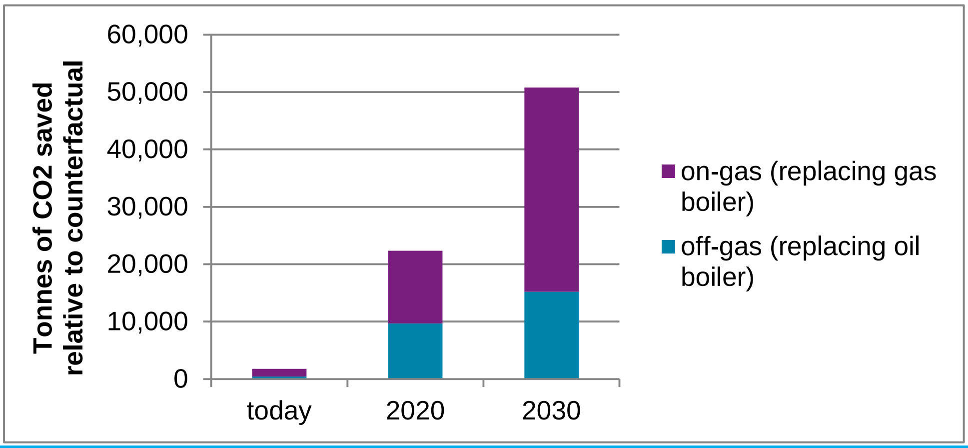


Figure 22: Renewable contribution associated with High Scenario

Source: Delta-ee modelling (see Appendix C for assumptions including carbon factors of different fuels)

6. Recommendations to DECC

Is government intervention necessary?

Government intervention is necessary

Our research indicates that government intervention is necessary in order to stimulate the GDHP market, based on our understanding of the economic proposition which GDHP can provide today combined with knowledge of the many market barriers which exist (discussed in Chapter 4)**.** In the short-term, an RHI will improve the economic proposition sufficiently to make them a possible option for new builds and replacement (for example, bringing payback periods down to within 5-7 years). In the longer term – and most critically – the RHI will give the industry the confidence to invest in developing the supply chain, and in R&D which will lead to efficiency increases and cost-reduction, setting the GDHP industry on course to being a sustainable industry without support.

Ultimately, we do not believe there is any evidence to suggest that GDHPs should be treated any differently from electric heat pumps with regards RHI support. There is a risk for both GDHP and electric HPs that, where the heat pump is not installed optimally (for example where it is over-sized or under-sized for the demand), it may not achieve the primary energy requirement to count as renewable. But the range of GDHP performances we have seen, backed up by anecdotal evidence from industry players including UK utilities and UK distributors and installers, indicates that GDHP can meet RES requirements at present to the same extent that electric heat pumps can.

There is little (no) evidence of heat pump adoption in the industrial sector. However, a number of independent, authoritative studies (commissioned by DECC and the IEA) suggest that heat pumps offer considerable carbon reduction potential the industrial sector. The introduction of an RHI to stimulate heat pump take-up in the industrial sector could enable significant carbon reduction to be achieved at a low abatement cost, although there are potential serious impediments associated with definitions of renewable energy[18].

Key recommendations on how the RHI should be implemented

- **The RHI will go some way to overcoming some barriers** by making the economic proposition more positive. However, an RHI alone will not overcome other barriers.
- **The RHI must come hand in hand with a marketing & awareness-raising campaign** which reaches across the value chain.
- **Manufacturers will invest in advancements to the technology and supply chain** once they have the confidence that policy makers are serious about supporting GDHP on a level playing field with other renewables, and once marketing and awareness-raising campaigns start to increase customer and installer pull for the technology.
- **Special attention should be paid to the building services professionals**

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[18] A major impediment to providing an RHI in the industrial sector may be the definitions associated with renewable heat adopted in the EU RES Directive. However the terminology used in the Directive is ambiguous and it is not clear if waste driven, or open cycle heat pump systems are precluded. It is recommended that DECC reviews the renewable heat definitions adopted in Directive 2009/28/EC to determine how or if they apply to industrial heat pumps.

responsible for specifying new heating/cooling systems in commercial buildings. This is the critical point in the value chain where a decision for a GDHP could be made - but in most cases is not.
- **The RHI design should ensure the possibility exists for 3rd party ownership of renewable systems** – to allow for alternative business models which can reduce upfront costs.
- **It should be considered to require performance monitoring with any RHI installation**, due to the extreme lack of available performance data in the UK.

Is the RHI key to delivering high growth scenario or can high growth happen in other ways?

Our research indicates that some market growth can occur without an RHI through marketing & awareness-raising, and some slow improvements to the economic proposition coming from the industry alone – but in order to reach a high uptake scenario, an RHI is required. We identify two key areas of work which will enable market growth, both of which the government must play a role in. A campaign to achieve (1) alone could enable reaching close to the levels of the Reference Scenario, though likely with around 5 years delay. Implementation of measures to achieve (2) will only be successful if measures are in place to also tackle (1) – and without an RHI the impact will be significantly delayed.

1. **Increasing awareness of and trust in GDHP:** Lack of awareness and lack of trust in GDHP is the biggest market barrier faced today. Some market growth can certainly be achieved through implementing a strong information dissemination and awareness-raising programme (by government and industry). But we do not believe this alone will be sufficient to reach a high growth scenario. Without an RHI, for example, the economic proposition will not be strongly competitive until beyond 2020, which means that the market will be restrained largely to niche applications by innovators and early adopters.
2. **Improving the economic proposition:** The RHI is needed in the short-term to achieve this. The industry can achieve this by itself in the long-term, but without an RHI it is unlikely to have the confidence – or the resources – to invest in the R&D and supply chain development necessary to cut costs, and we would expect the market to remain relatively close to today’s levels until 2020.

Does the amount of renewable heat generated (as defined by commission) create enough reason/benefit to develop an RHI, offer the subsidy and administer it?

Based on our research and data collection, it is clear that GDHP can achieve and exceed the 1.15 SPF necessary to count as being renewable. Further, the renewable heat produced is comparable to that provided by electric heat pumps – which do receive an RHI and have been deemed cost-effective. It is therefore critical that these technologies can all play on the same level playing field. In the long-term, electric heat pumps will become more ‘renewable’, as the electricity grid decarbonises, but there is still a clear window of opportunity for GDHP to provide renewable heat even assuming no decarbonisation of the gas grid (which is not considered in this report but which will increase again the renewable contribution which can come from GDHP).

The most cost-effective sectors are high demand sectors such as health, hotels and restaurants, but there are opportunities across the building stock. There is evidence that the introduction of an incentive would be cost effective in the industrial sectors, in particular associated with the Food & Drink and Paper & Board sectors.

Is RHI the right mechanism to generate growth of the GDHP market?

The RHI is the right mechanism if implemented alongside a strong marketing and awareness campaign, as discussed above. Without this, the RHI will have limited market impact.

Of key importance is that alternative business models involving, for example, third party ownership is legally possible for GDHP under the RHI. Upfront cost is ultimately the biggest economic barrier to GDHP, particularly in the existing building sector, and while the RHI can provide strong economics through lowering payback times, this does not overcome the upfront cost challenge. We can see strong potential for ESCos and other Service providers or utilities employing alternative business models to remove the upfront cost from the end-user and claim back the RHI over 20 years. This possibility will be dependent on the legal framework associated with the RHI – but it could have a significant impact on long-term market uptake.

In the industrial sector, the possible definitional constraints associated with Directive 2009/28/EC suggests that an alternative mechanism might be more appropriate than the RHI. Given the reputational legacy associated with poor industrial GEnHP performance in the 1980's & 90's, consideration should be given to providing grant support to a small number of well-designed demonstration schemes (with monitoring & dissemination of the results). Since the adoption of heat pumps in many industrial processes is already cost effective a mechanism is required to stimulate the generation of best practice design, specification, installation & maintenance and to overcome the poor reputational legacy. This approach would help to stimulate interest & demand in industrial heat pumps, without requiring long-term RHI support.

Is there any risk of 'perverse' incentives?

Risk of displacing other technologies?

Our research indicates that GDHP are not generally being installed instead of other renewables, but rather instead of other gas or electric VRF/cooling technologies. Many other renewable technologies (e.g. electric heat pumps) are generally installed in off-gas grid areas because even with an RHI, it is difficult to compete with gas. Therefore, an incentive for GDHP would rather support and incentivise decarbonisation of the challenging on-gas grid sector rather than displacing other renewables.

There is more competition in off-gas grid areas where GDHP today replace LPG and oil, and compete with electric heat pumps and biomass. The tariff levels should be set so as not to over-incentivise one of these technologies.

Revisions to Part L

The revisions to Part L of the Building Regulations being introduced in 2014 (and subsequent planned revisions to 2019), will result in the space heating demand in new or renovated buildings falling to a minimal (near non-existent) level. There are dangers that the introduction of an RHI associated with GDHPs could result in the technology being deployed as a subsidised/incentivised way of achieving Part L compliance and/or BREEAM credits. From a perspective of UK carbon reduction, this could be a highly perverse outcome, with a real risk that the GDHP will be primarily used to provide cooling. Furthermore, the availability of a GDHP RHI could result in new buildings being specified with a thermal performance no better than the minimum Part L FEES fabric compliance requirement (resulting in a cost saving to the developer, but considerable additional carbon emissions over the life of the building).

This unintended consequence of a GDHP RHI could be mitigated by limiting access the incentive to hard to heat/treat existing buildings (particularly where legacy buildings have simultaneous heating (and/or SHW) & cooling demands

What potential for gaming exists in the market?

Most GDHPs currently being installed in the UK are specified as a low cost way of providing cooling/air-conditioning in buildings where the electrical infrastructure capacity is limited. Again, it would be perverse to provide an RHI to incentivise the adoption of air-conditioning in new and refurbished buildings, where alternative low-carbon design solutions might enable the requirement for air-conditioning to be eliminated.

Furthermore, the majority of GEnHP VRF systems are capable of providing simultaneous heating and cooling. VRF systems are potentially highly problematic in terms of metering for the purposes of an RHI payment, since it is impossible to determine the proportion of gas consumption associated with heating and/or cooling. If an RHI is introduced for VRF systems capable of providing simultaneous heating & cooling, then there is a considerable risk of gaming, particularly if the heating proportion is based on a deemed estimate. To avoid this risk DECC should consider limiting any GEnHP/VRF RHI to heating only installations, however, this would significantly limit market take-up. Alternatively, the RHI could be based on the GEnHP hot water generation/utilisation within the building (as measured by a heat meter) –again precautions would be required to avoid gaming by heat dumping.

Potential for GDHP in industrial applications

This GDHP review has identified very considerable scope for the deployment of heat pumps in industry. However, current installations are at a de-minimis level (indeed we have identified no industrial installations of GDHPs as defined by the scope of work specified by DECC for this review).

DECC are strongly encouraged to consider an incentive and/or grant-funded demonstration scheme, with monitoring & dissemination, for all types of industrial heat pump (i.e. not only gas driven, but also include electric & waste heat driven systems, open cycle vapour compression heat pumps etc). This could be within the scope of a non-domestic RHI or as a separate initiative.

There is clear evidence that new skills are required in the design, specification, installation & maintenance of industrial heat pumps and a mechanism/incentive which stimulates the demand for industrial heat pumps is required and could be very effective.

The national carbon abatement potential associated with this recommendation is likely to be very considerable (NB we have not attempted to quantify the carbon saving potential, since most of the system types fall outside the scope of this study, however prior studies by DECC, US DoE, UK EEO and the IEA confirms that the carbon saving opportunity is considerable)

Appendix A: Types of heat pump included within the review

Within ITT scope

	Fuel	Non-domestic building applications	Industrial applications	Note
Internal combustion engine systems	Natural gas, LPG, Biogas	✓	✓	In scope
Turbine	Natural gas, LPG, Biogas	✓	✓	In scope
Organic Rankine Cycle	Natural gas, LPG, Biogas	✓	✓	In scope
Stirling/Brayton cycle	Natural gas, LPG, Biogas	✓	✓	In scope
Adsorption	Natural gas, LPG, Biogas	✓	✓	In scope
Absorption	Natural gas, LPG, Biogas	✓	✓	In scope

Outside ITT scope

Other fossil fuel fired systems	Heavy Fuel Oil, Diesel, coal, coke etc.	✓	✓	Non-compliant with ITT (except possibly with gasification-see note below)
Other renewable liquid fuel fired systems	Liquid biofuels (bioethanol/biodiesel)	✓	✓	Non-compliant with ITT (except possibly with gasification-see note below)
Biomass fired systems	Biomass	✓	✓	Non-compliant with ITT (except possibly with gasification-see note below)
Other renewable energy sources	Refuse derived fuel fired	✓	✓	Non-compliant with ITT (except possibly with gasification-see note below)
Waste heat thermally activated heat pumps for process integration	Process heat recovery	n/a	✓	Non-compliant with ITT - not "gas driven"
Mechanical vapour recompression (open cycle) for distillation, solvent recovery, concentration etc.	Any	n/a	✓	Non-compliant with ITT - not included in Para. 44 type specification

NB "Gas" driven systems are assumed to include natural gas, LPG and biogas systems where a gasifier is used with a carbonaceous feedstock are excluded

Appendix B: Source information on Heat Pumps in Industrial Applications

For more information on the technological possibilities and favourable and less favourable applications for thermally driven heat pumps in the industrial sector, we recommend the following sources: **Industrial Heat Pumps for Steam and Fuel Savings U.S. Department of Energy Energy Efficiency and Renewable Energy DOE/GO-102003-1735 June 2003**[19]**.** We present one of the key tables from this document on the next page.

NB: Most of the industrial applications identified in the US DoE report are out-of-scope with this study (since they are generally either not gas driven and/or are open cycle systems (or waste heat driven), however, in the context of a non-domestic RHI, considerable scope exists to utilise heat pumps for industrial decarbonisation and DECC is recommended to consider the scope offered by these systems in any future RHI review.

[19] http://www1.eere.energy.gov/manufacturing/tech_assistance/pdfs/heatpump.pdf

Table 1. Representative Overview of Heat-Pump Applications in Industrial Manufacturing Activities

Industry	Manufacturing Activity	Process	Heat-Pump Type
Petroleum Refining and Petrochemicals	Distillation of petroleum and petrochemical products	Separation of propane/ propylene, butane/butylene and ethane/ethylene	Mechanical Vapor Compression, Open cycle
Chemicals	Inorganic salt manufacture including salt, sodium sulfate, sodium carbonate, boric acid	Concentration of product salt solutions	Mechanical Vapor Compression, Open cycle
	Treatment of process effluent	Concentration of waste streams to reduce hydraulic load on waste treatment facilities	Mechanical Vapor Compression, Open cycle
	Heat recovery	Compression of low-pressure waste steam or vapor for use as a heating medium	Mechanical Vapor Compression, Open cycle
	Pharmaceuticals	Process water heating	Mechanical Compression, Closed cycle
Wood Products	Pulp manufacturing	Concentration of black liquor	Mechanical Vapor Compression, Open cycle
	Paper manufacturing	Process water heating	Mechanical compression, Closed cycle
	Paper manufacturing	Flash-steam recovery	Thermocompression, Open cycle
	Lumber manufacturing	Product drying	Mechanical Compression, Closed cycle
Food and Beverage	Manufacturing of alcohol	Concentration of waste liquids	Mechanical Vapor Compression, Open cycle
	Beer brewing	Concentration of waste beer	Mechanical Vapor Compression, Open cycle
	Wet corn milling/corn syrup manufacturing	Concentration of steep water and syrup	Mechanical Vapor Compression, Open cycle Thermocompression, Open cycle
	Sugar refining	Concentration of sugar solution	Mechanical Vapor Compression, Open cycle Thermocompression, Open cycle
	Dairy products	Concentration of milk and of whey	Mechanical Vapor Compression, Open cycle Thermocompression, Open cycle
	Juice manufacturing	Juice concentration	Mechanical Vapor Compression, Open cycle
	General food-product manufacturing	Heating of process and cleaning water	Mechanical Compression, Closed cycle
	Soft drink manufacturing	Concentration of effluent	Mechanical Compression, Closed cycle
Utilities	Nuclear power	Concentration of radioactive waste	Mechanical Vapor Compression, Open cycle
		Concentration of cooling tower blowdown	Mechanical Vapor Compression, Open cycle
Miscellaneous	Manufacturing of drinking water	Desalination of sea water	Mechanical Vapor Compression, Open cycle
	Steam-stripping of waste water or process streams	Flash steam recovery	Thermocompression, Open cycle
	Electroplating industries	Heating of process solutions	Mechanical Compression, Closed cycle
		Concentration of effluent	Mechanical Vapor Compression, Open cycle
	Textiles	Process and wash-water heating	Mechanical Compression, Closed cycle
		Space heating	Mechanical Compression, Closed cycle
		Concentration of dilute dope stream	Mechanical Compression, Closed cycle
	General manufacturing	Process and wash-water heating	Mechanical Compression, Closed cycle
		Space heating	Mechanical Compression, Closed cycle
	District heating	Large-scale space heating	Mechanical Compression, Absorption Closed cycle
	Solvent recovery	Removal of solvent from air streams	Mechanical Compression, Open cycle

Appendix C: Modelling Assumptions

The source of all data (unless otherwise stated) is Delta-ee modelling informed by primary research – consisting of extensive interviews with industry experts including manufacturers, distributors, installers and other building services professionals, utilities, academia and independent experts. This is combined with the limited data available from the data collection part of this work.

Assumptions about efficiencies of GDHP and evolution to 2030

Annual efficiency (HHV)

			2014	2020	2030
GEnHP	a/a	SPF	1.30	1.34	1.41
		SPF hot water	1.00	1.03	1.08
		SEER	1.20	1.24	1.30
GEnHP	a/w	SPF hi temp	1.10	1.17	1.29
		SPF lo temp	1.30	1.38	1.52
		SPF hot water	1.00	1.06	1.17
		SEER	1.20	1.27	1.41
GAbHP	a/w	SPF hi temp	1.10	1.17	1.29
		SPF lo temp	1.30	1.38	1.52
		SPF hot water	1.10	1.17	1.29
		SEER	0.55	0.58	0.64
GAbHP	b/w	SPF hi temp	1.20	1.27	1.41
		SPF lo temp	1.40	1.49	1.64
		SPF hot water	1.20	1.27	1.41
		SEER	0.50	0.53	0.59
GAbHP	w/w	SPF hi temp	1.20	1.27	1.41
		SPF lo temp	1.40	1.49	1.64
		SPF hot water	1.20	1.27	1.41
		SEER	0.50	0.53	0.59

- Hi temp = high flow temperature. This figure is used to calculate performance in retrofit (existing buildings) and assumes radiators would be used for heating with flow temperatures of at least 60°C.
- Lo temp = low temperature. This figure is used to calculate performance in new build and assumes underfloor heating or low temperature hydronic heat distribution would be used for heating with flow temperatures in the range of under 35-50°C.
- GEnHP a/a does not have a hi temp / lo temp, because it is air based heat distribution rather than hydronic.

Assumptions about efficiencies of Base Case technologies

BASE CASE: Annual Efficiency		
Off-Gas	η_H hi temp	0.8
	η_H lo temp	0.85
	η_{HW}	0.8
On-Gas	η_H hi temp	0.85
	η_H lo temp	0.9
	η_{HW}	0.85

- Off-Gas base-case technology is currently assumed to be an oil boiler
- On-Gas base-case technology is assumed to be a gas condensing boiler
- At this stage we have not modelled cooling
- We assume no change in efficiency of base case technologies to 2020 or 2030
- “H hi temp” refers to efficiency for space heating in retrofit (flow temperatures >65 degrees C)
- “H lo temp” refers to efficiency for space heating in new build (flow temp <50).
- “HW” refers to efficiency for hot water which we take as the same temp as for hi temp space heating.
- Source info: We referred to the DECC field study of gas condensing boilers20, combined with a Delta-ee view based on conversations with industry experts. For oil, available “real” data is limited, so final numbers we use here are based on a Delta-ee view based on conversations with people in the industry.

Assumptions about the costs of GDHP and evolution to 2020

Fully installed cost / kW (£)

	2014	2020	2030
GEnHP a/a	550	545	539
GEnHP a/w	650	640	631
GAbHP a/w	500	488	475
GAbHP b/w, w/w	800	788	776

O&M cost / kW / year

	2014	2020	2030
GEnHP a/a	9	9	9
GEnHP a/w	9	9	9
GAbHP a/w	7.5	7.5	7.5
GAbHP b/w, w/w	7.5	7.5	7.5

[20] https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/180950/In-situ_monitoring_of_condensing_boilers_final_report.pdf

Assumptions about the costs of Base Case technologies

BASE CASE: Fully installed cost / kW (£)

	2014	2020	2030
On-Gas Boiler	95	95	95
Off-Gas Boiler	105	105	105

BASE CASE: O&M cost / kW / year

	2014	2020	2030
On-Gas Boiler	7.5	7.5	7.5
Off-Gas Boiler	7.5	7.5	7.5

Assumptions about Demand

DEMAND					2014
Very large buildings (boundaries to be defined)	Hi demand	On-Gas	Heating Demand RF	kWh/yr	3066000
			Heating Demand NB	kWh/yr	1533000
			Hot Water Demand	kWh/yr	547281
			Cooling Demand RF	kWh/yr	306600
			Cooling Demand NB	kWh/yr	229950
		Off-Gas	Heating Demand RF	kWh/yr	3066000
			Heating Demand NB	kWh/yr	1533000
			Hot Water Demand	kWh/yr	547281
			Cooling Demand RF	kWh/yr	306600
			Cooling Demand NB	kWh/yr	229950
	Lo demand	On-Gas	Heating Demand RF	kWh/yr	1533000
			Heating Demand NB	kWh/yr	766500
			Hot Water Demand	kWh/yr	273640.5
			Cooling Demand RF	kWh/yr	153300
			Cooling Demand NB	kWh/yr	114975
		Off-Gas	Heating Demand RF	kWh/yr	1533000
			Heating Demand NB	kWh/yr	766500
			Hot Water Demand	kWh/yr	273640.5
			Cooling Demand RF	kWh/yr	153300
			Cooling Demand NB	kWh/yr	114975
Smaller buildings (boundaries to be defined)	Hi demand	On-Gas	Heating Demand RF	kWh/yr	613200
			Heating Demand NB	kWh/yr	306600
			Hot Water Demand	kWh/yr	109456.2
			Cooling Demand RF	kWh/yr	61320
			Cooling Demand NB	kWh/yr	45990
		Off-Gas	Heating Demand RF	kWh/yr	613200
			Heating Demand NB	kWh/yr	306600
			Hot Water Demand	kWh/yr	109456.2
			Cooling Demand RF	kWh/yr	61320
			Cooling Demand NB	kWh/yr	45990
	dema	On-Gas	Heating Demand RF	kWh/yr	107310
			Heating Demand NB	kWh/yr	53655

			Hot Water Demand	kWh/yr	19154.84
			Cooling Demand RF	kWh/yr	10731
			Cooling Demand NB	kWh/yr	8048.25
		Off-Gas	Heating Demand RF	kWh/yr	107310
			Heating Demand NB	kWh/yr	53655
			Hot Water Demand	kWh/yr	19154.84
			Cooling Demand RF	kWh/yr	10731
			Cooling Demand NB	kWh/yr	8048.25

- Our modelling of payback does not yet take into account different building sizes
- Demand is assumed to stay flat to 2030 at present – a rate of decrease could be agreed with DECC

Assumptions about system capacity

- All calculations are based on a 35% load factor - this would have to change to take into account different building sizes which are currently not reflected in the model outputs

Very large buildings (boundaries to be defined)	Hi demand	On-Gas	Heating RF	kW	1000
			Heating NB	kW	500
			Cooling RF	kW	306.6
			Cooling NB	kW	229.95
		Off-Gas	Heating RF	kW	1000
			Heating NB	kW	500
			Cooling RF	kW	306.6
			Cooling NB	kW	229.95
	Lo demand	On-Gas	Heating RF	kW	500
			Heating NB	kW	250
			Cooling RF	kW	153.3
			Cooling NB	kW	114.975
		Off-Gas	Heating RF	kW	500
			Heating NB	kW	250
			Cooling RF	kW	153.3
			Cooling NB	kW	114.975
Smaller buildings (boundaries to be defined)	Hi demand	On-Gas	Heating RF	kW	200
			Heating NB	kW	100
			Cooling RF	kW	61.32
			Cooling NB	kW	45.99
		Off-Gas	Heating RF	kW	200
			Heating NB	kW	100
			Cooling RF	kW	61.32
			Cooling NB	kW	45.99
	Lo demand	On-Gas	Heating RF	kW	35
			Heating NB	kW	17.5
			Cooling RF	kW	10.731
			Cooling NB	kW	8.04825
		Off-Gas	Heating RF	kW	35
			Heating NB	kW	17.5

			Cooling RF	kW	10.731
			Cooling NB	kW	8.04825

Assumptions about emissions factors for different fuels

		2013	Future trajectory – 2030 status
Natural Gas	$kgCO_2e/kWh$	0.1841	Constant - As 2013
Burning Oil	$kgCO_2e/kWh$	0.2456	Constant - As 2013
Fuel Oil	$kgCO_2e/kWh$	0.2688	Constant - As 2013
LPG	$kgCO_2e/kWh$	0.2145	Constant - As 2013

Source: Green Book supplementary guidance: valuation of energy use and greenhouse gas emissions for appraisal, Tables 1-20: supporting the toolkit and the guidance

ELECTRICITY	2013	2014	2015	2016	2017	2018	2019	2020	2021
Services $kgCO_2e/kWh$	0.508	0.483	0.437	0.346	0.313	0.295	0.272	0.233	0.220
Industrial $kgCO_2e/kWh$	0.498	0.474	0.429	0.339	0.307	0.289	0.266	0.229	0.216

ELECTRICITY	2022	2023	2024	2025	2026	2027	2028	2029	2030
Services $kgCO_2e/kWh$	0.231	0.202	0.198	0.181	0.159	0.168	0.149	0.128	0.110
Industrial $kgCO_2e/kWh$	0.227	0.198	0.195	0.177	0.156	0.165	0.146	0.126	0.108

Source: Green Book supplementary guidance: valuation of energy use and greenhouse gas emissions for appraisal, Tables 1-20: supporting the toolkit and the guidance. NB: unless otherwise stated, we always use the figure for “Services”, due to the low level of activity expected in the industrial sector.

Assumptions about fuel costs

	2013	2020	2030
Electricity - Services	9.2	13.3	15.4
Electricity - Industrial	7.8	12.0	14.2
Gas - Services	3.2	3.7	3.8
Gas - Industrial	2.7	3.15	3.2
LPG – Service	6.0	6.3	6.9
LPG - Industrial	6.0	6.3	6.9
Oil - Services	6.1	6.7	7.5
Oil - Industrial	5.9	6.5	7.2

Source (Electricity & natural gas): DECC Updated Energy & Emissions Projections - September 2013, Appendix F, Fossil fuel, wholesale and retail prices; Growth assumptions. NB: unless otherwise stated, we always use the figure for “Services”, due to the low level of activity expected in the industrial sector.
Source (LPG): Delta-ee (and Ecofys) interviews with industry experts and end-users currently using LPG in the commercial sector

Appendix D: Data collection summary & challenges

See separate file

Appendix E: Summary of GDHP product and availability in the UK

Source: Delta-ee primary research- interviews with a wide range of industry experts in the UK and Europe

Manufacturer	Description	Level of commercialisation	Presence in the UK
Absorption			
Robur	GAbHP available in a/w, b/w or a/a, with solar thermal integration possible	10,000 installed in Europe	Available under Robur brand through four distributors, of which ESS currently the most active. Also sold under Bosch and Baxi brands packaged with the boiler companies' controls. 100-200 in total in the UK
Climatewell	OEM absorption unit with new concept involving integrated energy storage, being packaged by others.	Absorption solution fully commercial in other applications, but incorporation into a GDHP still under development	No direct sales channels in UK, and will depend on partners who package the Climatewell solution.
E-Sorp	GAbHP	Not yet commercial - at field trial stage.	Not yet, but sister brand Heliotherm (electric HP) available in UK, and E-Sorp expected to target UK
Gas Engine			
Panasonic	Gas engine driven VRF system. 3 way multi, designed to provide simultaneous heating & cooling plus 2 pipe systems for heating or cooling.	>10,000 / yr installed in Asia and 100s of 1,000s in total - Low 1,000s total installed in Europe (large share old Sanyo units – Sanyo was bought by Panasonic and the technology is now branded Panasonic).	Most active GEnHP company in Europe. UK sellers include Oceanair and ESS, as well as Panasonic UK. Calor has been involved in installation of LPG versions.
Aisin	Gas Engine VRF	>10,000 / yr installed in Aisa; Available in Europe	Minimal (one installer is known to work with

Manufacturer	Description	Level of commercialisation	Presence in the UK
		through Tecnocasa	Tecnocasa)
Mitsubishi Heavy Industries (MHI)	MHI branded gas engine driven VRF system (manufactured for MHI by Aisin but with MHI energy management system). 2 models: 53kW heating (45kW cooling) & 67kW heating (56kW cooling). 3D Air Sales Ltd. literature claims that 16,000of the MHI GDHPs installed in Japan	Supplied in the UK between 2002 and 2008 by 3D Air Sales Ltd. Installations reported at Holiday Inn, Woking, GSK Weybridge & a commercial office in Sheffield. None of these installations are still operational and/ no performance data is available.	3D Air SalesLtd. was acquired by HRP Ltd. in 2008 -no further MHI GDHPs have been sold and HRP has no interest in marketing the product (all staff involved with GDHPs were made redundant in 2008 and HRP have no staff with knowledge of the product or installations.
Yanmar	Gas Engine VRF	10,000 / yr installed in Aisa; limited European availability	None known so far
Tedom	GEnHP designed for simultaneous heating & cooling, based on gas engine technology used in CHP applications	Europe's only GEnHP company – Czech CHP company now branching into GDHP, have installed only a handful in Europe so far, none known in UK.	Limited so far – but the only GEnHP to come from Europe so potentially advantages for UK presence in long-run.
Other			
BROAD	Large **waste heat driven** absorption heat pumps for cooling (630kW cooling capacity), heating and providing hot/cold water in large scale buildings & industrial process. Chilled water to 5°C and heated water up to 95°C(NB: Waste heat driven -out of scope with study)	Installed in industrial applications -waste heat driven	Marsh Environmental are the official UK distributor for the BROAD Absorption Chiller. see http://www.broad.uk.com/
Boost Heat	France-based company developing thermal compressor GDHP	Not yet commercial - at field trial stage.	No availability yet in the UK
Thermolift	US Department of Energy funded company developing thermal HP. The technology may be	Not yet commercial - at field trial stage. First commercialisation will be in US	No availability yet in UK, but Thermolift already developing networks in Europe and likely to target

Manufacturer	Description	Level of commercialisation	Presence in the UK
	similar to products developed in the 1980s, but it is too early to draw conclusions.		UK

Appendix F: Use case examples

Here we present a series of use case examples to illustrate the discussion above, taken from three important sectors for GDHP in the UK today: education, hospitals and hotels. The tables below were used for interviews with end-users and contractors on the various projects.

Education:

Energy demand in school buildings is dominated by heating. Cooling is uncommon and hot water demand is generally low.

The demand pattern of school buildings is very stable throughout the heating period, with demand only reducing during weekends and school holidays. The overall demand in a school is significantly less than in some sectors such as health, meaning that - economically - schools are not necessarily the ideal GDHP installation. Higher running cost savings would be achieved with greater demand. However, there are many GDHP installations in the sector, predominantly for heating and hot water but the ability to provide some cooling is also an advantage.

EDUCATION	**Church of England Academy**
GDHP system	
Robur GAbHP, installed 16 months ago. Provides heating and cooling for the whole school. 3 standard boilers and 6-8 Gas source heat pumps (325 kW heating capacity)	
Demand requirements	
Is it a new build or old building?	*New building*
What is the typical size of your buildings? [e.g. number of rooms, buildings, if possible m^2 of heating/cooling demand]	*Approximately 81 rooms including sports hall, drama area, science laboratories, internal gardens, 550-seat theatre.*
What is the typical energy demand (e.g. in kWh) in your buildings (if possible divided by space heating, hot water, cooling)?	*n/a*

What type of heat distribution do you have (e.g. air-based / hydronic), and if hydronic, what are required flow temperatures (e.g. is it underfloor heat, LT rads, HT rads)	*Underfloor heating and radiators*
Demand profiles: how much do heating/cooling/hot water demands vary throughout a year or throughout a week, or day – e.g. do you have regular predictable 'peaks' in demand?	*Peaks around lunch and in the morning. School is also used in the evening for community activities. So system is used all day.*
Experience with GDHP	
What were the most important criteria for you in choosing the new system?	*1st reason is that C of E academy is an "Eco school" – this is the main reason for the renewable technology. The GDHP enabled points for BREEAM assessment* *2nd factor of consideration - lifetime costs*
What was the sales process?	*An architect designed the school and a contractor was responsible for the GDHP.*
What was your experience like?	*GDHP has been "brilliant" and the respondent is "confident that the technology is good and not likely to go wrong". The integration with BEMS makes the system easier to understand. A gas safety check required every 6 months.*
Are you able to provide any information on costs?	*End-user unsure of costs. Robur marketing materials claim £4,000 / year running cost savings relative to standard gas boiler on this site.*

Table 16: Example use-case - School with GAbHP

Source: Delta-ee primary research

EDUCATION	Suffolk One Sixth Form College
GDHP system	
16 Sanyo/Panasonic GEnHP units installed providing heating & cooling via 283 VRF indoor cassettes and concealed ducted terminal units. A further 3 GEnHP's provide heating & cooling to Air Handling Units providing ventilation. Believed to be the largest GEnHP installation in the UK 	
What is the dominant use for your heating/cooling system (e.g. domestic hot water, space heating, cooling) – and which part of the system does what?	*The system was primarily specified to provide cooling to 20,200m2 of conditioned space. Space heating is mostly provided by a separate ground source heat pumps, however, the GDHPs provide some additional/supplementary heating in cold weather.*
Demand requirements	
Is it a new build or old building?	*New build –4 years old.*
What is the typical size of your buildings? [e.g. number of rooms, buildings, if possible m^2 of heating/cooling demand]	*20,200m2 Detailed breakdown of heated/cooled spaces not available.*
What is the typical energy demand	*Not known*
What type of heat distribution do you have	*Air based. Ceiling mounted cassettes & AHU's.*
Demand profiles	*No peaks. Sync west controls used – simple timer system with step controller.. However physical switch to heat and cool managed by estates.*
Experiences with GDHP	
What were the most important criteria for you in choosing the new system	*Air conditioning was required as a consequence of the college's location next to a major/very busy road. GEnHPs were specified because of constraints in electrical supply capacity to the site. The GEnHPs were a much more expensive option then a conventional electric VRF system, but significantly lower overall cost than upgrading the electricity supply.*
What was the sales process?	*GDHP specified by the M&E consultant (John Packer Associates) as a cost effective alternative to upgrading the site electricity supply.*
What was your experience like?	*The Director of Estates at Suffolk One is very pleased with the performance of the GEnHPs to date. He recognises but accepts the on-going maintenance cost penalty, but considers this to be a small price to pay for avoiding upgrading the site electrical*

	supply. Some control problems have been experienced and poor evaporator defrosting when the units are used to provide heating in the winter.
Are you able to provide any information on costs?	*Total equipment supply cost for 19 GEnHPs including all indoor units and controls = £411,000+VAT (NB excludes AHU's and installation cost).* *The GEnHP installation was part of the Design & Build Contract –no separate GEnHP installation cost is available*

Table 17: Example use-case - School with GEnHP

Source: Delta-ee primary research

EDUCATION	Bethany School
GDHP system	
Gas Driven Heat Pump Installed?	*4 x VRF, LPG 30kW Sanyo units on LPG, Calor gas. Also have solar thermal on the roof to top up. Electrically started.*
What is the dominant use for your heating/cooling system (e.g. domestic hot water, space heating, cooling) – and which part of the system does what?	*HP does heating & cooling. Reclaimed heat from the system heats the swimming pool. Also in the process of planning an indoor swimming pool which reclaimed heat will also be used for.*
Demand requirements	
Is it a new build or old building?	*New build – 5 years old. Building is very cost effective, was a modular/match box build with good thermal properties and sun pipes.*
What is the typical size of your buildings? [e.g. number of rooms, buildings, if possible m^2 of heating/cooling demand]	*Science department – 2 storeys, ~ 60x40m^2.* *Swimming pool - 25 m pool, 6 lane ~15 m.*
What is the typical energy demand	*Energy demand n/a but provided bill comparison;* *Usage from Nov – March £1110 gas bill. (Science building with daily experiments/Bunsen burners etc); Same period for the kitchen (building run on standard boilers) - £3500 gas bill.*
What type of heat distribution do you have	*Air based. Ceiling mounted cassettes.*
Demand profiles	*No peaks. Sync west controls used – simple timer system with step controller. When the timers kicks in it starts a sequence of controls. However physical switch to heat and cool managed by estates.*
Experiences with GDHP	
What were the most important criteria for you in choosing the new system	*Most important criteria was that GDHP was one of the only options available for the school. The position of school is in the middle of nowhere with limited electrical power to the estate.*

	2nd criteria of importance - had already heard about GDHP and had an existing relationship with a supplier (Calor) *Other criteria: (1) minimising running costs to meet end users requirements – heating and cooling. (2) Ticks the green box with planners.*
What was the sales process?	*Estates manager was aware of GDHP and approached Calor and Sanyo for a good deal. Existing relationship with Calor gas on other standard boilers in the school Estates indicated their preference and Calor went away and put together a sales pitch.*
What was your experience like?	*Self-sufficient system, positive feedback. Would recommend – very impressed with the tech. High understanding – 'same as a car engine'. Building can run on 3 out of 4 systems, so prevents against failure. However no problems over the last 5 years.*
Are you able to provide any information on costs?	*GDHP installed cost = £120K per piece.* *Cost of the GDHP is significantly more expensive than LPG gas driven boilers.* *Minimum payback is 10 years.*

Table 18: Example use-case - School with LPG GEnHP

Source: Delta-ee primary research

Health

Hospitals have constant year-round base-load need for hot water, as well as heating and cooling needs. In the wider health care sector, care homes - also identified as a key sector - have high heating demand throughout the year, with higher comfort requirements than most commercial buildings. For GDHP, the health sector is a strong opportunity. The high demand for heating, cooling and hot water create a strong proposition, where GDHP are one of few technologies able to deliver all three needs.

HOSPITAL	Leverndale Hospital
GDHP system	
Gas Driven Heat Pump Installed?	*4 x 40 kW Gas absorption air-source HP units from Robur*
What is the dominant use for your heating/cooling system (e.g. domestic hot water, space heating, cooling) – and which part of the system does what?	*The units are used for underfloor heating – generate heat at around 50 degC. Back-up boiler used to raising T to 60 degC for hot water*

Demand requirements	
Is it a new build or old building?	*new building*
What is the typical size of your buildings?	*n/a*
What is the typical energy demand	*n/a*
What type of heat distribution do you have	*underfloor heating*
Demand profiles	*Fairly constant need for underfloor heating without major peaks*
Experiences with GDHP	
What were the most important criteria for you in choosing the new system	*The reason for installing – BREEAM Excellence Specified*
What was the sales process?	*ESS was the main supplier, McGill was the Contractor*
What was your experience like?	*The installation was excellent, and the technology is working fantastically – no problems at all.*
Are you able to provide any information on costs?	*£76,000 purchase cost from Robur for the 4 units, with the installed cost coming to £82k. The back-up boiler which was installed was £5,500*

Table 19: Example use-case – Hospital with GAbHP

Source: Delta-ee primary research

Hotels

Hotels have generally high demand for hot water, heating and cooling. A wide range of heating/cooling demand must be met across each individual hotel room, determined by individual guest preferences about room temperature. The high and constant demand for heating, cooling and hot water means that again, GDHP can deliver savings. This case-study is from Italy due to lack of available case-studies thus far from the UK.

Use-case	**Holiday Inn Hotel, Bergamo, Italy**
GDHP system	
Gas Driven Heat Pump Installed?	*Robur GAHP solution: x5 reversible HP systems + chillers + heat recovery units (20 units in total) – 435 kW heating capacity; 406 kW cooling).*
What is the dominant use for your heating/cooling system (e.g. domestic hot water, space heating, cooling) – and which part of the system does what?	*GAHP primarily for heating & cooling, hot water backed up by 2 gas boilers & solar thermal (ST meets 70% of HW demand).*
Demand requirements	
Is it a new build or old building?	*new building*
What is the typical size of your buildings?	*New build hotel constructed in 2008, 3,000 m^2 building with 98 bedrooms - 900 m^2 of which is public area* *Thought to be relatively typical of the requirements of a business hotel in a comparable climate (and representative scale – the majority of European hotels have 50-200 rooms).*
What is the typical energy demand	*Total demand for 1 year 450,000 kWh (of which 350,000 kWh is for rooms, the rest common areas – restaurant, halls etc)*
What type of heat distribution do you have	*air-based*
Demand profiles	High heating demand in winter when the temperature can be very cold, and high cooling demand in summer when it can be very hot Because it is a “business” hotel, the main demand is from 5pm – 9am (overnight), with peaks in the evening and the morning.
Experiences with GDHP	
What were the most important criteria for you in choosing the new system	Running cost: Most important criteria – running cost savings relative to traditional system, short payback time Guest comfort: The system needs to ensure that any temperature

	from 18 -26ºC is possible at any time of year. Maintenance requirements: Low maintenance important – it should be "fit & forget". Experience / reputation of contractor and manufacturer: It was important that the contractor had good references from the hotel sector. It helped that Robur is a well respected brand in Italy, the hotel could be confident in the technology. Upfront cost is a consideration, but there was a willingness to invest above the level of a traditional system in order to secure lower running costs.
What was the sales process?	A standard contractor was employed to gather information on the different technology options The management then made the decision to use the GAHP/boiler/solar thermal based primarily on the expected running cost savings compared to an electric HP solution or a traditional boiler / air conditioning system The choice of system was all made via the contractor, but now the hotel goes direct to Robur with any problems.
What was your experience like?	Positive experience – successfully met needs & at lower running cost than traditional system System performance is monitored via Siemens equipment – exact SPFs unavailable, but hotel knows the performance is good because of cost implications.
Are you able to provide any information on costs?	The whole system, including the boiler, solar thermal and heat pump, had an upfront cost 120-125% of the cost of a "traditional" system – gas boiler & air conditioning. Running cost savings over a traditional system of over 25% per year, and payback achieved within 3 years – they are now making money.

Table 20: Example use-case – Hotel with GAbHP

Source: Delta-ee primary research

Appendix G: Detailed methodology for forecasting

We have developed high level market forecasts for GDHP uptake in the UK based on analysis of the building stock, the addressable market (annual replacement and new build heating systems per year), economic attractiveness (based on payback), and the impact of 'soft' factors (non-economic market drivers and barriers). It should be noted that it is DECC's intention to develop its own more detailed forecasting model – what is presented here is some high level forecasting which provides an indication of possible future scenarios, but we are restrained by limitations on commercial building stock and heating market data.

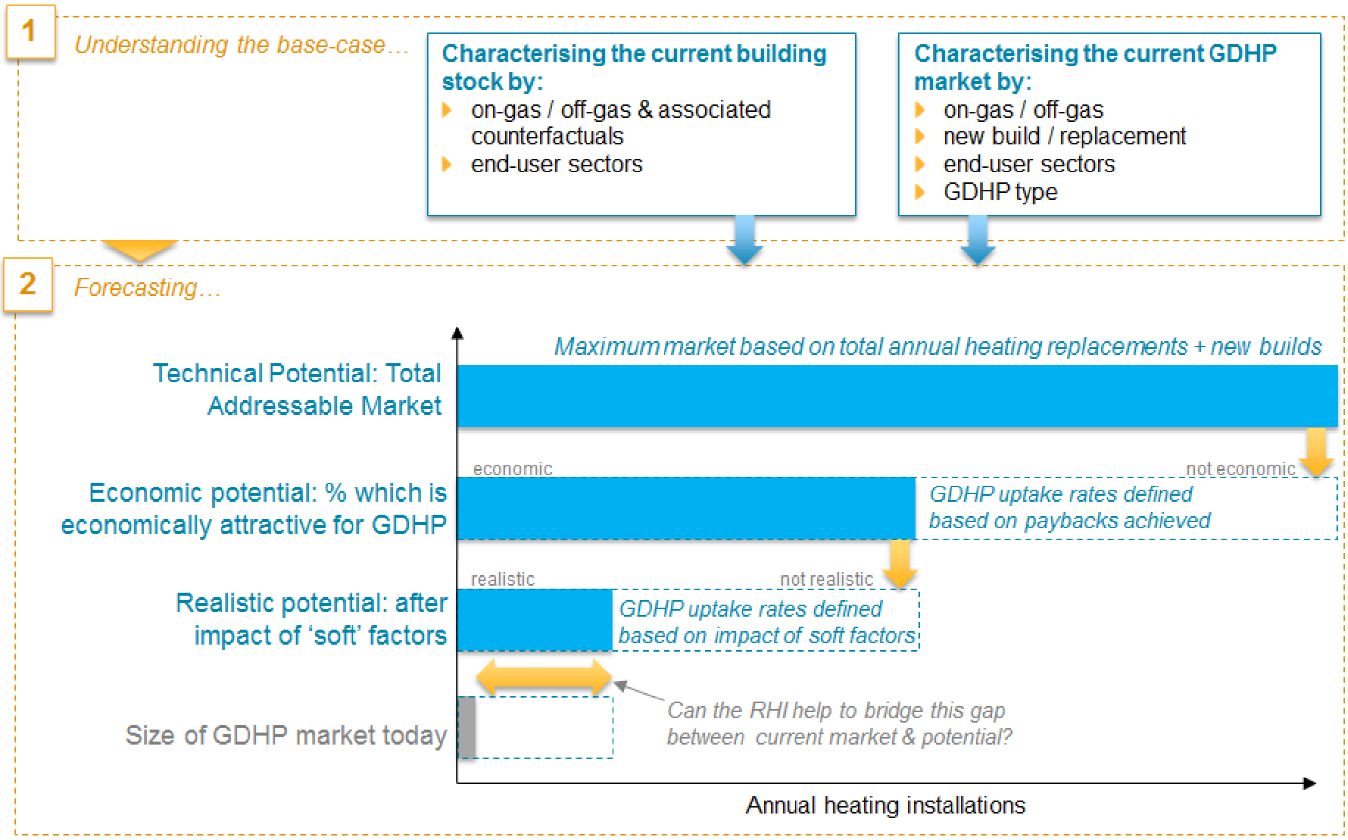

Figure 23: Methodology for GDHP market forecasting

This sets the starting point for the development of the GDHP market. We provide an indication of the total installed base and annual installations of GDHP in the UK, and provide a break-down as far as possible including e.g. the split between new build / retrofit, on-gas / off-gas, the split by GDHP type, and the split by end-user sector. Note that there is extremely limited data available on GDHP market size and characteristics, so what is presented is based on primary research with industry experts (consisting of interviews with utilities, manufacturers, distributors, specifiers, contractors and installers).

The Current GDHP market is discussed in detail in Chapter 3. Below, wWe highlight the major characteristics today, and provide a view as to how this may change in the future (by 2020):

Characteristic	Today	Future (2020)
Split of new build / retrofit	We estimate (informed by the outcomes of our interviews) about 90% of the market is currently for new builds and major renovation (i.e. where whole building is overhauled) – the dominant driver for has been “meeting/ exceeding building regulations”.	The technology is capable of meeting the high flow temperature requirements of retrofit but there are insufficient market drivers for GDHP in retrofit to create market growth at present. As market barriers are removed (particularly ‘low awareness’), retrofit growth is anticipated. An RHI targeting existing buildings would be a strong driver.
Split of on-gas / off-gas	We are not able to obtain detailed figures on the split of on-gas and off-gas GDHPs. Based on our interviews, we think that around 75%of GDHP are on-gas – a proportion a little lower than the proportion of all buildings which are on-gas (close to 90%)	The proportion of on-gas and off-gas GDHP in the future is likely to remain similar – GDHP running on LPG can and will likely continue to provide good savings against LPG boilers and oil boilers in areas where there is little choice of heating system. In on-gas grid areas however, GDHP may be one of few low carbon options which will be economic on-gas.
End-user sectors	Education and the Health Sector dominate GDHP installations to date – although there are installations in a much wider range of sectors.	With increasing product availability and awareness-raising, we expect Health to remain important but for other high demand sectors such as hotels and restaurants to become stronger. Experience from Europe shows that these sectors as well as e.g. multi-family homes, offices can be very attractive GDHP sectors.
Type of GDHP - technology	We estimate the market is split between ~70% GAbHP and 30% GEnHP.	The current split of GAb and GEnHP is related to the greater availability of GAbHP in the UK – with expansion of sales channels and crucially maintenance networks in the UK for GEnHPs, we could see their proportion grow.
Type of GDHP – capacity & application	GDHP range in size from around 30 kW to ~80 kW for a single unit, but can be cascaded up to several 100s of kW. Most current installations are cascaded systems with 5-7 units. In most installations, the full demand is not met only by the GDHP, but the GDHP is generally designed to meet at least 2 of the 3 main demands (e,g, heating and hot water, heating & cooling).	We do not expect significant changes in this set up in the future. There may be some single units of larger capacity and also at a lower capacity becoming available, but it will not create a step change in the possible applications in the non-domestic sector by 2020 (the biggest development will be the greater availability of domestic scale products).

Table 21: Characterising current GDHP market and likely future evolution

Source: Delta-ee primary research – numbers presented above are Delta-ee views informed by extensive interviews with utilities, manufacturers, distributors, specifiers, contractors and installers

Characterising the current building stock

In order to understand the nature of the GDHP opportunity, detailed analysis of the commercial building stock is necessary. We are limited in this analysis by the lack of up-to-date and complete datasets for the UK commercial building stock, so the data presented below is based on a variety of sources, some of which draw conclusions based on a representative sample of the building stock[21]. It would benefits DECC's further analysis to seek more detailed building stock datasets.

Split between on-gas and off-gas

We use an assumption based on the Display Energy Certificate Register dataset, based on a 40,000 building sample – 88% on-gas, 12% off-gas[22].

The counterfactual for heating in the off-gas sector is an oil boiler. In the on-gas sector it is a gas condensing boiler. In both cases we assume a storage tank is already installed and therefore costs associated with storage tanks are not included. While we acknowledge that there are more possible counterfactual technologies in each sector, we select the most common one based on where existing GDHP installations have been made, and based on our knowledge of the overall heating market.

Note that in many cases a GDHP would be installed to meet both heating and cooling demand – in which case it would also be replacing a chiller for cooling. However, because cooling is not the focus of the RHI, the modelling is based only on heating (GDHP replacing gas or oil boiler).

Characterising the building stock by end-use type

The analysis in Figure 16 below provides:

- An indication of the number of buildings in different end-user sectors – which indicates the size of the addressable market in terms of number of GDHP solutions.
- An indication of an average capacity (in kW) of any GDHP (or other heating system) which would be likely to be installed in that sector.
- An indication of the number of heating system units this capacity could equate to (i.e. as a cascaded system).

The following analysis in Figure 17 then identifies the size of the market in each sector in terms of a typical number of heating system units which could be installed in each sector (I.e. taking into account for the fact that some sectors have many sites but only require 1 unit per site, while others have a small number of sites but each one requires >20 units).

Due to limitations on available data sources, some commercial building sectors are not included here in terms of the total addressable market. Based on the sectors where data could be found, the following observations are made based on these two Figures:

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[21] Notes on the building stock data: We are currently working with the following data sets to provide DECC with the answers they require. The data on the number of non-residential buildings in the UK and their average size and heat demand has been derived from three main sources – data from display energy certificates in England and Wales published by the Centre for Sustainable Energy (CSE, 2011), a report on the European building stock by the Building Performance Institute Europe (BPIE, 2011) and data from the N-DEEM, the National Non-domestic Buildings Energy and Emissions Model (2002). These sources have been complemented and sense-checked by data from the ONS, the Oscar Research Public Sector Database and a variety of articles and publications on the topic. Despite a wide variety of sources the derived data on the commercial building stock in the UK is fragmentary and subject to significant uncertainty.

[22] Split derived from the Display Energy Certificate Register dataset, based on a 40,000 building sample

- The biggest opportunity in terms of number of buildings is offices, where demand is primarily in the lower range – equating to just one heating system per building.
- One of the smallest opportunities in terms of number of buildings is hospitals, but these on average have much greater demand, and could require upwards of 20 units per site.
- Schools, care homes and hotels are the three other largest sectors in terms of number of buildings, and number of heating system units.

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Demand intensity (i.e. demand per m2) for each sector

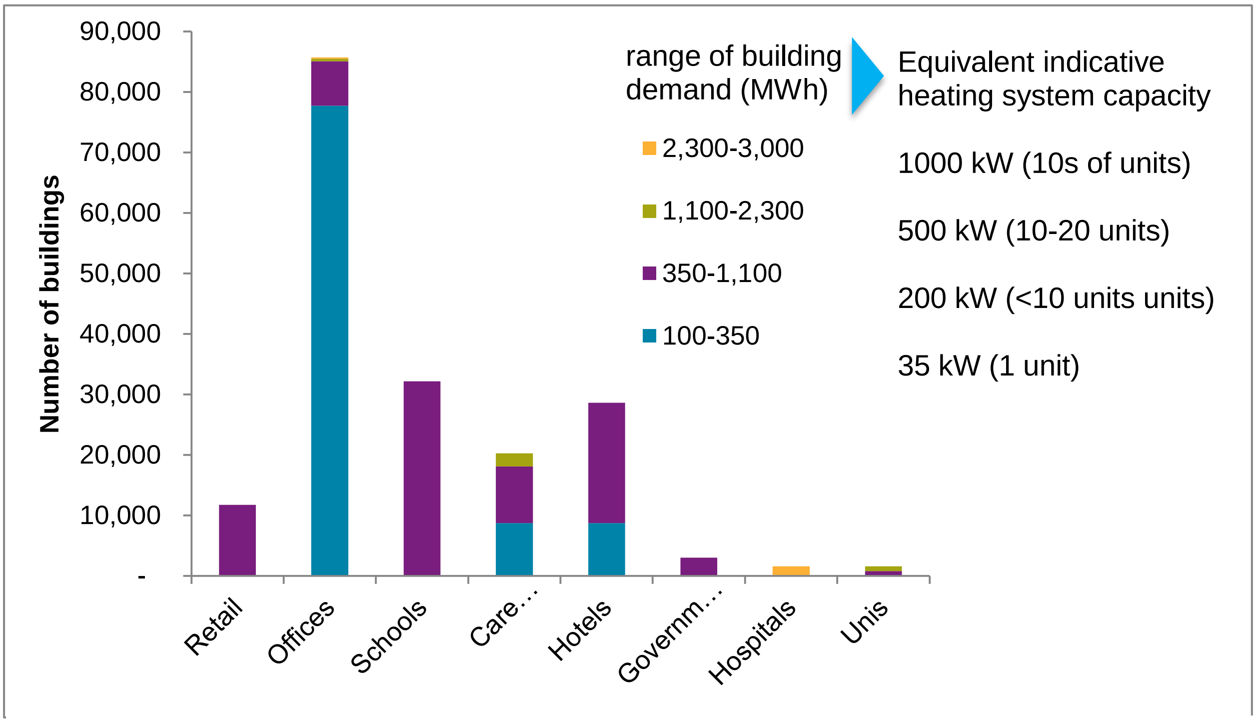


Figure 24: Number of buildings within different demand ranges (public buildings only)

Source: Total numbers of buildings in each sector come from various sources (listed in the References), combined with Delta-ee existing knowledge and primary phone research. Information regarding building demand is derived from the Display Energy Certificate Register dataset, based on a 40,000 building sample. The calculation of the number of units is from Delta-ee interpretation of the above datasets.

The total demand intensity of each end-user sector (for heating, hot water and cooling)

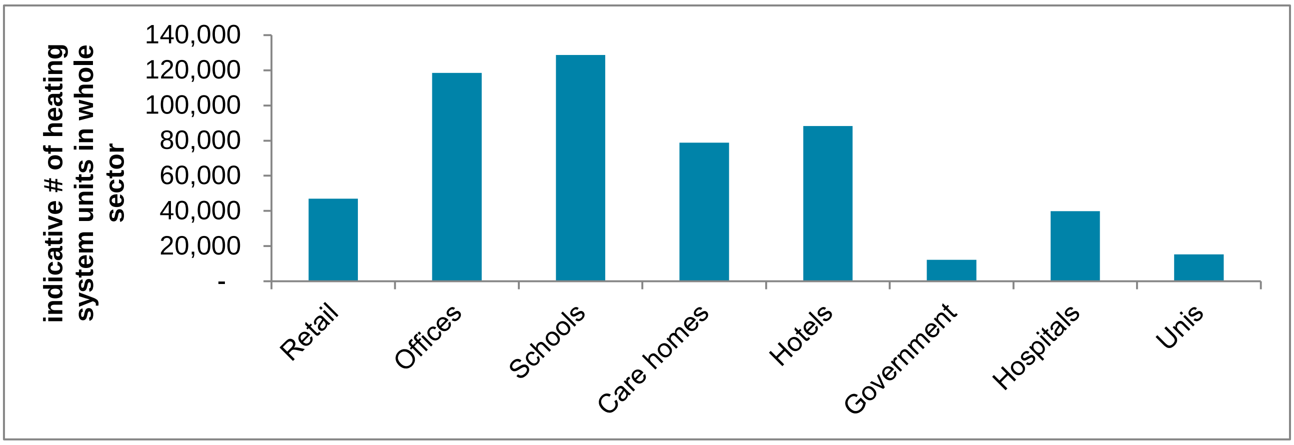


Figure 25: Size of each sector in terms of the total number of individual heating system units (public buildings only)

Source: Delta-ee interpretation based on data sets presented in Figure 23.

determines both the economic case for GDHP (higher running cost savings are made where overall kWh demand is higher). The type of demand (proportion of heating, hot water and cooling), influences the types of GDHP which can best serve the sector. These points are discussed in detail in Chapter 3. As such we compare the demand characteristics of key end-user sectors, below.

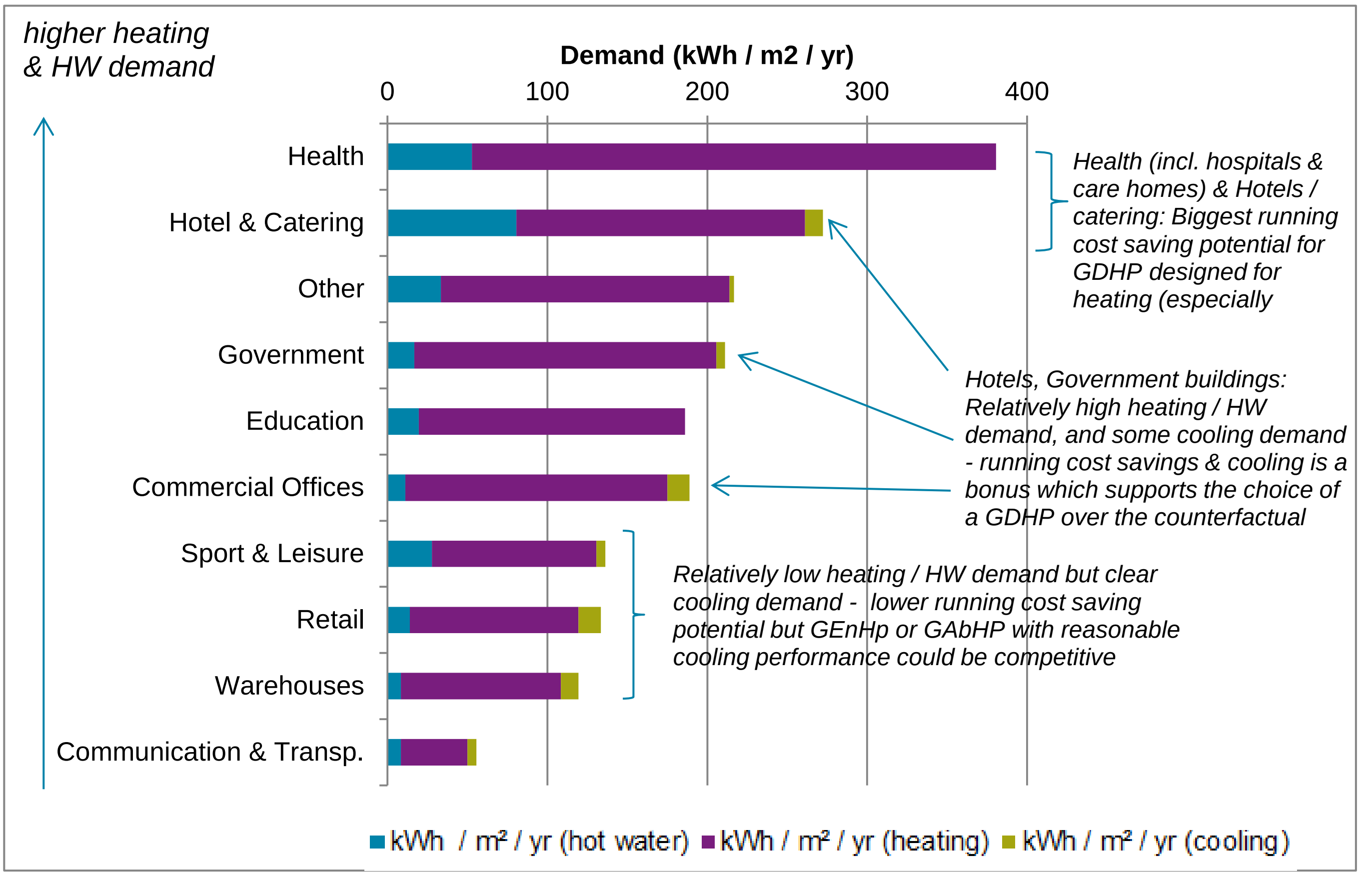


Figure 26: Demand intensity of different sectors

Source: NDEEM

The following observations arise:

- Heating is the primary demand in all sectors – therefore good heating efficiency is a more important GDHP characteristic than cooling efficiency, in the UK commercial building stock.
- The two stand-out sectors in terms of demand are health (including care homes and hospitals) and hotels & catering – these will provide the greatest running cost savings through GDHP. This is backed up by the industry view that these sectors are some of the best opportunities.
- Education has almost half the heating demand intensity of the health sector – but we know from Chapter 3 that it is one of the most successful GDHP sectors at present. These figures illustrate the point made by many interviewees during the research – that the drivers for GDHP in schools are not necessarily economic (i.e. this is not the sector with the highest running cost savings).
- Several sectors have some cooling demand – while cooling is a relatively small proportion of all demand, the ability of GDHP to provide cooling in addition to heating and/or hot water is a distinct advantage over many competing technologies.

Conclusions about the type and topology of GDHPs which could be installed in the most important end-user sectors

- Both GAbHP and GEnHP could be installed across all sectors - and it is clear that optimising heating efficiency is key for both technologies.
- Traditionally GAbHP are better designed for heating & hot water production than GEnHP, but with the increasing emergence of hydronic conversion modules for GEnHP, this distinction is becoming less clear cut. GAbHP are likely to have some advantages in the heating/hot water dominated sectors (i.e. health, hotels).
- Traditionally GEnHP are more designed for cooling – and they do generally have much higher cooling efficiencies than GAbHP, which makes them better suited to applications with significant cooling requirements and lower heating / hot water requirements (e.g. retail).

We identify the top 4 sectors below based as those which are biggest in terms of number of heating system units (from Figure 17), have the highest demand intensity (from Figure 18), or are the current biggest sector for GDHP.

Top 4 Sectors	GDHP type	Number of GDHPs cascaded[23]
Hospitals	GAbHP or GEnHP	>20 units cascaded
Care Homes	GAbHP or GEnHP	Most sites 1-10 units, small proportion requiring <20 units
Hotels	GAbHP or GEnHP	Most sites <10 units
Schools / education	GAbHP or GEnHP	Most schools <10 units, universities <20 units

Table 22: Summarising potential GDHP type and topology in the key end-user sectors

Source: Delta-ee analysis informed by NDEEM and Display Energy Certificate Register data, and interviews with end-users, installers and other technical experts to identify typical capacities

Technical potential: Size of the addressable market

The above analysis has provided in indication of the total size of the market – but to understand the market potential for GDHP, we need to understand the number of replacement heating systems every year in existing buildings, and the number of new builds per year. For the purpose of our modelling, we assume that these rates of replacement and new build will remain relatively flat through time.

Replacement market: 40-50,000 buildings per year

Acquiring definitive numbers on the number of replacement heating systems per year in the commercial sector is not straightforward due to lack of available data. Based on our primary

[23] A “cascaded” system means that several single GDHP units are installed and controlled together at a single site.

research and interviews with experts in the industry, **a range of 40-50,000 buildings per year have their heating systems replaced**[24].

Applying the on-gas / off-gas split from the Display Energy Certificate Register, this would mean that:

- ~35,000 are on-gas (replacing gas boilers)
- ~5,000 are off-gas (replacing oil or LPG)

We assume the same split between sectors in annual replacements as across the whole building stock.

New build market: 400-800 new buildings per year

As with the replacement market, there is limited data available on new build rates in the commercial sector. Based on analysis of the Office of National Statistics Output in the Construction Industry, December and Q4 2013, we estimate around 600 new builds per year, with a safe range of 400-800 per year.

We assume that the sector split and on-gas/off-gas split is the same as for the total building stock.

How many of these buildings could be technically feasible for GDHP?

Based on experience in the UK and Europe, we know that GDHP can be installed in a wide variety of building types with heat demand, right across the commercial building stock. Therefore we assume that GDHP are feasible across all the discussed sectors. We expect the top four sectors – hospitals, care homes, hotels and education, to account for the largest share of GDHP. These four sectors account for about 50% of public buildings. There is insufficient data on the number of private buildings to give a clear view as to the proportion of all commercial buildings which are made up by these four sectors.

Economic potential: Sizing the GDHP economic proposition

To assess the economic potential, we have modelled payback times for GDHP against the assumed counterfactual technologies under different scenarios. Based on primary research with industry experts we identify 'minimum payback' periods which are deemed necessary to make a GDHP an attractive proposition (based only on economics). We use our payback modelling combined with these minimum required payback periods to assign market uptake rates in different sectors and in different timeframes (today, to 2020 and to 2030 – based on the assumption that upfront costs will come down and performances will increase over time – making payback times decrease with time).

NB: Based on our primary research (interviews across the industry), it is clear that payback is not the only defining factor in determining economic attractiveness. As identified in Chapter 4, up-front cost is a significant barrier to uptake even if payback is acceptable. Further, there are many ways to measure economic attractiveness. But we will take into account these additional factors in our analysis of the "soft" factors. Payback is chosen as the measure because it is the economic measure most often referred to in our discussions with the industry and end-users.

[24] Based on ranges identified by 2 contacts in the commercial heating replacement system business – and tested more widely in our research across the UK industry. There is no clear data available on commercial heating system replacements.

Assessing payback times for GDHP

Counterfactuals

The counterfactual technology can be varied depending on site-specific circumstances. For the purpose of the modelling, we make the following assumptions:

1. For the on-gas sector: Gas combi-boiler
2. For the off-gas sector: Oil boiler

Full details of counterfactual assumptions are in Appendix C

Comparing the basic economics of different types of GDHP

The numbers presented below in this report are based on modelling (See Appendix C for assumptions) which as far as possible have been correlated with the final view of GDHP performance and cost taken from the aggregated data set. However, the limited available data means that the figures can be taken as indicative only.

What level of payback is expected by end-users?

Based on interviews with those involved in GDHP currently being installed in the UK (primarily interviews with end-users and installers / specifiers), a payback of 3-5 years is in most cases a minimum expectation. In some cases it can be as long as 10 years - in sectors where a longer-term view can be taken or economics are not such a driving factor (e.g. schools), or in situations where the options for heating systems are very limited.

We acknowledge that “acceptable” paybacks will vary on a case-by-case basis, but for the purpose of our modelling, we use the following ‘minimum’ payback periods we expect will be needed to drive significant uptake of GDHP, dividing between on-gas and off-gas sectors. We expect the required payback times to come down with time as GDHP and competing technologies increase in efficiency and reduce their costs, creating more market competition. Our primary research with the industry and end-users indicates that off-gas customers are more willing to accept longer paybacks because they have less choice of heating system:

	On-gas	Off-gas
Today	Acceptable payback 5 years	Acceptable payback 7 years
2020	Acceptable payback 4 years	Acceptable payback 5 years
2030	Acceptable payback 3 years	Acceptable payback 4 years

Note regarding capacity of installations and impact on economics

The current model does not take into account differences in economics with size of demand (i.e acknowledging the fact that there is a cost regression for larger capacity solutions). This is because there is insufficient data available covering a wide enough range of capacities to draw meaningful conclusions as to the price digression with capacity. Indeed there is a relatively limited range of capacities available on the market from which to gather data. Generally we would expect paybacks to look better for larger systems.

Note regarding cooling

In the below analysis, we have assessed the payback only taking into account heating and hot water - not cooling. When cooling is included in the calculations of payback it can potentially significantly change the outcome (likely bringing the payback down). For the purpose of this report (and as identified by DECC as the key priority) we look at heating only – but in the long-term we recommend that DECC does make consideration of cooling, as during our research, the cooling capability of GDHP in addition to heating can be a strong driver.

Below we present:

1. A comparison between paybacks achieved by GEnHP and GAbHP
2. A comparison between paybacks achieved on gas and off gas
3. A comparison between paybacks achieved in new build and retrofit
4. The impact of an RHI on payback times achieved
5. The impact of different rates of technology cost reduction on payback times

Investigating how payback varies with type of heat pump: Gas Engine Heat Pumps vs Gas Absorption Heat Pumps

There are significant differences in price of different types of GDHP and different system set-ups. We present in Chapter 1 the approximate break-down of costs based on data we were able to collect from industry professions in the UK (supplemented with some additional information from Europe).

This cost information feeds into our modelling, and we investigate the magnitude of change in payback times for different types of GDHP over time.

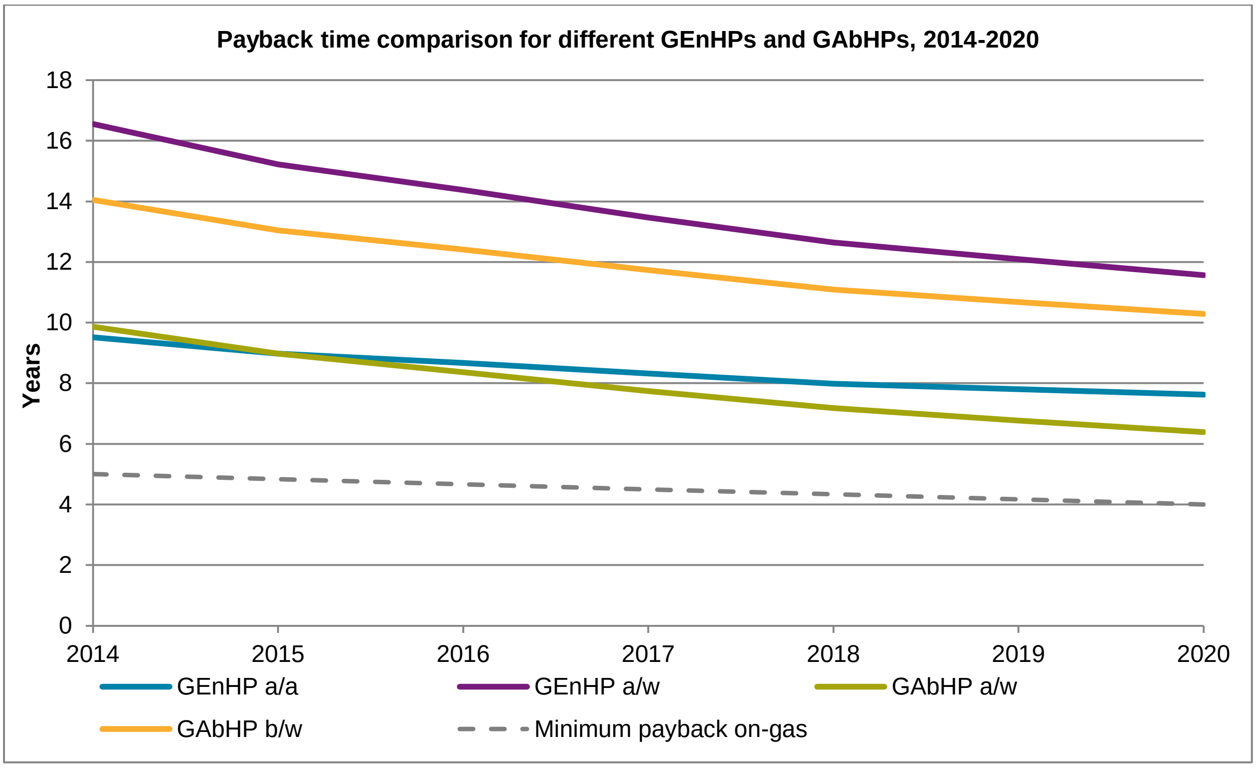


Figure 27: Payback time comparison for GEnHP a/a and a/w and GAbHP a/w and b/w

Source: Delta-ee modelling – See Appendix C

Observations based on current modelling:

- None of the GDHP technologies reach a minimum payback necessary for a step change in market uptake – with paybacks close to 10 years, they will remain a niche product.
- With efficiency increases and cost reduction towards 2020, paybacks will come down for some technologies towards 6 years which will widen the opportunities.
- GAbHP (a/w) provides the strongest proposition based on our modelling. While GEnHP provides a similar proposition, it cannot provide hot water.

- GAbHP (a/w)s payback decreases faster than GEnHP (a/a) because the technology is less mature and has more scope for cost reduction.
- GAbHP (b/w) have a much higher payback largely because of the cost of the ground works, which adds significant upfront cost.
- GEnHP (a/w) have a higher payback because of their higher upfront cost – particularly of the additional cost associated with the hydraulic module (though there is scope for this to come down in price).

Investigating how payback varies on gas and off gas

The on-gas sector is the biggest market representing nearly 90% of the UK building stock. It is also the most challenging for other renewable technologies to penetrate, because of the low cost and easy availability of gas. GDHP could offer a good opportunity to decarbonise this challenging on gas grid sector – it is more efficient than a boiler, can reach high flow temperatures and ultimately can support renewable penetration of the on-gas sector.

The off-gas sector offers good opportunities, particularly where the electricity grid is weak, and there is very limited choice of technologies.

We investigate the extent to which payback periods vary on and off-gas, in order to better understand the GDHP opportunity in both sectors.

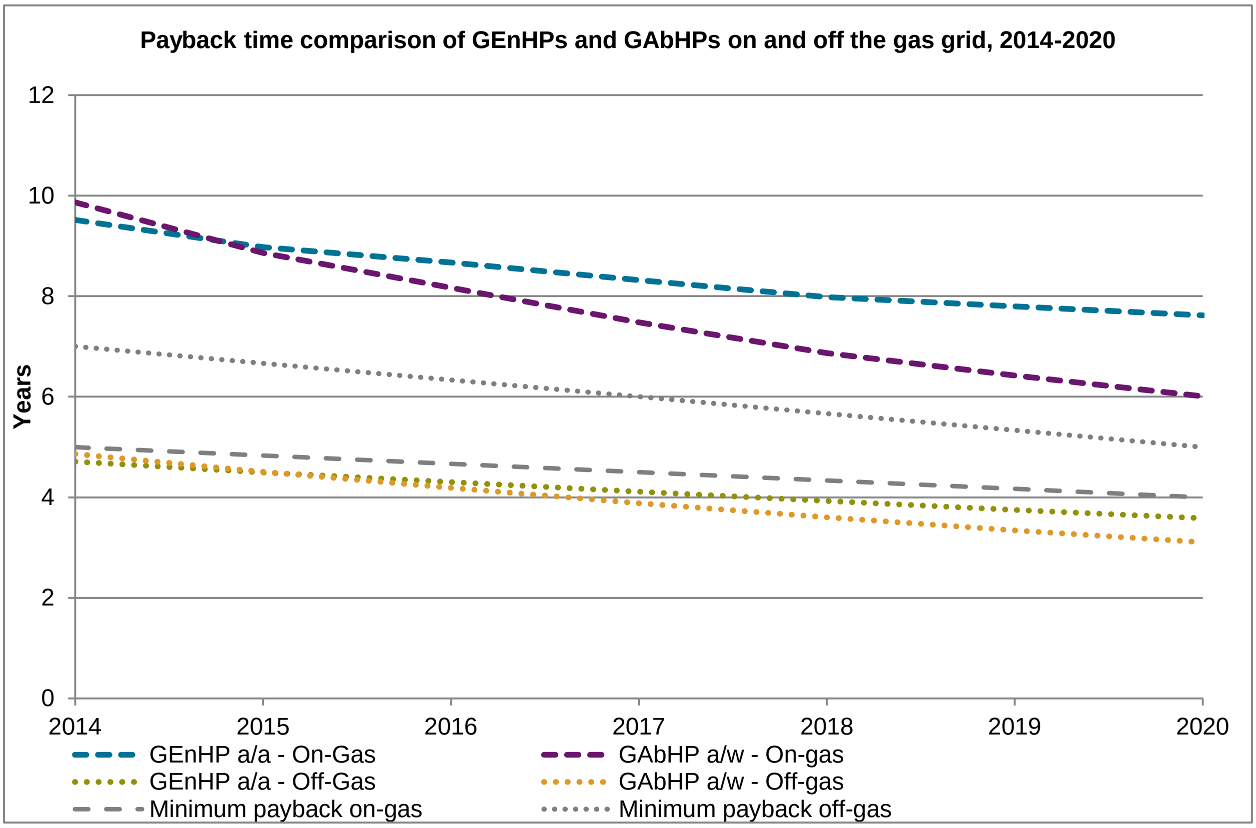


Figure 28: Payback time comparison for GEnHP a/a and GAbHP a/w on-gas (compared to gas condensing boiler) and off-gas (compared to oil boiler)

Source: Delta-ee modelling – See Appendix C

Observations based on current provisional modelling:

- Based on our current modelling, the economic proposition for GDHP looks more attractive off-gas than on-gas.

- Given that required payback times are higher for off-gas grid customers, there is already potentially a sweet spot in the market for GDHP running on LPG.
- In contrast, based on the current modelling inputs, it is much more difficult to achieve low paybacks on-gas.

Investigating how payback varies in new build or retrofit

Because of the better insulation and lower flow temperature requirements in new build, economics are expected to be more attractive. It should be borne in mind that this does not apply only to GDHP but to other renewable technologies *and* to standard boilers.

Payback does not strictly lend itself as an analysis tool in the new build sector, but for the purpose of this comparison, payback refers to the payback relative to the standard solution which would have been installed instead of a GDHP. It should also be noted that since the customers for new build are building developers or architects rather than end-users, payback is a much less important driver for heating system choice than it is in the retrofit sector.

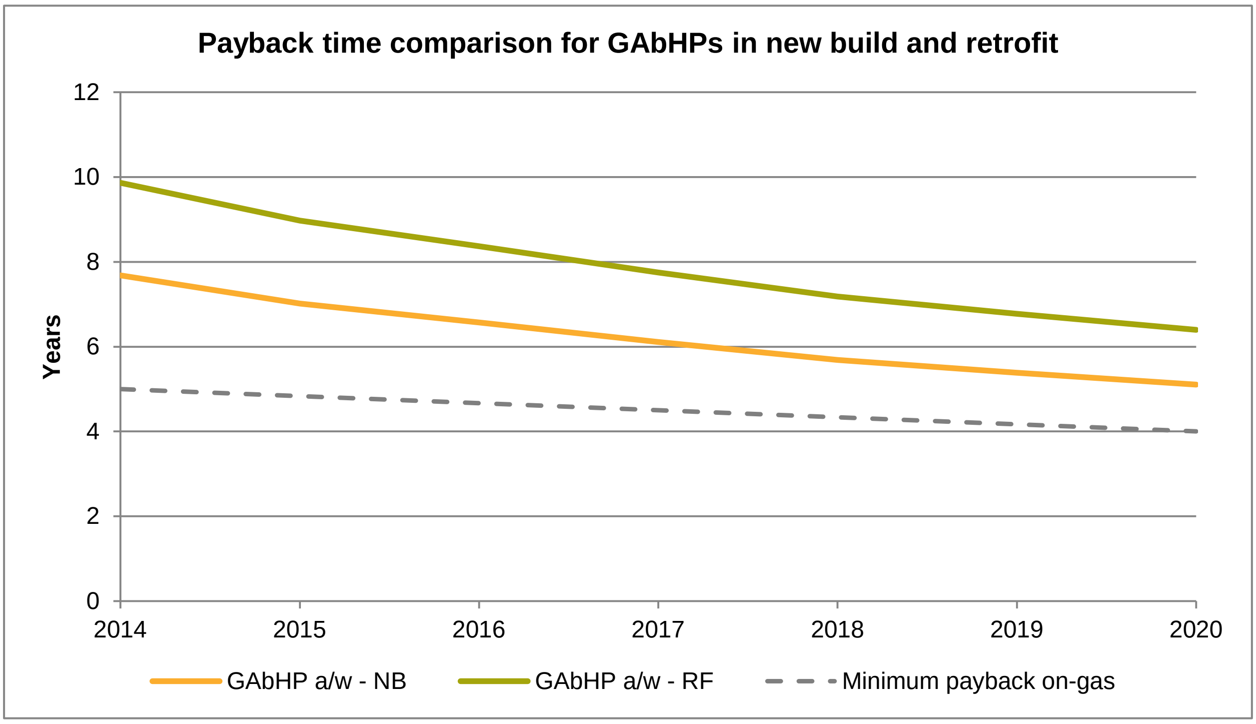


Figure 29: Paybacks time comparison for GAbHP a/w in new build and retrofit

Source: Delta-ee modelling – See Appendix C

Observations based on current provisional modelling:

- As expected, payback is more attractive in new build than retrofit (the system is running more optimally - because of lower flow temperature requirements associated with better insulation).
- The improved payback in new build is not significant enough to push paybacks down to the minimum levels required to create significant market uptake.
- We expect the same difference between new build and retrofit for GEnHPs as are shown here for GAbHPs.

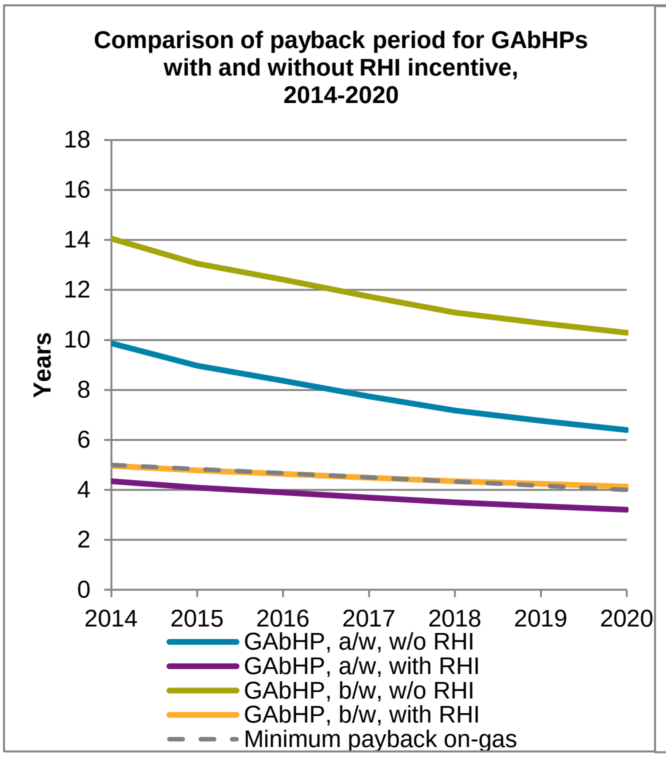
Investigating sensitivities: Impact of RHI

The above analysis has shown that it is relatively difficult for GDHPs to reach a payback period in the range of 5-7 years – even by 2020 – based on the current prices. As stated, this modelling is based on provisional performance data which is representative of a whole range of systems, whose performance will vary on a case-by-case basis depending on the individual demand patterns. However, we would not expect GDHPs on the market to achieve significantly better paybacks across the building stock. Here, we investigate the impact of adding an RHI payment to the model inputs, to investigate its effect on payback times. Indicative RHI rates (payable on renewable heat generated) which are used in the modelling are presented below.

		2014
a/a GEnHP	£/kWh	0.008
a/w GEnHP	£/kWh	0.017
a/w GAbHP	£/kWh	0.017
b/w & w/w GAbHP	£/kWh	0.030

Table 23: Indicative RHI rates used in the RHI sensitivity analysis

Source: Delta-ee – indicative rates for illustrative purposes, chosen in order to reach a payback period of between 4 and 6 years for GDHP[25].



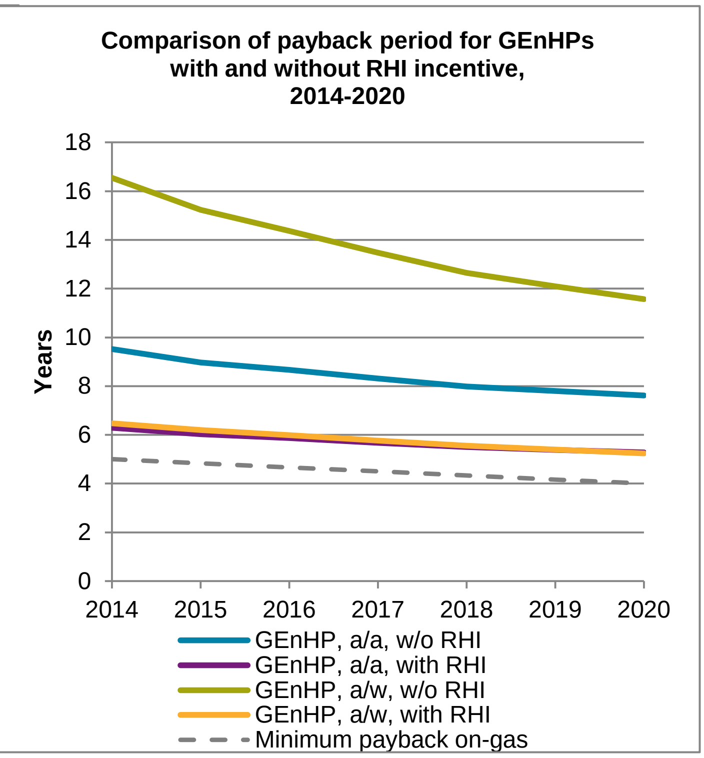


Figure 30: Comparison of paybacks for a GAbHP (left) and GEnHP (right) with an RHI and without an RHI

Source: Delta-ee modelling (see Appendix C) using RHI tariff rates suggested in Table 18 above.

[25] It should be noted that consideration of tariff rates for GDHP as compared with electric heat pumps should take into account the relative fuel price differences between the heat pumps and the counterfactuals (especially relating to on-gas versus off-gas sectors). These prices significantly affect the economic proposition and therefore the required tariff levels.

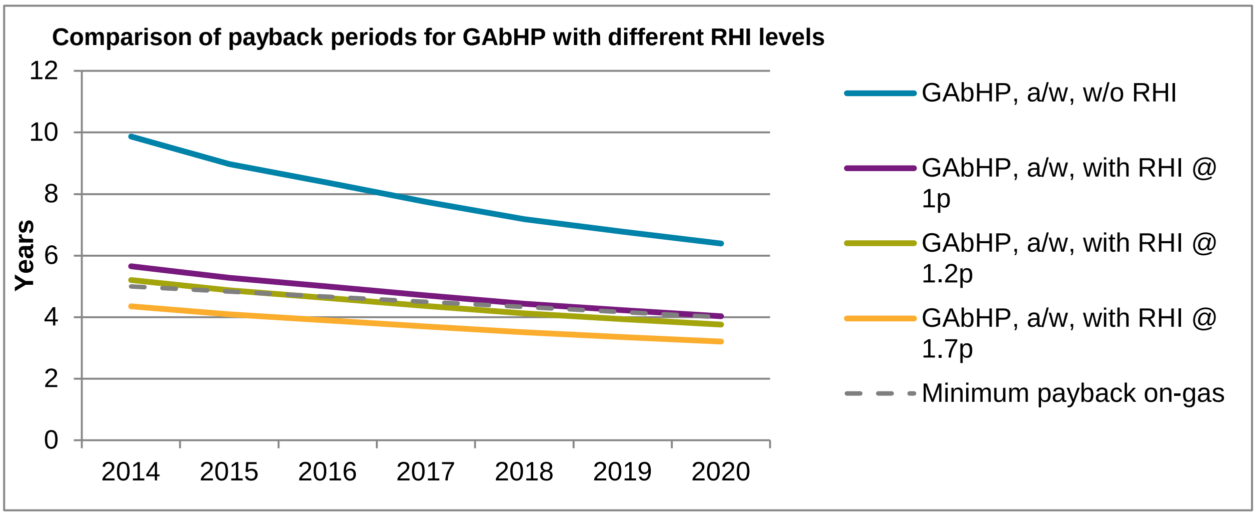


Figure 31: Investigating the sensitivity of payback periods to different RHI tariff levels

Source: Delta-ee modelling (see Appendix C) using RHI tariff rates suggested in Table 18 above.

Observations based on current provisional modelling:

- It can be seen from Figure 23 that the payback times for the systems with an RHI is sufficient to push payback times to close to or below the 5 year mark – the point at which the economics become attractive enough to have a real impact on market uptake (please note these graphs all refer to the on-gas sector – we expect the sensitivities to be similar for off-gas, with the achievable payback period and the required payback period both being relatively higher than in the on-gas sector).
- From our sensitivity analysis, based on current modelling, even a fairly low RHI rate of 1p per kWh has a significant impact on payback times, and an increase in the tariff by less than half to 1.7p can bring the payback down by around a year.
- All of the tariffs tested are significantly lower than those used for electric heat pumps today but are able to trigger an economic case for GDHP - it is clear that the economic proposition for GDHP is very sensitive to the tariff level, so detailed analysis should be carried out to ensure consistencies with other technologies.

Investigating sensitivities: Rate of technology cost reduction

The rate of GDHP cost reduction over time has a significant impact on the economics of GDHPs. Below we present results of our modelling regarding the impact of cost reduction on payback. Detailed explanation of the potential for cost reduction in GDHPs is presented in

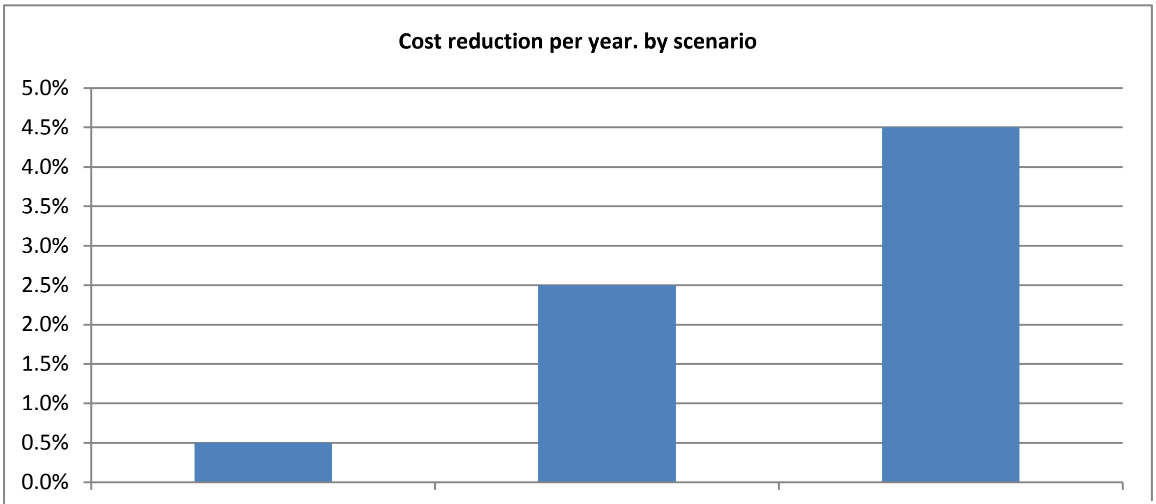


Figure 32: Three cost reduction scenarios

Source: Delta-ee primary research -% rates are a Delta-ee view informed by our interviews and tested with industry experts.

Chapter 2, where we present our Reference scenario (the most likely scenario, based on our extensive discussions with the GDHP industry in the UK and internationally). The average rate of cost reduction across the GDHP technologies in the Reference Scenario is 2.5% per year. Based on the range of opinions we gathered from our interviews, combined with our knowledge of where cost reduction could come from, it is feasible that this cost reduction could be as low as 0.5% per year (e.g. if market growth does not occur, the industry does not invest in R&D and industrialisation of production) or as high as 4.5% per year (e.g. if the market grows faster than anticipated with strong investment from industry and rapid industrialisation of production). 0.5% and 4.5% therefore become our Low and High Scenario for cost reduction. Note that for the purpose of the model we assume a 'flat rate' of cost-reduction year by year. In reality it is likely to be more step-like.

We investigate the sensitivity of payback times to these cost reduction scenarios.

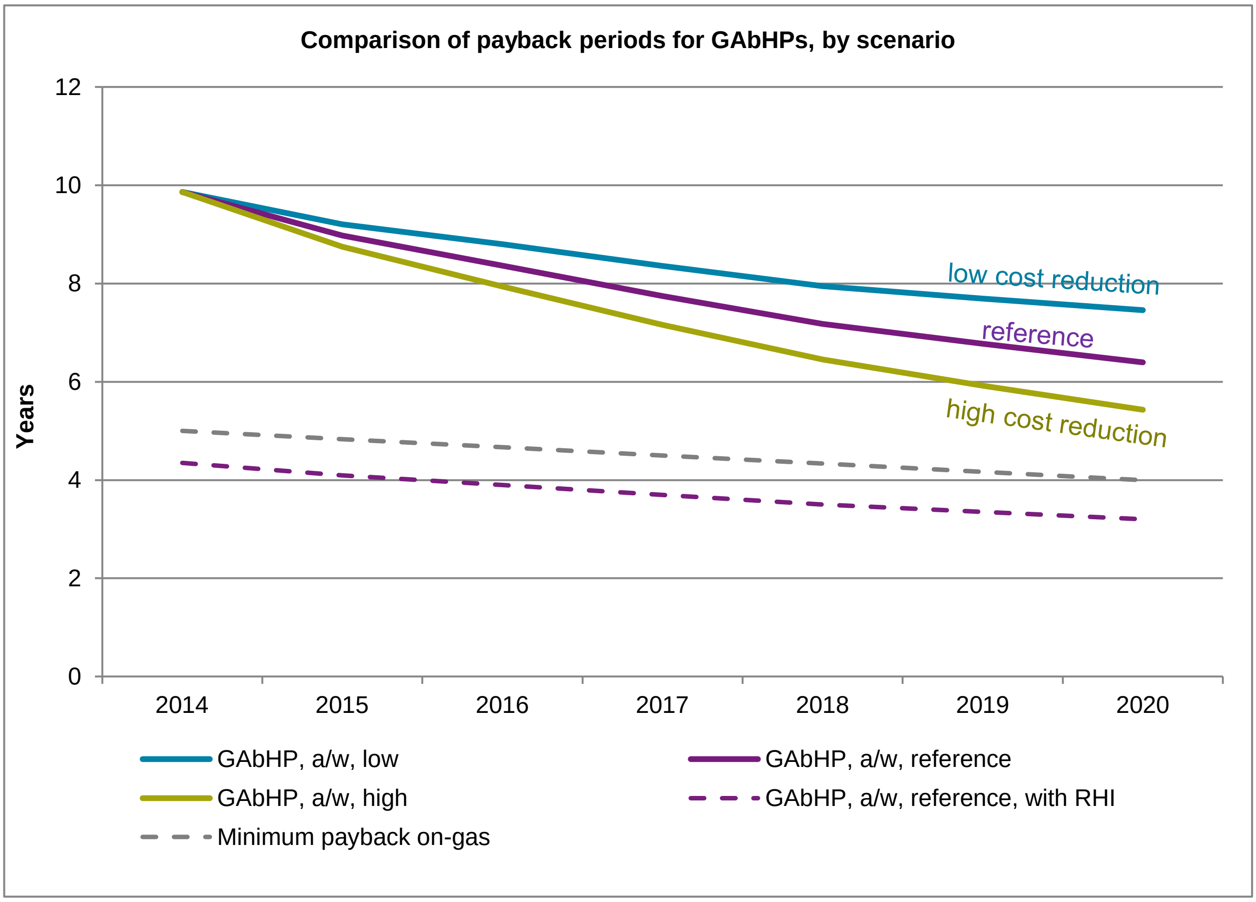


Figure 33: Comparison of paybacks for GAbHP a/w under the 3 cost reduction scenarios

Source: Delta-ee modelling based cost reduction scenarios from primary research

Observations based on current modelling:

- Even in our high cost reduction scenario, paybacks do not reach a level which becomes 'economically attractive' to a level which would create a step change in market uptake.
- Based on our discussions with industry experts, we do not expect that cost reduction of significantly higher rate than this can be expected by 2020.
- The existence of an RHI will give the industry more confidence to invest in R&D which may lead to cost reduction, but this is not likely to create a step change in costs by 2020 – it will rather enable cost reduction rates closer to those indicated in our high scenario.
- Payback periods may be able to reduce further if we add the impact of installer margin reduction. But we do not expect this to have an impact by 2020 – installers are unlikely

to drop their costs significantly in the next 5 years and until they feel some real pull from their customers for GDHP. We do not expect this pull to strengthen sufficiently in the next 5 years because transforming market awareness and perception is not an overnight process.

Investigating sensitivities: Rate of technology efficiency increase

Efficiency increase is as critical to determining payback times as upfront cost. Chapter 2 discussed how efficiency increases could be gained, and the rate of improvement was expected

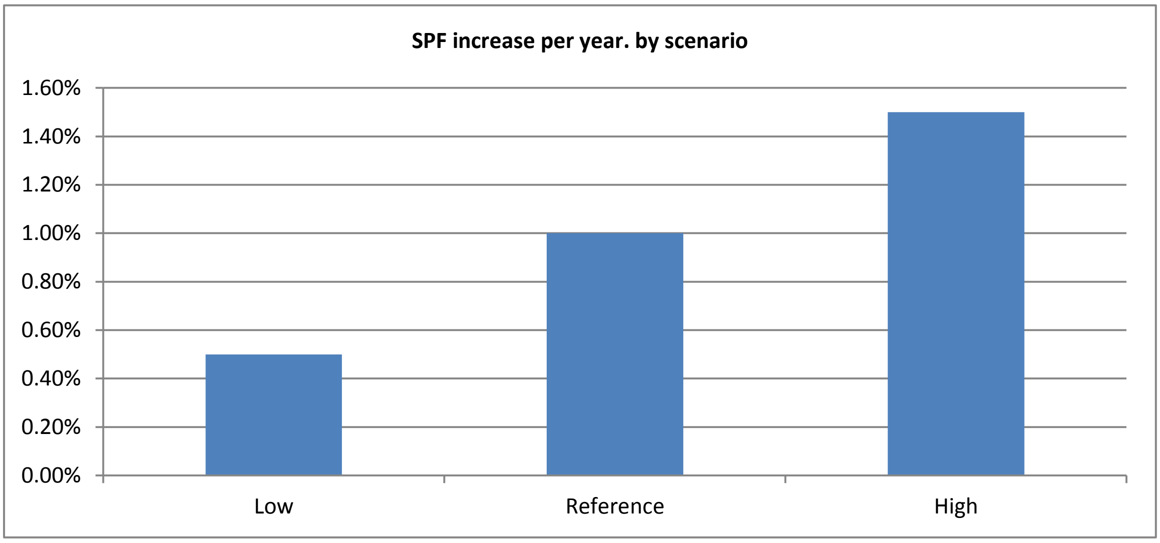


Figure 34: Three efficiency increase scenarios

Source: Delta-ee primary research -% rates are a Delta-ee view informed by our interviews and tested with industry experts.

to be around 1% SPF increase per year (the Reference Scenario). With greater market confidence and investment, we could see R&D resulting in a bigger step up in efficiency – our High Scenario anticipates 1.5% SPF increase per year. However, if the market does not begin to grow and market confidence remains low, it is unlikely that manufacturers will invest in the necessary R&D to create significant increases – our Low Scenario is of 0.5% SPF increase per year. We present sensitivity analysis on the impact of efficiency increase rates on payback.

Observations based on current modelling:

- Even in our high efficiency increase scenario, paybacks do not reach a level which becomes ‘economically attractive’ to a level which would create a step change in market uptake.
- Based on our discussions with industry experts, we do not expect that SPF increases of a significantly higher rate can be expected by 2020.
- The existence of an RHI will give the industry more confidence to invest in R&D which may lead to efficiency increases, but this is not likely to create a step change by 2020.
- A ‘wild card’ is that a more revolutionary than evolutionary advancement is made due to, for example, discovery of a new working pair with better efficiencies at high flow temperatures. However, such changes are extremely unlikely between now and 2020, and the view from the industry is that there are few working pairs not already known about.

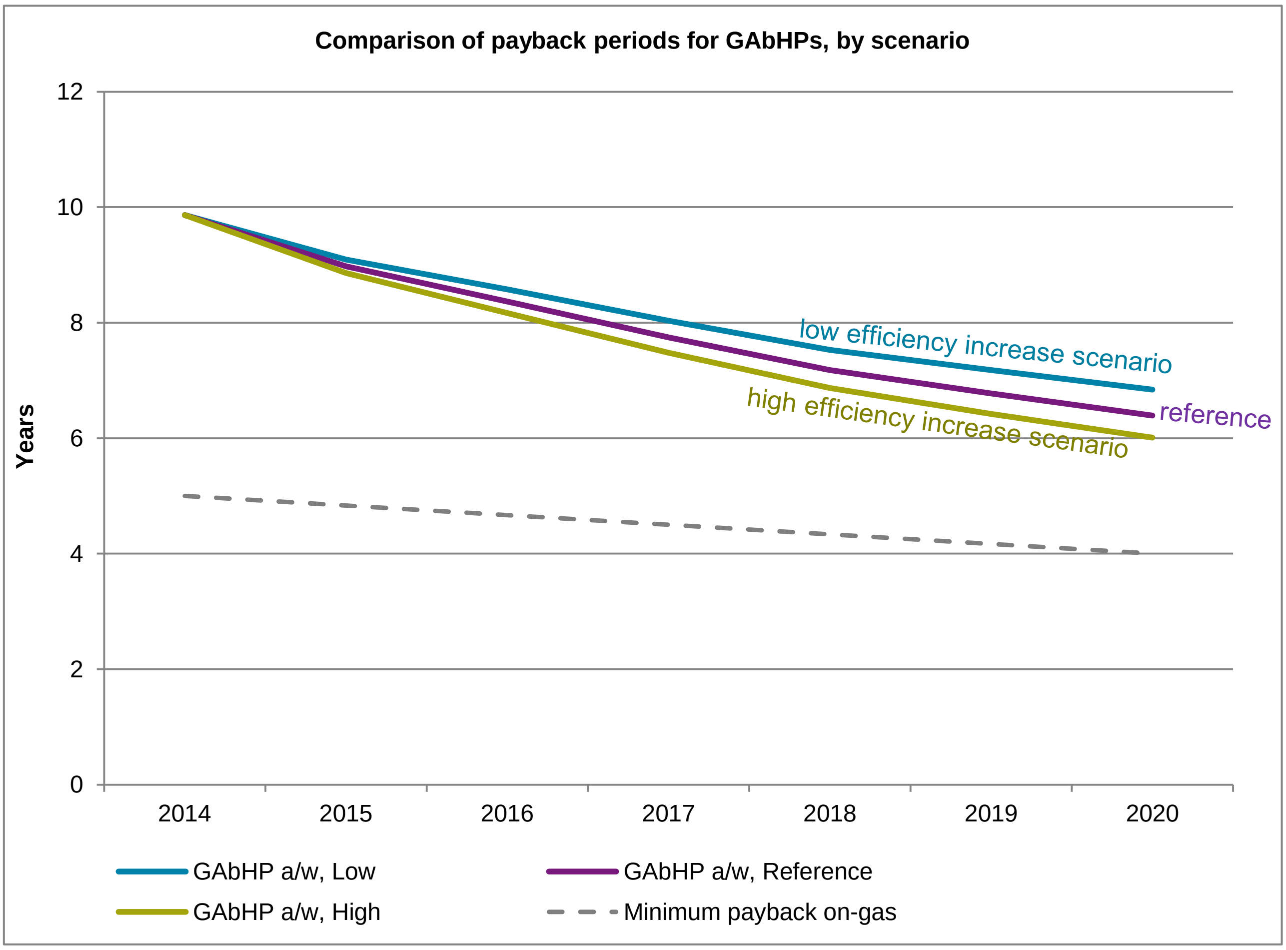


Figure 35: Comparison of paybacks for GAbHP a/w under the 3 efficiency increase scenarios

Source: Delta-ee modelling based efficiency increase scenarios from primary research

Calculating the market uptake rate based on payback times

A market uptake rate is estimated based on the achievable payback period – before accounting for the influence of 'soft factors'. Please note this is an initial indication based on our primary research, and in the context of current payback times and market uptake rates.

Payback achieved (years)		Indicative market uptake rate	
On-gas (yrs)	*Off-gas (yrs)*	*% of annual replacements*	*% of annual new builds*
>5	>7	0.30%	5.00%
5	7	1%	8%
4	5	2%	10%
3	4	5%	13%

Table 24: Framework for indicating market uptake rates based on achievable payback

Source: Delta-ee view interpreted from interviews across industry & end-users

We map out the achievable payback periods in each sector of the building stock (on-gas/off-gas and new build/retrofit) from today to 2030, assigning market uptake rates based on when specific payback times are achieved. At present, based on our research, paybacks of at 3-5 years are expected in the on-gas sector, and 5-7 years off-gas for a GDHP project to make economic sense. Today market uptake rates are well below 1% in existing buildings and under 5% in new build. Please note that there is no data existing regarding the GDHP market size in different sectors, so the figures in our modelling are based on our opinion following interviews with industry experts.

Realistic potential: Influence of soft factors

We present the most important soft factors influencing the market potential (explanation on next page):

Impact of soft factors:	LOW BAND: No impact / negative impact on GDHP uptake rate	HIGH BAND: Positive impact on GDHP uptake rate (e.g. as in HIGH SCENARIO)
1.Level of awareness of GDHP	No impact on market uptake if awareness is low – this is the critical first stage of market growth and without it growth will be limited to only a small niche of innovators	Positive impact if high because it lays the foundations upon which to base a market – awareness must be high amongst specifiers and other building services professionals in particular, so that GDHP at least get considered in new build and replacement options.
2.Perception of GDHP	Negative impact if mis-trust pervades amongst building services professionals (meaning GDHPs don't get specified) and end-users / building developers (meaning there is no 'customer pull')	Positive impact if GDHP thought to be reliable – particularly where this translates into recommendations being made in favour of GDHP by specifiers & other building services professionals
3.Level of choice for an alternative system	There is a negative impact on the GDHP market if there are many competing systems to choose from	This has a positive impact on GDHP sales if the choice is limited (including because of the major issue identified of the electrical grid being often too weak to support electric solutions – and/or requiring significant investment to resolve. We do not have precise enough cost figures to quantify this in the economic modelling so account for it here)
4.Treatment of GDHP in future building regulations	Negative impact on GDHP in new build if GDHP are one of many options which can meet regulations (or for example achieve a BREEAM 'excellent'), and there is strong competition from a more familiar / trusted "traditional solution" such as a boiler plus solar thermal or PV.	Where GDHP are one of very few solutions able to meet regulations – or are seen as a cost-effective and reliable option, it is feasible that GDHP could take a large share of some new build sectors.
5.Level of supply chain development (including scaling up of production facilities)	No impact on market uptake if industry confidence to invest is low so supply chain does not develop beyond today – growing demand cannot be met (i.e. today GDHP are available from only a handful of suppliers and maintenance networks have only patchy coverage of the UK). A limited supply chain is also likely to remain high cost – meaning costs to customers remain high.	Positive if industry confidence to invest is high and the supply chain is significantly expanded, creating a strong aftersales support network, easier access to products, and ultimately enabling lower costs to customers (e.g. if the GDHP can be locally rather than internationally sourced).
6.Level of R&D in technology development	No impact on market uptake if the GDHP industry does not invest in R&D at all (due to low confidence) and no efficiency gains (or cost reductions) are achieved.	There will be a positive impact if the industry is confident to invest and achieves major efficiency increases and/or cost reduction – creating a much stronger economic proposition.

Table 25: Most important soft factors influencing GDHP market uptake rates

Source: Delta-ee view based on several interviews across industry & end-users

As indicated in Chapter 4, economics alone are not enough to drive the market. Significant barriers and drivers exist – varying from sector to sector – which are as important as or even more important than technical and economic viability. We refer to these as 'soft' factors and they incorporate human behavioural and non-economic decision-making criteria. We highlight the most important factors in Table 26. Each of these factors has varying impact in new build or retrofit, on-gas or off-gas, and we take these varying impacts into account when quantifying the relative impact for the forecast modelling.

For the scenario modelling, we assign market uptake rates based on the strength of these drivers and barriers in each sector. These are combined with the uptake rates defined in the economic analysis, to arrive at a number of GDHP deployed per year today, to 2020 and to 2030.

We have developed bands within the framework of which we characterise the impact of the soft factors. Table 26 highlights the most important soft factors and describes what the impact of them at the two extremes of the banding - Low and High.

Calculating the market uptake rate based on influence of 'soft' factors

We account for the impact of the soft factors by applying a "reduction factor" to each market uptake rated calculated based on the economic (payback) analysis previously discussed. We indicate the framework for these reduction factors below. Within each scenario there are variations within this framework assigned on a per year or per sector basis to account for differences in – for example – the impact of building regulations in new build, the impact of a stronger marketing & awareness raising campaign in existing buildings.

Market Uptake based on Economic Potential

Indicative market uptake rate based on payback analysis in each given year and for each sector (new build / retrofit & on-gas / off-gas) – as discussed earlier in this chapter.

Market Uptake based on Realistic Potential

Reduction factor applied to each market uptake rate identified in the economic analysis to take into account for the influence of 'soft factors'. The framework for the reduction factors is as follows:

YEAR	Reduction factor 2014	Reduction factor 2030
Low Scenario	-75%	-65%
Reference Scenario	-65%	-55%
High Scenario	-55%	-45%

Calculating realistic market uptake: Example

If the *economic* market uptake rate for a given sector is 10%, and the reduction factor is "-50%", then the *realistic* market uptake rate is 5%.

Appendix H: Details of the three main GDHPs available in the UK

Robur	
 	**Company background:** ROBUR is an Italian company focusing fully on gas driven chillers and heat pumps. ROBUR's products are sold under its own brand but the products are also packaged by some of the most important heating brands in Europe (e.g. Bosch and Baxi in the UK). **Unique Selling Point:** Most established and experienced GAbHP player in Europe, with product designed for heating applications in northern European climates – so a potentially strong UK product. **Challenges:** Robur is still a small company with a production rate of around 3,000 units per year, and a reliance on manufacturing many of its own components rather than out-sourcing, because the overall GAbHP market is small and there are no OEM suppliers for some components. This means costs are relatively high – with significant potential for reduction if sales volumes can be increased.
Design philosophy	ROBUR's products include a range of gas absorption heat pumps and chillers as well as a peak load gas condensing boiler. The company also offers preassembled cascades of its systems to serve larger heating or cooling demands. Robur's focus is on optimising heating efficiency. GDHP available as heating only solutions (E^3 series) in a high and low temperature version as well as reversible systems (PRO series).
Efficiency & Performance	Heating: 126-135% (A7/W35-50), 165% maximum; Cooling: 60% *Source: Manufacturer marketing materials – in LHV (not from aggregated data)*
Maintenance / servicing	Essentially requires the same gas safety checks as a gas boiler, and for air-source, ensuring the fans are not blocked. But there are very few moving parts in a GAbHP so requirements are minimal.
Capacity	Heating 15 - 40 kW / Cooling (PRO only) 17-40 kW (the range reflects capacity range achievable through modulation of individual unit. Can also be cascaded up to 100s of kW
Fuel types	Can be run using natural gas or LPG. No information on use with biogas

	yet.
Operating parameters	Heat source: Ground, water or air (down to -20°C). The additional (direct) use of ST is possible. Flow temperatures: >60 degrees achievable
Physical dimensions / weight (m3/kg)	1.37-1.65 m^3 380 kg
Cost (source: Aggregated data)	Cost for 38 kW unit from major UK distributor is £13,000 – 19,000/unit including installation cost (which is typically £2,000-£5,000 of the total cost). NB: cost excludes installation of a standard hydronic heat distribution system within building
Future developments – new products/concepts	For the existing commercial products, the main anticipated development is around further industrialisation of production, and some incremental efficiency improvements. The fact significant focus is not on further improvement is due more to a business decision not to invest the capital at this stage than any technical limitation on efficiency. The biggest on-going project is the Heat4U project, within which British Gas is a partner, developing a ~18 kW GAbHP designed for the residential market. This is expected on the market by next year - there is currently one prototype installed in the UK in a British Gas employee home as well as several around Europe.
End-use sectors	Robur has installed in a wide range of sectors in the UK and Europe including multi-family homes, hotels, offices, schools, and industry.
Level of commercialisation	8,000 installed in Europe at the end of 2012, with annual sales of low thousands per year.
Presence in the UK	Most established GDHP in UK with 100-200 installed in 2013 and several 100s installed in total. The most active supplier is ESS Ltd, and there are 4-5 other distributors in the UK selling in relatively small numbers. There are also sales channels via Bosch and Baxi (though these are not being heavily pushed at present). Robur has also worked closely with British Gas on the Heat4U project, and British Gas is now also selling the Robur 40 kW through its commercial heating business (early stages).

Table 26: Robur

Source: Delta-ee primary research with Robur and Robur distributors, installers and partners in the UK, plus manufacturer marketing materials.

Panasonic	
	**Company background:** PANASONIC bought SANYO in 2008, which then was the largest Japanese exporter of GEnHPs. The company is still one of the most active participants in the GEnHP market outside of Japan as well as in the Japanese market. **Unique Selling Point:** Most established GEnHP in UK - 4-5 UK installers with most units supplied by ESS and Oceanair. Ability to provide simultaneous heating and cooling as standard (3 pipe system) **Challenges:** No challenges specific to Panasonic, but for all GEnHPs they are generally specified as a cost saving alternative to upgrading the electricity supply to a site. They are not specified for carbon reduction reasons and are considerably more expensive (both capital & maintenance cost) than a conventional electric VRF system.
Design philosophy	Gas engine driven VRF system. 3 way multi designed to provide simultaneous heating & cooling plus 2 pipe systems for heating or cooling.
Efficiency & Performance	heating: 129-150%; cooling: 164 – 197% (incl. heat recovery for DHW, without heat recovery cooling efficiencies around 120-140%) *Source: Manufacturer marketing materials – in LHV (not based on aggregated data)*
Maintenance / servicing	Annual oil change required & major service/overhaul every 10,000 to 20,000 running hours
Capacity	heating 50 - 160 kW / cooling 45-142 kW (up to 85 kW cooling for single unit, up to 142 kW in cascade)
Fuel types	Can be run using natural gas or LPG. No information on use with biogas yet.
Operating parameters	Heat source: ambient air / waste heat Flow temperatures: >60 degrees achievable with air/water system
Physical dimensions / weight (m3/kg)	165-340 x 108 x 227 m3 755 – 1620 kg
Cost	The most detailed indicative systems costs we could find to provide a cost break-down were based on conversation with a single Panasonc distributor - in the range £15,500 to £19,880 per GEnHP unit for the range of capacities available (excluding indoor units & controls) Average total equipment cost (including indoor units & controls) = approx. £24k/GEnHP unit excluding installation cost. Total equipment cost (GEnHP + indoor units & controls) = approx. £1000/kW heating (£1125/kW cooling). Maintenance is typically £5,000/year for approx. 4 GEnHP's plus a major additional overhaul/service every 3 to 5 years

	(dependent on running hours/year)
Future developments – new products/concepts	Panasonic is also investing in development of trigeneration systems – for heating, cooling and power generation, which will further widen the potential applications.
End-use sectors	A wide range of applications usually where there is heating and cooling demand and insufficient electricity network capacity. In the UK, end-user sectors for Panasonic systems include hospitals, schools, universities, care homes, GP surgeries, universities and public buildings.
Level of commercialisation	Several thousand installations per year in Japan. Panasonic is investing in developing distribution and support networks in Europe for its GEHP, which is currently the limiting factor to the size of its market.
Presence in the UK	Most established GEnHP in UK with ~100 installed in 2013. There are 5 distributors in the UK .Two most active installers are ESS Ltd and Oceanair. Since 2003 ESS have sold 350 units (and Ocenair approx.. the same number) and expect to sell about 60 units in 2014. Oceanair supplied around 30 per year (installed at around 6 sites with typically 5-7 units per site). The total number of Sanyo/Panasonic units installed in the UK is estimated as 1200 to 1500.

Table 27: Panasonic

Source: Delta-ee primary research – interviews with Panasonic and Panasonic UK distributors and installers, plus manufacturer marketing materials.

Aisin	
	**Company background:** AISIN is one of the main Asian GEnHP manufacturers and is one of the most active outside the Japanese and wider Asian core markets. The company sells its GEnHP range through distributors in various markets worldwide, including Europe (exclusively via Tecnocasa). **Unique Selling Point:** Aisin's extensive experience with GEnHP and large number of installations; one of widest capacity ranges on market; longest reported running hour intervals without maintenance of all GEnHP (30,000 running hours) **Challenges:** Limited sales channels, servicing and maintenance networks, and experience in UK Currently does not offer 3 pipe system, which enables production of simultaneous heating and cooling. Cannot be installed as the sole source of heating/cooling *and* hot water. Hot water can only be produced when (ambient air) heat source is at a high enough temperature (typically above 7 degrees). Back up boiler must be installed for hot water.
Design philosophy	Standard solution is an air-air GEnHP (essentially a VRF), primarily for

	air-based heating & cooling applications. Hot and cold water can be produced via hydrobox add-on with additional heat exchanger (making an 'air/water' system. Additional hot water can be produced with heat recovery solution (but only where the air temperature is above ~7 degrees C).
Efficiency & Performance	Heating: 150-160%; Cooling: 130-140% (180-200%, with heat recovery) *Based on manufacturer marketing materials – in LHV (not based on aggregated data)*
Maintenance / servicing / installation	Oil change required after 30,000 running hours, plus an annual gas safety check.
Capacity	Heating 25-80kW; Cooling 22.4-71kW
Fuel types	Can be run using natural gas or LPG. No information on use with biogas yet.
Operating parameters	Heat source: air Flow temperatures: >60 degrees with hydronic system
Physical dimensions / weight (m3/kg)	166 x 88 x 208 | 765kg
Cost	System costs in the range of €22,000 – €40,000 without installation (based on manufacturer materials and industry opinion from delta-ee interviews). The additional heat recovery system for production of hot/cold water typically adds ~30% to the cost (based on an interview with one distributor).
Future developments – new products/concepts	Incremental improvements but no revolutionary concept changes. Considering developing 3-pipe system to enable simultaneous heating and cooling for UK market.
End-use sectors	Wide range of commercial buildings including offices, schools, public & commercial buildings, hotels. Retrofit and new build.
Level of commercialisation	Install average of 20,000 GEnHP / year in Japan in the last five years (18% on LPG). Distribution/sales bases are located in South Korea, the US and Europe (Tecnocasa). Of the GEnHP manufacturers, Aisin - through Tecnocasa - is amongst the most active in Europe.
Presence in the UK	No direct sales channels in the UK but one installer active (Air Conditioning Services Ltd, covering Surrey and SE England), working with Aisin's exclusive European distributor Tecnocasa in Italy.

Table 28: Aisin

Source: Delta-ee primary research – interviews with Aisin European distributor specifically for this project, and on interviews with Aisin directly ~ 1 year ago, plus manufacturer marketing materials.

Glossary

Terms used throughout the report:

a/a	Air to Air
a/w	Air to Water
b/w	Brine to Water
BPIE	Building Performance Institute Europe
BREEAM	Building Research Establishment Environmental Assessment Method
CO_2	Carbon dioxide
COP	Coefficient of Performance
CSE	Centre for Sustainable Energy
DEC	Display Energy Certificate
DECC	Department of Energy & Climate change
DoE	Department of Energy
EC	European Commission
EEO	Energy Efficiency Office
FEES	Fabric Energy Efficiency Standard
GAbHP	Gas Absorption Heat Pump
GAdHP	Gas Adsorption Heat Pump
GCB	Gas Condensing Boiler
GDHP	Gas Driven Heat Pump
GEnHP	Gas Engine Heat Pumps
HHV	Higher Heating Value
HP	Herat Pump
IEA	International Energy Agency
IEA HPP	International Energy Agency Heat Pump Programme
LHV	Lower Heating Value
LPG	Liquid Petroleum Gas
MHI	Mitsubishi Heavy Industries
MVC	Mechanical Vapour Compression
N-DEEM	National Non-domestic Buildings Energy and Emissions Model
O&M	Operation and maintenance

OEM	Other Equipment Manufacturer
ONS	Office for National Statistics
R&D	Research and development
RES	Renewable Energy Sources
RHI	Renewable Heat Incentive
SEER	Seasonal Energy Efficiency Ratio
SHW	Sanitary Hot water
SPF	Seasonal Performance Factor
ST	Solar Thermal
UK	United Kingdom
VRF	Variable Refrigerant Flow
w/w	Water to Water

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