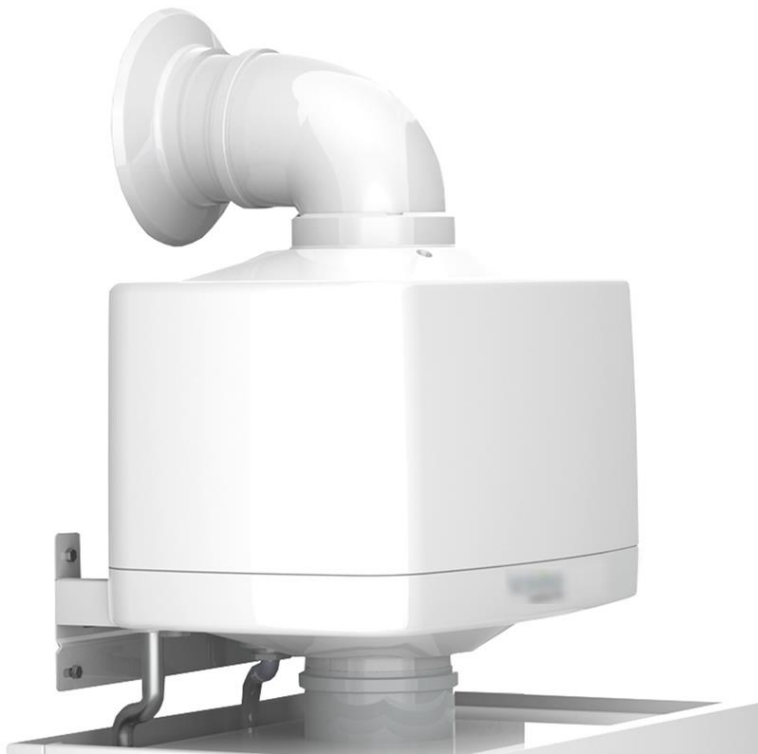




Department for  
Business, Energy  
& Industrial Strategy

# Evidence Gathering: Passive Flue Gas Heat Recovery Technologies



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## Acknowledgements

Prepared for BEIS by Delta Energy & Environment Ltd. & Enertek International Ltd.

The views expressed in this report are those of the authors, and do not necessarily reflect those of the Department for Business, Energy and Industrial Strategy. This report was commissioned to inform BEIS's evidence base for future policy development.

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# Key messages

- 1. PFGHR products can broadly be segmented into two types: those with additional thermal storage and those without.** PFGHR devices *without* thermal storage only provide energy savings when the boiler is operating in ‘domestic hot water’ mode (or ‘summer’ mode). Those *with* thermal storage (typically a 5 to 10 litre store) provide additional energy savings when the boiler is operating in ‘space heating’ mode (or ‘winter’ mode), as well as when operating in ‘domestic hot water’ mode. Current products are designed to work only with combination boilers (producing instantaneous hot water), not system boilers (products for these boilers would be much more expensive and complex to develop).
- 2. PFGHR products are estimated to be able to save approximately 9% (no thermal storage in the PFGHR product) to 31% (PFGHR incorporating a thermal store) of the gas used to heat domestic hot water when operating in ‘domestic hot water’ mode in a typical house, equivalent to a boiler efficiency improvement of around 1 to 5 percentage points when considering the total domestic hot water and space heating requirements of a home.** (Actual savings will vary within and beyond this range according to actual and relative domestic hot water and space heating demands, the volume of thermal storage and the extent to which space heating and domestic hot water demands overlap).
- 3. The marginal price of a boiler with a PFGHR compared to a conventional boiler without PFGHR ranges from less than £200 to over £1,000,** with the majority of products being between £250 and £600. The difference in price can largely be attributed to different designs of PFGHR, with those using additional thermal storage typically costing two to three times that of those without thermal storage.
- 4. Given today’s prices for PFGHR products, and an assumed annual domestic hot water demand of 2,000 kWh per year, payback periods do not fall within a period of 10 years for most (but not all) products.** Some integrated PFGHR units without storage are showing paybacks down to approximately 10 years, and PFGHR units with storage can achieve approximately 13-year paybacks in a typical house. Payback periods are sensitive to variations in actual savings noted in point 2 above, and will be less than 10 years for certain products for certain thermal demands.
- 5. There is considerable scope for price reduction if PFGHR is produced at volume** (in a similar way to other boiler components) – as low as <£100 for PFGHR without storage, and ~£200 for PFGHR with storage. There is nothing inherently complex or expensive about the technology. This would reduce payback periods by a factor of 2-3 on today’s prices.

6. **When external PFGHR devices are fitted to a boiler, they become a component part of the boiler installation and are therefore subject to the boiler design, performance and installation Standards.** This eliminates the possibility of fitting a stand-alone PFGHR unit to a boiler unless it has been certified for use with the boiler concerned. **This severely limits the potential for retro-fitting the technology.**
7. **The PFGHR market in the UK is relatively immature; there are approximately 100,000 devices currently installed.** Most (but not all) boiler manufacturers sell PFGHR products.
8. **The number of units installed in 2014 is estimated to be around 14,000** compared to a gas combination boiler market of approximately 1.3 million (and a total gas boiler market of approximately 1.6 million).
9. **The only significant driver for PFGHR in the UK today is SAP compliance.** Likely more than 90% of PFGHR sales can be attributed to the greater SAP score which can be achieved within new-build properties by installing the technology – with RSL new-builds accounting for around three-quarters of these sales as they often build to specifications higher than Building Regulations.
10. **Hardly any PFGHR devices are sold to the owner-occupiers.** There has been no effort to develop this market, and paybacks are long, typically more than 12 years, and usually greater than the expected life of a boiler.
11. **Despite a thorough search, we have found no evidence of the existence of any in-field data relating to the performance of PFGHR products within ‘real life’ dwellings. Therefore, all the numbers provided within this report should be considered as indicative only.** Furthermore, unless specified, all performance figures in this report are in reference to a typical existing dwelling. We expect large variations from the mean average in gas savings from one property to the next depending on domestic hot water usage and other factors.
12. **Cost-per-tonne of carbon saved** is typically ~£465 for PFGHR devices *without* thermal storage and ~£235 for PFGHR devices *with* thermal storage (note that there will be significant variation around this mean), with the potential to fall *if* PFGHR prices reduce as indicated above.
13. All figures relating to the performance, costs and market size of PFGHR have been developed and compiled following in-depth interviews with many PFGHR designers, manufacturers and retailers and, while we believe they represent a sound analysis of the market status and available data today, and the true energy savings which can be achieved, **we strongly recommend a second phase of research, based around a field trial using a range of different PFGHR products in a range of houses**, if a greater understanding and certainty of the actual performance characteristics of PFGHR products is to be achieved.

## Executive summary

Passive Flue Gas Heat Recovery (PFGHR) technologies offer the potential to increase gas savings within the UK domestic sector. By recovering heat from the flues of boilers and pre-heating incoming domestic hot water, a PFGHR device can increase gas boiler efficiency by 1 to 5 percentage points within a typical existing dwelling when compared to a conventional condensing gas combination boiler.

The mean savings (and variation around this mean) will vary according to the amount and profile of hot water consumption – and there will be strong variation of this from house to house. A lack of in-use data creates a significant evidence gap around these figures.

PFGHR is a seldom used technology within the UK domestic sector; less than 1% of homes currently have a PFGHR device installed. Yet, approximately 10% of new-build properties are estimated to be having the technology installed today, installing the technology for compliance targets that are more stringent than the base-case new-build regulations. The technology is either integrated into a boiler, or installed as an ‘add-on’ on top of a boiler (although retrofit to existing boilers is rare and, for regulatory reasons, very challenging).

PFGHR provides gas savings when a combination boiler is used to pre-heat domestic hot water using heat recovered from the flue gas when the boiler is operating in domestic hot water or, in some cases, space heating mode. Available evidence gathered, and analysis carried out, during this project suggests that *domestic hot water* gas savings ranging from approximately 9% to 31% can usually be achieved when the boiler is providing hot water within a typical existing property, saving between £10 to £45 per year, or 1.5% to 5% on annual household gas bills. (This is the equivalent to an overall boiler efficiency improvement of around 1 to 5 percentage points.)

There is a large range of efficiency improvements since the gas savings which can be achieved depend on the type of PFGHR, and for some devices the co-incidence between domestic hot water consumption and space heating demands. Furthermore, despite extensive research we have found no evidence from in-use field trials, and there may be significant differences in actual in-use performances of PFGHR devices compared to laboratory and manufacturer data.

We have carried out in-depth research looking at Passive Flue Gas Heat Recovery (PFGHR) in the UK in order to identify:

- The overall carbon savings, energy savings and cost savings which can be achieved when using the technology
- The different PFGHR system architectures that are employed
- The size of the market today, and future growth scenarios
- Typical prices, and how these differ across different system designs
- The primary market drivers and barriers which influence sales volumes
- The availability of in-field and laboratory PFGHR performance test data, and gaps in available information



## 1. Performance and savings

The extent to which a PFGHR system can increase the efficiency of a dwelling and reduce natural gas consumption is dependent on many factors, including the domestic hot water and annual space heating demand of the specific building, whether or not the PFGHR has built-in thermal storage, and the extent to which domestic hot water demand overlaps with space heating periods.

However, we have analysed the gas savings which can be expected within typical households by using manufacturer data and desk-based analysis of boiler and PFGHR operation given certain thermal demand assumptions.

The results are summarised as follows:

Type of PFGHR	Typical increase in DHW efficiency (%)	Typical increase in overall boiler efficiency, for DHW & space heating (percentage points)	Likely variation
Without thermal storage	9%	1 percentage point	<i>Actual DHW gas savings are likely to range from around 5% to 10%</i>
With thermal storage	31%	5 percentage points	<i>Actual DHW gas savings are likely to range from less than 15% to around 35% depending on DHW demand, space heating demand, and the volume of thermal storage.</i>

For every type of PFGHR device, the volume of gas saved is closely linked to the domestic hot water demand for a given dwelling; higher hot water demands will result in higher gas savings when using a PFGHR device. This will likely result in a significant variation of savings from property to property.

It should be noted that throughout the research for this report, we found no evidence for 'real-life' in-field monitoring data for PFGHR technologies within residential applications. Hence all data we report on and analyse relies on laboratory tests and manufacturers views.

## 2. Market today and future scenarios

The PFGHR market in the UK is relatively immature, with sales of approximately 14,000 per year, and a total installed base anticipated to be in the region of 100,000 units. With sales of approximately 1.3 million gas combination boilers each year (out of a total boiler market of 1.5-1.6 million), PFGHR represents little more than 1% of this market.

In the future, any significant increase in PFGHR sales is likely to be driven by government intervention rather than any changes in customer behaviour or technology advances. As such, we have considered four potential future scenarios to determine the extent to which each could stimulate an increase in PFGHR sales, and consequently a reduction in CO<sub>2</sub> emissions, and the cost-per-tonne of CO<sub>2</sub> saved.

In each scenario, we have assumed PFGHR units with no thermal storage as it would likely be impractical to mandate larger PFGHR units with additional storage within the existing building stock where space is often restricted. This allows a like-for-like comparison of each scenario.

The results are summarised as follows:

Scenarios	Annual sales	Total PFGHR units installed by 2025	Additional tonnes of CO <sub>2</sub> saved annually	Total tonnes of CO <sub>2</sub> saved per year in 2025 versus BAU	Cost per tonne of CO <sub>2</sub> saved (£ / tonne)*
Business-as-Usual (BAU)	14,000	~240,000	~600	N/A	~£465
Policy Support	~80,000	~900,000	~3,400	~28,000	~£390
New-build mandation	~110,000	~1,200,000	~4,600	~40,000	~£310
Boiler replacement mandation	1,300,000	~13,100,000	~56,000	~553,000	~£140

### 3. Cost analysis

During the course of this research we have compiled cost information through multiple interviews with PFGHR manufacturers and retailers. Our analysis indicates that the marginal retail price for a PFGHR unit (in addition to the price of an equivalent boiler without PFGHR) varies significantly from one company to the next, and can range from around £150 to over £1,000. However, **a price range of £250 to £600 captures the large majority of PFGHR products on the market today.** The most significant factor which impacts the price of a PFGHR product tends to be the design, and whether or not the unit utilises additional thermal storage; those with storage tend to cost two to three times the price of those without.

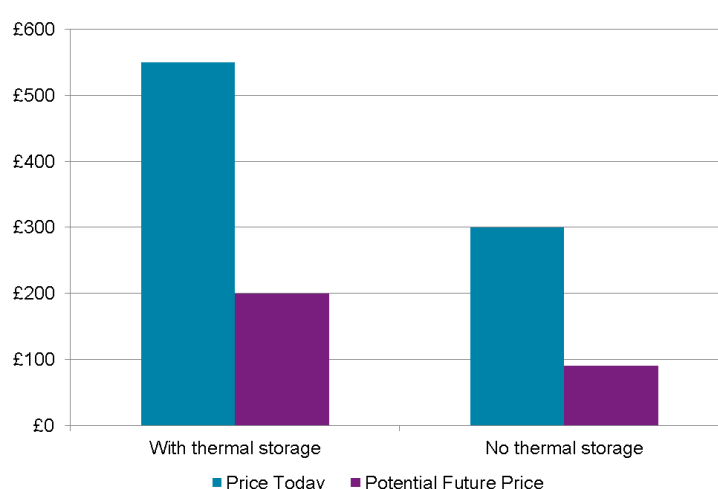
#### Typical marginal retail price for PFGHR units:

- **Without additional thermal storage: A median of £300**, with a range from £150 to £400
- **With additional thermal storage: A median of £550**, with a range from £400 to £1,000

The payback periods for PFGHR are closely linked to the domestic hot water demands of individual households; those with high hot water demands will save more gas, on average, and the PFGHR unit will pay back more quickly.

Based on typical assumptions on domestic hot water demand (2,000 kWh per year), and using the median retail prices listed above, we have calculated that for **PFGHR with additional thermal storage, payback periods of approximately 13 years can typically be achieved.** For PFGHR without thermal storage, payback periods are typically more than 20 years (although this figure is very sensitive to the price of the product, and the annual domestic hot water demand).

We estimate that costs could come down to approximately £200 (with storage) and £90 (without storage) if PFGHR units are mass-produced (around 500,000 units or more).



**Figure 1: Indicative median prices for PFGHR today and in the future if > 500,000+ units were manufactured each year.**

Source: Delta-ee Analysis

#### 4. Conclusions and Recommendations

**Our research indicates that government intervention would be necessary in order to stimulate a significant increase in PFGHR sales** based on the information available to us during this project, and our understanding of the economic proposition which PFGHR can provide.

The number of PFGHR units which could be installed, under the right conditions, has the potential to reach hundreds of thousands or even millions per year. In the scenario where all new gas combination boilers are required to be fitted with a PFGHR, an *additional* 56,000 tonnes of annual CO<sub>2</sub> savings could be achieved every year. However, even using optimistic cost reduction assumptions, based on high sales volumes, payback periods are likely to remain as high as 8 years for typical homes with an annual domestic hot water demand of 2,000 kWh. Therefore, even under scenarios where PFGHR has become a mature market, government support or regulation would still likely be necessary in order to maintain the market.

In order to determine whether government intervention of the PFGHR market is a prudent step to take, it is necessary to consider how PFGHR compares to other low-carbon domestic heating technologies in terms of a '£ per tonne of carbon saved' basis. **Our analysis indicates that at high sales volumes, prices of PFGHR products could come down significantly compared to today's prices, and for a PFGHR system without thermal storage, a '£ per tonne of carbon saved' value of £140 could be achieved.**

# 1. Characterising Passive Flue Gas Heat Recovery Technology

## 1.1 Introduction to PFGHR

### What is PFGHR?

Passive Flue Gas Heat Recovery (PFGHR) is the extraction of waste heat from the products of combustion (flue gases) which can then be used for the purpose of pre-heating domestic hot water (or the central heating circuit). By doing so, the amount of gas used to heat domestic hot water (or provide space heating) can be reduced, thereby increasing the overall efficiency of the boiler. It should be noted that the term 'passive' implies that no additional (electrical) energy is consumed during the operation of the PFGHR device.

While PFGHR can theoretically be applied to both combination and system-type boilers, using different fuel types, all evidence found during the research for this project indicated that PFGHR products are only being targeted at gas combination boilers today, due to the increased complexity (and consequential higher costs) of plumbing a PFGHR into a system with a separate hot water cylinder. Today, it is thought that gas system-type boiler sales account for less than 15% of the total gas boiler market in the residential sector, and with PFGHR sales equivalent to only ~1% of the gas boiler market, all effort is currently focussed on increasing the PFGHR market share within the larger gas combination boiler market segment.

Furthermore, all PFGHR devices currently on the market are designed to transfer recovered heat into the domestic hot water circuit; within most UK dwellings, the return temperature of the space heating circuit is not sufficiently low to benefit from pre-heating from the boiler flue gases.

### A brief history of PFGHR development

Flue gas recuperators have been used with commercial gas boilers for many years. The original devices typically consisted of an arrangement of tubes manifolded together and inserted into the flue of a non-condensing commercial boiler to recover waste heat energy which was usually fed into the heating circuit. This was possible because the temperature of the flue gas on a non-condensing boiler is much higher than the central heating return temperature.

As gas prices increased, thermal efficiency became increasingly important for end-users, and certification requirements were introduced (especially the advent of CE Marking in 1995). These external recuperators evolved into secondary heat exchangers fitted within the extremity of the boiler casing thereby becoming the first generation of condensing boilers, both within domestic and commercial applications. These products typically used atmospheric combustion but were fan assisted to overcome the additional resistance in the flue.

During the 1990's, improvements in gas controls technology made possible the development of pre-mix combustion (where all necessary air required for safe combustion is mixed with the gas prior to entry to the burner, improving performance). Although pre-mix combustion was invented many years earlier it was not until improvements in gas valve design and fan technology that

pre-mix became cost effective and reliable for the domestic market. The key innovation behind this was the development of DC fans which have more effective speed control than earlier AC models. These developments made the prospect of cost-effective condensing boilers a reality.

The government introduced the Building Regulations Part L (initially in April 2002) to drive efficiency levels upwards, and to reduce CO<sub>2</sub> emissions. This stimulated manufacturers to strive for 'SEDBUK A' rated efficiencies which was most easily achieved by specifying a single heat exchanger incorporating primary and secondary sectors to maximise efficiency. With high efficiency (SEDBUK A) appliances, the flue gas temperature is only a few degrees above the boiler return temperature and the energy content in the flue gases is low compared to the original atmospheric (non-condensing) appliances.

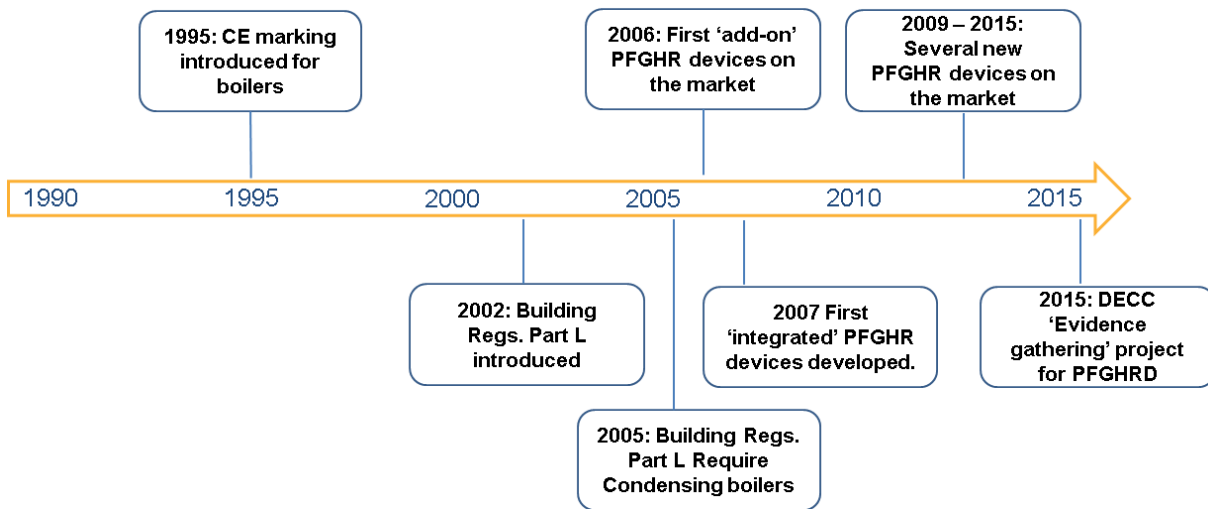
In 2006, Zenex Technologies Ltd., pioneered by Chris Farrell, designed an 'add-on' secondary heat exchanger, or recuperator, for use with condensing combination boilers. This technology was based on recovering energy from the flue gases and pre-heating sanitary water. Zenex worked with BRE to create a methodology for proving energy saving and was accepted onto Appendix Q of the Building Regulations, thereby achieving recognition in SAP. During this procedure, the term 'Passive Flue Gas Heat Recovery' (PFGHR) was conceived to describe the function of the device in a way that could be differentiated from the earlier 'recuperators' which often used additional pump or fan energy (and were therefore not considered to be 'passive').

This new type of recuperator was specifically aimed at boosting domestic hot water performance, and not the performance of the central heating system. This innovative development takes advantage of the lower water temperature of the incoming mains sanitary water and pre-heats it before entering the appliance.

During 2007, Johnson & Starley, a niche heating appliance manufacturer, developed an alternative solution whereby the Zenex type PFGHR was incorporated within the boiler casing. This resulted in a slightly different approach to measurement and certification but had a similar overall performance benefit.

During the period 2010 to the present day, most 'mainstream' boiler manufacturers started offering a PFGHR option (either by supplying a system which has been designed by a third-party, or by designing a system in-house).

In conclusion, the development of PFGHR devices has been a natural progression in efficient gas utilisation, with original non-condensing efficiencies being enhanced by a secondary heat exchanger, this being then incorporated within the appliance, then further evolving into a fully condensing primary heat exchanger. The PFGHR is a natural 'next generation' of supplementary heat recovery device.



**Figure 2: Timeline of significant PFGHR events**

Source: Delta-ee & Enertek International

## 1.2 An Overview of Different PFGHR Designs

PFGHR technologies are primarily differentiated by their location, being either 'external' (fitted in the flue but external to the boiler) or 'integral' (fitted within the boiler casing). They can also be differentiated as to whether the device incorporates any thermal storage, such as a five litre hot water store which stores energy captured from the flue gases when the boiler is operating in 'space heating' mode.

Hence there are four types of PFGHRD:

- External with storage
- External without storage
- Integral with storage
- Integral without storage

In all cases, the PFGHRD works during the production of instantaneous hot water by extracting heat from the flue gases and transferring the heat into the incoming cold sanitary water supply.

In addition, devices with storage capture and store energy from the flue gases whilst the boiler is operating in central heating mode. This heat is then used to pre-heat the cold sanitary water when there is a demand for hot water, thereby providing an efficiency boost over and above that gained instantaneously during DHW production. Devices with storage will decrease the response time for a combi boiler in providing hot water to the point of use (if the heating has been running), which has the potential to save water as well as energy.

### 1.3 Comparison of different system architectures

#### How do different system designs vary in their approach to increasing efficiency?

As described earlier, in simple terms, there are four types of PFGHR design and each has a different mode of operation and thus effect on increasing energy efficiency. However, the design variable which has the biggest impact on how much gas each type of PFGHR saves relates to whether or not the product incorporates additional thermal storage. As such, for the purposes of this chapter, we have grouped together products *with* and *without* additional thermal storage.

It should be noted that for PFGHR devices which incorporate additional thermal storage, some heat loss from the thermal store is likely to occur. However, following conversations with PFGHR manufacturers, the authors of this report believe the heat stores to be well insulated and heat losses to be minimal and not significantly impacting the ability of PFGHR to save on gas consumption.

#### PFGHR with storage

The design of a storage-type PFGHR device typically stores heat recovered from the flue gases and transfers this to the incoming cold sanitary water which is then pre-heated before it enters the boiler.

Two types of external storage exist. The first one is where the device collects and retains within its housing an amount of condensate as shown below.

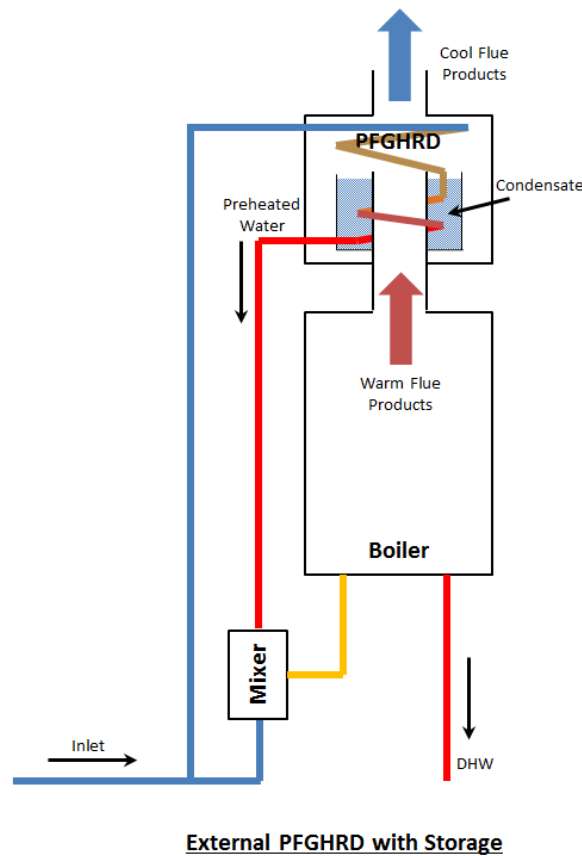
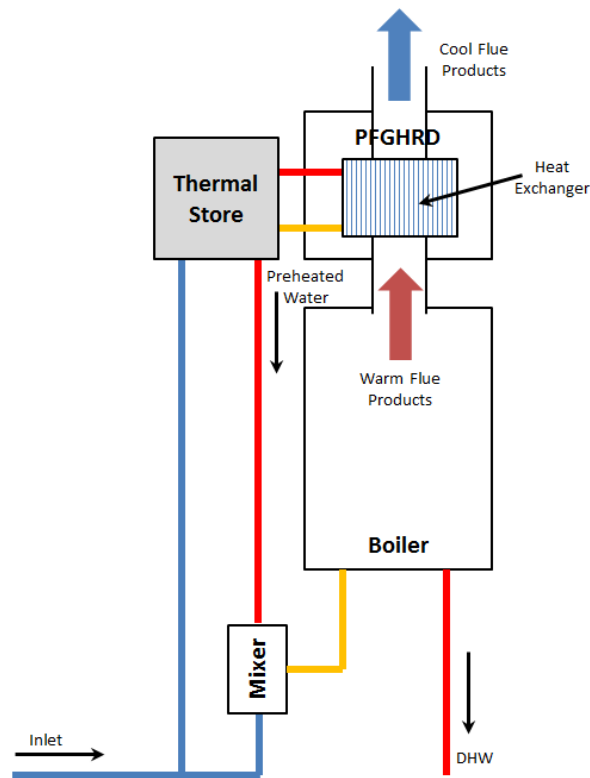


Figure 3: Schematic of external PFGHR with thermal storage

Source: Enertek International



The other type of external storage is where a separate sanitary water store is heated via gravity circulation from the PFGHR.

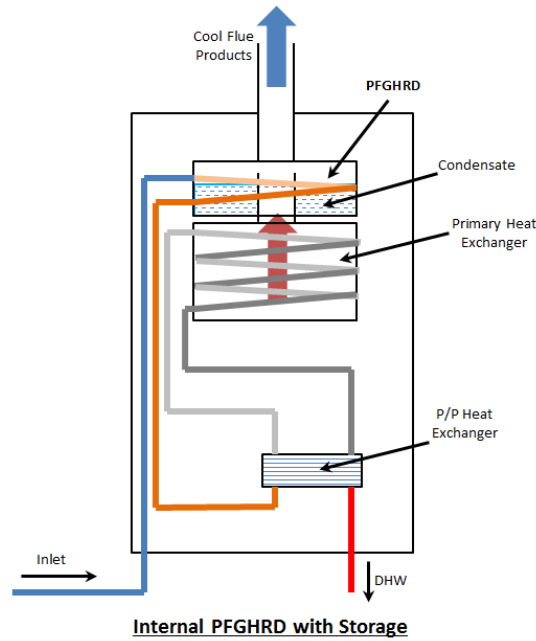


**External PFGHRD with External Storage**

**Figure 4: Schematic of external PFGHR with external thermal storage**

Source: Enertek International

The above schematic illustrations are examples of external storage but it is possible to incorporate a limited amount of storage within an appliance (internal storage) as shown in Figure 5



**Figure 5: Schematic of internal PFGHR with thermal storage**

Source: Enertek International

With both types of storage, (whether internal or external) heat is transferred from the flue gas to the store as flue gases pass through the device. The sanitary water circuit pipework passes through the store before entering the boiler so that the store pre-heats the incoming cold water for domestic hot water production. Neither type of storage provides any increase in central heating efficiency.

**Operation in domestic hot water (DHW) mode:**

When the boiler is operating in ‘DHW’ mode, in addition to heat from the store pre-heating the cold water to provide an initial boost to the incoming mains water temperature, heat is also recovered from the flue gases and transferred to the cold water as it flows through the PFGHR on an instantaneous basis. The additional heat recovered (compared to a boiler without the PFGHR) provides the saving and is recorded as additional efficiency.

**Operation in Central Heating mode:**

When operating in ‘Central Heating’ mode, heat recovered from the flue gases is stored in the reservoir (or external store) until there is a demand for hot water, in which case not only is heat recovered instantaneously as in DHW mode, but the stored heat provides an additional ‘uplift’ to the output and therefore provides even higher efficiency until a point where the store has been depleted and instantaneous operation continues as in the case of ‘DHW’ mode operation. Depending upon the size of the store and the length of operation in central heating mode before the DHW demand, instantaneous mode is only likely to happen with a prolonged DHW draw off.

The maximum temperature theoretically achievable in the store is the flue gas temperature. The flue gas temperature depends upon the operating mode, the length of operation and thermostat

settings of the boiler. In practice, even when the boiler runs in thermal equilibrium at full load (only normal in a laboratory environment) the store temperature is closer to the boiler return temperature (rather than the flue gas temperature).

A correctly sized boiler operating in a typical domestic central heating system would be set to run with a flow temperature of between 60°C and 80°C. The return temperature would normally be around 20°C below the flow temperature at maximum rate, or 7°C below the flow temperature at minimum rate.

The optimum condition for a storage type PFGHR is when the boiler has been operating in central heating mode for a sustained period prior to a domestic hot water draw-off.

### PFGHRD without storage

Where no storage facility is fitted, no significant amount of heat is retained within the PFGHR unit (except that contained in the small amount of residual sanitary water contained within the unit). Therefore, no additional energy efficiency benefit can be gained from operating the PFGHR unit in space heating mode.

#### Operation in DHW mode:

When the boiler is operating in 'DHW' mode, heat is recovered from the flue gases and transferred to the cold water as it flows through the PFGHR on an instantaneous basis. The additional heat recovered (compared to a boiler without PFGHR) provides a gas saving when operating in DHW mode.

#### Operation in Space Heating mode:

When operating in 'space heating' mode, no heat is captured except the volume of water contained within the PFGHR unit itself. At the start of any DHW draw off, there may be an initial uplift in efficiency due to the inherent water content of the boiler, but this is quickly used up and instantaneous heat recovery commences immediately thereafter.

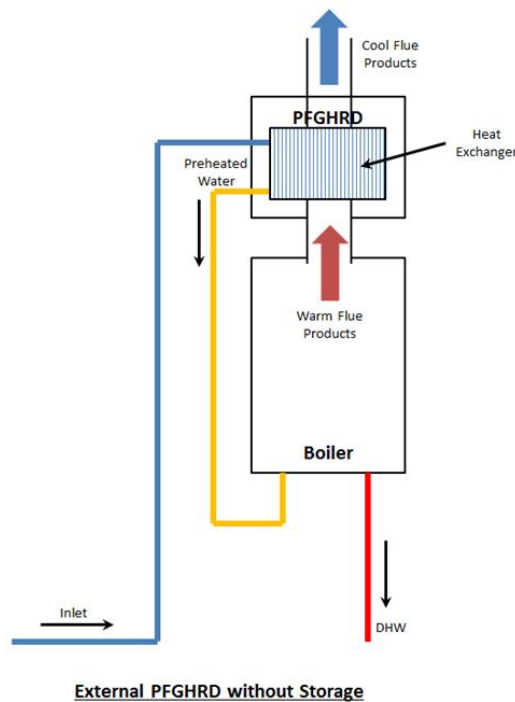
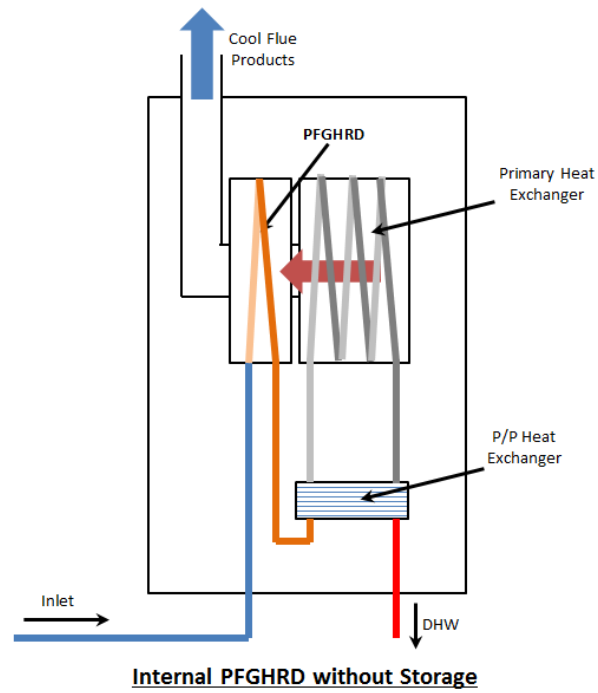


Figure 6: Schematic of external PFGHR without thermal storage

Source: Enertek International

Figure 6 shows an external PFGHR without storage. It is clear to see that the PFGHR unit is visible as an additional 'bolt-on' to the boiler. Figure 7 shows an internal non-storage schematic whereby the PFGHR is not visible to the user because it is fully contained within the appliance.



**Figure 7: Schematic of internal PFGHR without thermal storage**

Source: Enertek International

## How does design impact product certification?

### Internal PFGHR: design and application

Internally-fitted PFGHR units are fitted to the boiler during assembly of the boiler during the standard production. The design often requires an increase in physical dimensions of the boiler, although anecdotal evidence gathered during the course of this project suggests that in as many as 50% of existing houses, the increase in size of a boiler with an internal PFGHR would not normally prohibit the installation of the device due to space restrictions. In general those featuring internal storage do increase the boiler dimensions whereas those without storage are less likely to do so.

Although the PFGHR adds resistance to the flue circuit, the design and development of the appliance can compensate for this (for example by specifying a larger or higher speed fan, but this may incur slightly higher electrical power consumption) so that extended flue lengths can be offered, similar to flue lengths offered on conventional boilers.

In practice, manufacturers offering PFGHR devices as a bolt-on optional 'extra' accept a reduction in overall flue length as compensating for the resistance of the PFGHR device rather than redefining the fan speeds or specification. Manufacturers supplying boiler-integrated PFGHR products use a standard specification factor which incorporates the increased resistance into the overall design of the heating appliance.

### Internal PFGHR: certification requirements

Certification requirements apply to the boiler as supplied to the market. The addition of an internal PFGHR system does not affect the EC certification requirements for the boiler, although it does improve the DHW efficiency results and an extra set of tests to satisfy SAP requirements needs to be completed to quantify the efficiency gains and enable the device to be added to the 'Product Characteristics Database', and to qualify for SAP.

### External PFGHR: design and application.

External PFGHR's are usually supplied as optional extras to be used with a specific boiler. Hence the design of the boiler is not affected in any way, but the PFGHR unit is a separate component, usually in a white casing of similar cross sectional area to the boiler and is designed to fit immediately above the boiler (so that the condensate overflow can pass through the boiler's internal condensate drain in the normal way).

It is important to note that the external PFGHR effectively increases the height of the boiler and therefore the position of the horizontal flue terminal relative to the ceiling height. If the boiler is being installed in a single storey building it is sometimes not possible to route the flue in the normal way due to the proximity of the guttering outside.

### External PFGHR: certification requirements.

There are no specific certification requirements for the PFGHR itself, but it has to be certified for use with specific boilers.

Hence for the device to be used with a boiler, the boiler has to be certified;

- a) in its own right without a PFGHR (for applications where the device is not fitted) and
- b) it has to be certified for use with the PFGHR fitted.

In addition, it is necessary to carry out additional tests (as described in the BRE documentation, see below) to quantify the efficiency gains and enable the device to be added to the Product Characteristics Database for use in SAP.

When an external PFGHR is added to the boiler, it adds resistance to the flue system, and reduces the flow-rate of exhaust gases leaving the system. Therefore the maximum flue length permitted with the appliance is likely to be reduced.

The Standards allow a maximum 5% down-rating with long flues, without the necessity to declare the reduction. Therefore, at development stage, boilers are often tested with increasing flue length until a 5% down-rating is reached; that being the maximum permissible flue length, above which the flow rates are deemed not to be high enough to be safe. If a PFGHR is fitted this is likely to have a resistance equivalent to a length of several meters, so the 5% down-rating is likely to be achieved earlier hence shorter flue lengths, which should be declared.

The allowable variation in heat input is limited by Standards (+/- 5%). Flue length (resistance) influences heat input. Blocked flue and freezing constitute fault conditions and are not relevant in this context

The BRE documents referred to above are:

- Flue Gas Heat Recovery Systems (FGHRS): Data requirements and assessment methodology for recognition in SAP (SAP 2009 revision): John Hayton (March 2008)
- Treatment of FGHRS with close-coupled heat store in Appendix Q of SAP: John Hayton (November 2008)
- Treatment in SAP Appendix Q of a close-coupled store in a FGHRS with an electric immersion heater powered by photovoltaic modules: John Hayton (Feb 2009)

Note that stores incorporating an electric immersion heater are not considered as 'passive'.

## 1.4 PFGHR Standards

### A summary of applicable standards

All domestic gas boilers fall within the scope of the European Gas Appliance Directive (2009/142/EC) and therefore require third-party certification. Product certification is owned by the manufacturer (or their agent). PFGHR units are installed within the flue gas circuit of condensing gas boilers. When fitted, they become a component part of the boiler installation and are therefore subject to the boiler design, performance and installation Standards. This eliminates the possibility of fitting a stand-alone PFGHR unit to a boiler unless it has been certified for use with the boiler concerned. This severely limits the potential for retro-fitting the technology.

In addition to the boiler Standards, which are required to prove compliance with the European Directives and therefore enable the product (boiler + PFGHR) to be CE Marked (subject to the usual quality system requirements), there are additional procedures prescribed by BRE to enable the application (boiler + PFGHR) to be recognised in SAP and therefore listed on the Product Characteristics Database. (The Product Characteristics Database is publically available and used to provide information needed to calculate a building's SAP rating.)

## European Directives and Standards

All boilers must comply with the relevant Directives in order to be CE marked.

If the boiler is available with a PFGHR, either as standard or as an option, the boiler must comply with all of these requirements with the PFGHR fitted.

The relevant Directives and Standards are listed below:

TYPE OF DIRECTIVE	DIRECTIVE NAME AND DESIGNATION	MAIN APPLICABLE STANDARDS FOR TESTING	RELEVANCE TO PFGHR
<b>Safety and Performance</b>	Gas Appliance Directive (2009/142/EC)	<b>EN15502</b>	Covers boiler design, construction, safety and performance. Considers PFGHRD to be a component within a boiler and therefore captures all aspects of performance.
<b>Efficiency Performance</b>	Boiler Efficiency Directive (92/42/EEC + amendments)	<b>EN15502</b>	As above
	Energy related Products Directive (2009/125/EC + amendments)	<b>EN15502</b> and <b>EN13203</b>	As above. EN13203 covers domestic hot water performance. Considers PFGHR to be a component within a boiler and therefore captures all aspects of performance.
<b>Labelling</b>	Energy Labelling Directive (2010/30/EU + amendments)	<b>EN15502</b>	No specific requirements for PFGHR. Considers PFGHR to be a component within a boiler and therefore captures all aspects of performance.
<b>Electrical Safety</b>	Low Voltage Directive (2006/95/EC: valid up to 20/04/2016)	<b>EN60335</b>	Covers electrical safety. Considers PFGHR to be a component within a boiler and therefore captures all aspects of performance.
	Electromagnetic Compatibility Directive (2004/108/EC: valid up to 20/04/2016)	<b>EN61000</b>	Considers PFGHR to be a component within a boiler and therefore captures all aspects of performance.



## Impact and limitations of Standards on PFGHR

Standards severely restrict the opportunity for retrofitting PFGHR technology because the boiler to which it is being specified must have been certified for use with the exact model which is being fitted.

Some of the performance benefits of PFGHR units which use additional thermal storage (i.e. when store is charged in heating mode and depleted in DHW mode) are not recognised because none of the Standard tests take account of this additional benefit. This means that the SAP results do not take into account the additional gas savings which can be achieved during the heating season, so SAP tends to under-represent the actual savings which can be achieved when using PFGHR with storage.

## Future development of Standards

We understand that there are currently no plans to develop new Standards for PFGHR technology because the requirements are deemed to be adequately covered by the current regulations. The boiler Standards cover safety aspects and the majority of the performance criteria whilst the additional BRE test methods cover the enhanced efficiency of the DHW system.

However additional tests would need to be developed to adequately record this benefit of storage devices when operating in winter (combined central heating and domestic hot water) heating mode.

If the effect of PFGHR is to be fully recognised in SAP, new tests would be needed to evaluate the relationship between energy capture and energy dissipation. In practice, the relationship between heating demand and hot water demand in the property would affect the overall improvement in annual efficiency attributed to PFGHR.

## 2. Current Market for Passive Flue Gas Heat Recovery

### 2.1 Key Sectors for PFGHR

From interviews conducted during the course of this research, it has been possible to build up a picture of the sectors in which PFGHR products are typically installed. However, no statistics on PFGHR are collected by the industry or are available, so all the figures presented in this chapter are estimates based on interviews with manufacturers and other companies, and should be considered as indicative only.

Residential uptake of PFGHR technology is almost exclusively within new-build properties; over 90% of PFGHR sales are in the new-build sector. Of this 90%, approximately three quarters of sales are estimated to be within the RSL (Registered Social Landlord) space, where higher building standards are often specified. Less often, PFGHR is installed as a bulk-retrofit within multiple existing houses during boiler replacement programmes (to meet the Decent Homes Standard for example). See Figure 8 below for a chart of 2014 PFGHR sales estimates segmented by housing type.

The reason for the high share of sales within the new-build sector is almost entirely due to the one market driver which is promoting the uptake of PFGHR; SAP compliance.

#### Market drivers and routes to market

##### **SAP is the primary market driver for PFGHR**

The Standard Assessment Procedure (SAP) is the UK Government's recognised method for measuring the energy rating of residential buildings. Each building is assigned a score, typically between a range of 1 to 100, with a higher score indicating a higher level of energy efficiency. Buildings with a score of more than 100 are deemed to be net exporters of energy. PFGHR technologies are a qualifying measure within SAP and can 'score points' during SAP assessments. As such, PFGHR units are often installed in new-build properties as a 'least-cost' method (or a combination of least cost and least risk or 'hassle') of meeting a pre-determined SAP score. This is normally the reason why contractors choose PFGHR within new-build RSL housing projects. During interviews for this project, all PFGHR manufacturers and installers indicated that SAP is the key driver for PFGHR.

SAP is the only vehicle which PFGHR products can use to demonstrate an energy saving, and improve the energy rating for the building. Assuming EN13203 Tapping Cycle 2, the anticipated energy saving per month based on SAP is between 12 and 18 kWh in summer mode, depending on the specific PFGHR product used.

The Green Deal did briefly create a market for PFGHR within existing buildings during 2013/2014; the funding mechanism resulted in a close to zero-cost for homeowners who opted for the technology. During this time, likely low 100s of PFGHR units were installed within existing buildings alongside (or within) a new replacement boiler, but the relatively short period in which the Green Deal was operating meant that the retrofit market never had a chance to develop, according to PFGHR retailers spoken to during the course of this research. Therefore, PFGHR remains a niche product, rarely adopted today as a retrofit heating technology option.

As discussed below, in the absence of any financial support, the typical payback period for PFGHR systems both with and without additional thermal storage exceeds the typical lifetime (15 years) of the technology itself. Therefore the technology is not an attractive proposition today for the majority of home owners who would typically seek a payback period of less than three years.

**The most common route-to-market involves selling multiple PFGHR into the new-build 'specification' market, from the manufacturer directly to the housing contractor,** according to interviews carried out during the course of this research

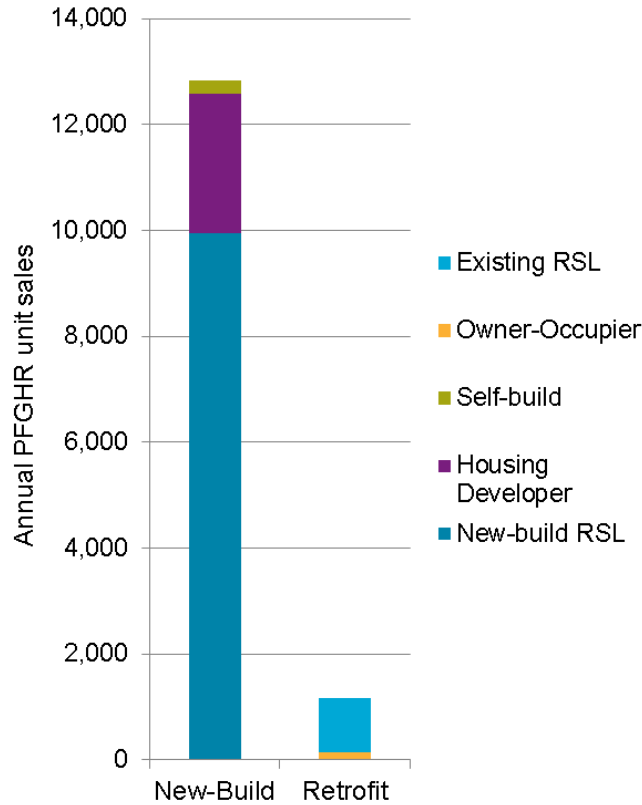
Nearly all boiler manufacturers in the UK offer a boiler with PFGHR and sell them through standard boiler channels. Therefore, there exists the option for PFGHR units to be sold from the manufacturer to the wholesaler and then to the installer like with the majority of conventional boiler sales. However, this route-to-market is rarely adopted due to challenges (discussed later in this report) such as installers not being aware of, not engaging with, and not promoting, PFGHR systems (installers are rarely "market creators" and on the whole are very conservative).

The large majority of PFGHR units are sold into the 'specification' new-build market, where 10s or 100s of units are installed within the same development. In these cases, PFGHR units are typically sold directly in bulk by the manufacturer, or the wholesaler, to the contractor who is responsible for the heating system. This route-to-market is clearly beneficial to the manufacturer (or wholesaler) as they can sell many PFGHR units in one transaction. It is also beneficial to the customer (in this case the contractor) who will often be able to negotiate a more cost-effective package by purchasing in bulk and benefiting from economies of scale. This is the standard route to market for boilers for 'bulk' purchases in the new-build market.

### Key market segments for PFGHR

Due to the drivers described above, it is little surprise that the majority of sales of PFGHR (over 90%) are within the new-build housing sector. As the chart below illustrates, the large majority of those are sold within the RSL housing segment, although some - approximately 2,000 to 3,000 - are also installed by housing developers every year. A much smaller share of the PFGHR market (2%, or ~200 to 250 units) can be attributed to the 'self-build' market, where the technology is selected as a way to increase the energy efficiency of the building despite lengthy (more than 15 years) payback periods.

In the retro-fit sector - i.e. where PFGHR units are installed alongside or within replacement boilers - sales of PFGHR are relatively low in number (less than 10% of the market). As with the new-build sector, the majority of PFGHR sales into the existing building stock are to RSLs, where multiple units are installed during a boiler replacement programme across many dwellings.



**Figure 8: 2014 PFGHR sales estimates segmented by housing type**

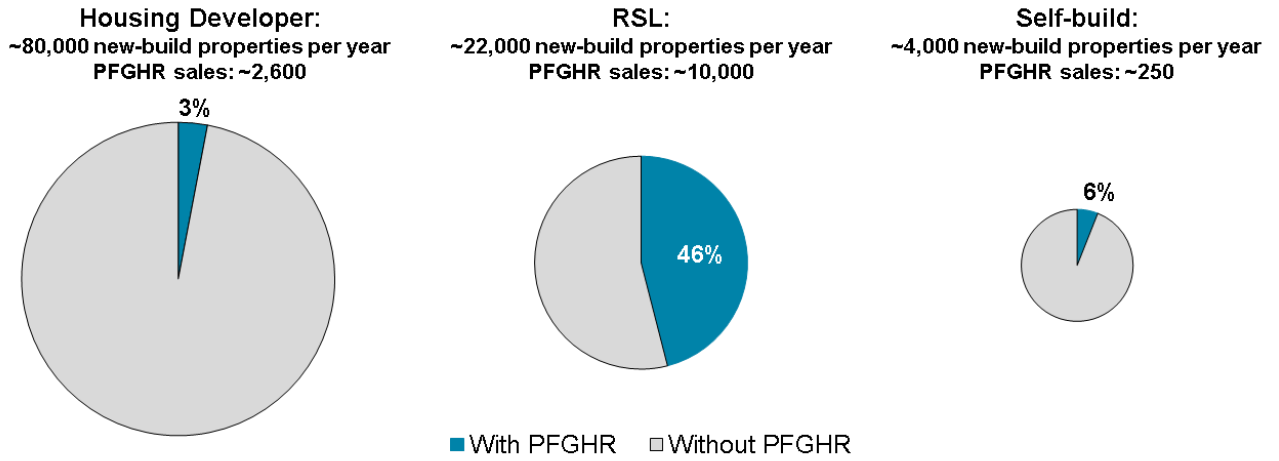
Source: Delta-ee analysis

In this section, we have also considered what share of different new-build housing types are being supplied with a PFGHR system. The chart below illustrates the relative size of the new-build ‘housing developer’, ‘RSL’, and ‘self-build’ markets in the UK in 2014, and also indicates the percentage of properties which are fitted with a PFGHR device.

The ‘housing developer’ sector is the largest new-build housing sector in the UK with approximately 80,000 new properties built in 2014 (the government has ambitions for this sector to grow substantially). Since PFGHR is normally not required to meet building regulations, PFGHR accounts for only a small share of this segment – around 3%.

The ‘RSL’ sector witnesses approximately 22,000 new-build properties each year, and since SAP compliance is a major consideration within this segment, and PFGHR can be employed to help meet the SAP target, it is little surprise that this housing segment is served with the largest percentage of PFGHR units; almost half of all new-builds in the RSL sector are currently installed with a PFGHR device.

Finally, the ‘self-build’ sector, where individual dwellings are built predominantly for self-use, the number of new properties is relatively few – approximately 4,000 in 2014. Nevertheless, approximately 6% of these new properties are installed with a PFGHR device, often in a bid to maximise the energy efficiency of the building despite the increase in upfront cost.



**Figure 9: 2014 new-build rates segmented by housing type, and percentage uptake of PFGHR**

Source: New-build rates from government sources. PFGHR data estimates from Delta-ee analysis

## 2.2 Historic and Current PFGHR Sales Trends

Through many conversations with boiler companies and PFGHR manufacturers, we estimate that approximately 14,000 PFGHR units are currently sold and installed in the UK each year. This compares to a total gas combination boiler market of approximately 1.3 million. Thus, PFGHR units are installed within or alongside only 1% of newly installed gas combination boilers today. However, historically, PFGHR sales have been responsive to different market drivers with a peak in annual sales of approximately 20,000 as recently as 2013.

In this section, we discuss historic sales and the market conditions which impacted sales trends in the period 2009 to the present day.

### PFGHR sales to date

The concept of PFGHR within the residential sector was first developed in 2004 with early prototypes coming to market in the mid-2000s. However, only from 2008, when the technology was first adopted by major manufacturers in the heating industry, did PFGHR sales increase to meaningful volumes. The chart below provides an illustrative view of past sales trends from 2009. However, it should be noted that sales volumes have been compiled using estimates provided by different PFGHR players and, while we believe they represent a sound overview of past trends, the actual sales figures should be taken as illustrative only.

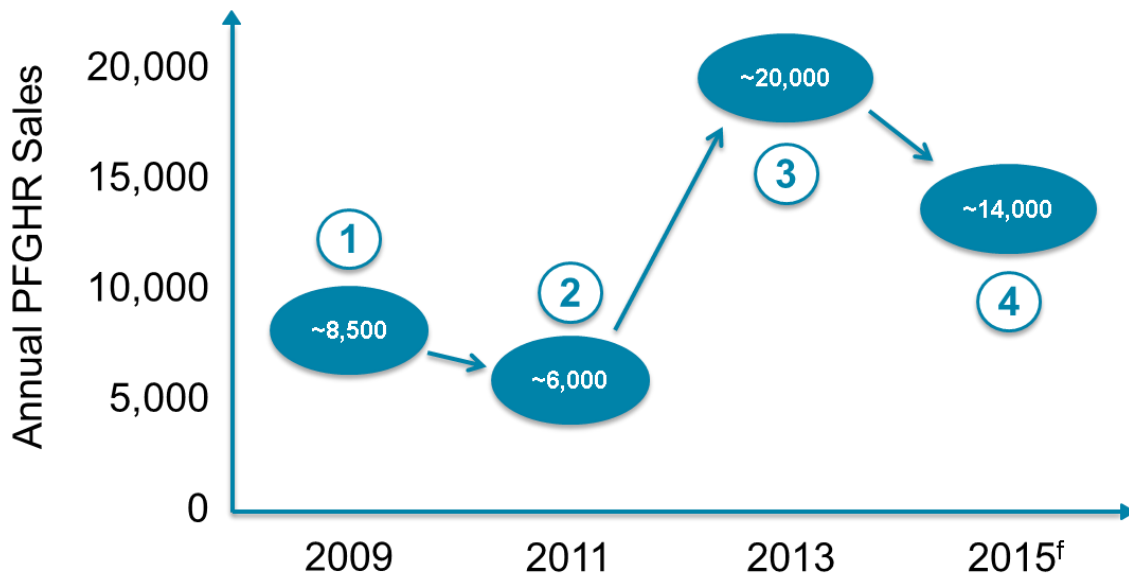


Figure 10: Historic sales trend of PFGHR

Source: Delta-ee analysis

**1. 2009: Sales of ~8,500 achieved through launch of new products and prior to change in SAP**

In 2009, sales of PFGHR units were approximately 8,500 per year, with the external Zenex unit achieving the greatest market share. At this stage, there were relatively few PFGHR products on the market, and all used a system design that required an external PFGHR unit with thermal storage. As such, almost all sales in 2009 were likely to have been within the new-build sector given the inherent space restrictions of the existing building stock. Like today, the main driver in this period was SAP compliance. During this time, the incentive provided by SAP was even greater than it is today but the SAP revision, which came into effect in 2010, reduced the benefit of installing PFGHR.

**2. 2011: Slump in sales to ~6,000 due to change in SAP and introduction of feed-in tariffs which diverted funding towards other low carbon technologies**

2011 marked the period when PFGHR sales have been at their lowest in the last five years. It was also suggested in our discussions with industry in this project that the introduction of feed-in tariffs (for technologies such as solar PV) had the effect of distorting the market for low carbon technologies, with those who might choose to install a PFGHR device instead opting for a technology that benefits from the FiT. Furthermore, SAP was not as strong a driver as it had been prior to 2010. Nevertheless, some new products were beginning to emerge at this time, suggesting the market was soon to rebound.

**3. 2013: Sales peak of ~20,000 units, driven by 'Green Deal' and new products coming to market**

In 2013, a PFGHR sales peak of approximately 20,000 units was observed, likely representing the most PFGHR units to have been sold in any given year to date. The main market driver at this time was the short-lived Green Deal which provided financing for energy efficiency technologies such as cavity wall insulation and double glazing, and also PFGHR. New PFGHR products were also launched at this time, including the Ideal Logic Code series – the top-selling PFGHR product today.

**4. 2015 Forecast: Current sales of ~14,000 units per year, with SAP compliance continuing to be the major market driver**

Today, sales of PFGHR products are approximately 14,000 units per year, with approximately half the market made up of PFGHR units with additional thermal storage, and half the market without thermal storage. SAP compliance continues to be the overriding market driver for the technology and therefore more than 90% of sales are within the new-build sector. Only a very small number of units are installed within the owner-occupier housing segment.

### Future sales trends

Major increases in future sales of PFGHR will likely be dependent on regulatory forces rather than any changes in customer behaviour or technology advances. Currently, as discussed previously, SAP compliance is the major driver for PFGHR and will likely remain so for the foreseeable future.

As building regulations become more stringent within the non-RSL new-build segment, we *may* witness increasing sales of PFGHR as a way to meet pre-determined energy efficiency criteria

within the new-build segment. In this scenario, it is conceivable to imagine sales increasing to as much as 50,000 to 100,000 units per year if the technology becomes a favoured option among the 'housing developer' new-build segment to meet more stringent regulations (if these come into force).

However, stronger interventions in the market – such as capital grants or regulations – would likely be necessary in order to capture a significant share of the boiler replacement market within the existing building stock (the 'mass market' part of the boiler market).

See Section 5 for detailed analysis of future sales scenarios, including the introduction of policy support, and PFGHR mandate within all on-gas new-build properties.



## 3. PFGHR Performance Analysis

### Key findings:

- PFGHR units without additional thermal storage can typically save 9% of the gas used to heat domestic hot water, equivalent to a boiler efficiency improvement of approximately 1 percentage point. (*Actual DHW gas savings are likely to range from around 5% to 10%*)
- PFGHR units with additional thermal storage can save additional gas, with total annual gas savings for heating domestic hot water typically around 31% for a typical existing building, equivalent to a boiler efficiency improvement of 5 percentage points. (*Actual DHW gas savings are likely to range from less than 15% to around 35% depending on DHW demand, space heating demand, and the volume of thermal storage.*)
- For every type of PFGHR device, the volume of gas saved is closely linked to the domestic hot water demand for a given dwelling; higher hot water demands will result in higher gas savings when using a PFGHR device. This will likely result in a significant variation of savings from property to property.
- Throughout the research for this report, we found no evidence that there exists 'real-life' in-field monitoring data for PFGHR technologies within residential applications. Hence all data we report on and analyse relies on laboratory tests and manufacturers views.

### 3.1 Introduction to PFGHR Performance Analysis

In this section, we have considered annual gas savings which can be achieved by using PFGHR technologies across a number of different house types with varying annual domestic hot water and space heating demands. The gas savings have been calculated using the following inputs, and therefore should be treated with some caution as there are no inputs from in-use data.

- Data gathered from manufacturers (laboratory data only)
- High-level modelling which is informed by previous experience (within the project team) of the performance of PFGHR technologies during lab tests
- Assumptions on space heating and domestic hot water demand.
- Assumptions on condensing boiler efficiency (without PFGHR)

In order to have a greater understanding of the actual energy efficiency which can be achieved using PFGHR, a programme of field trials using a range of PFGHR products across a range of different property types would be necessary.

During the course of this research, we sought to uncover all available data relating to the performance of PFGHR technologies within real-life scenarios. Yet, following conversations with many PFGHR players – including designers, manufacturers and retailers – it became clear that no in-field monitoring data has so far been collected for PFGHR. Therefore, it has been necessary to rely on the following sources to help inform our overall view of the efficiency savings that can be provided by the technology:

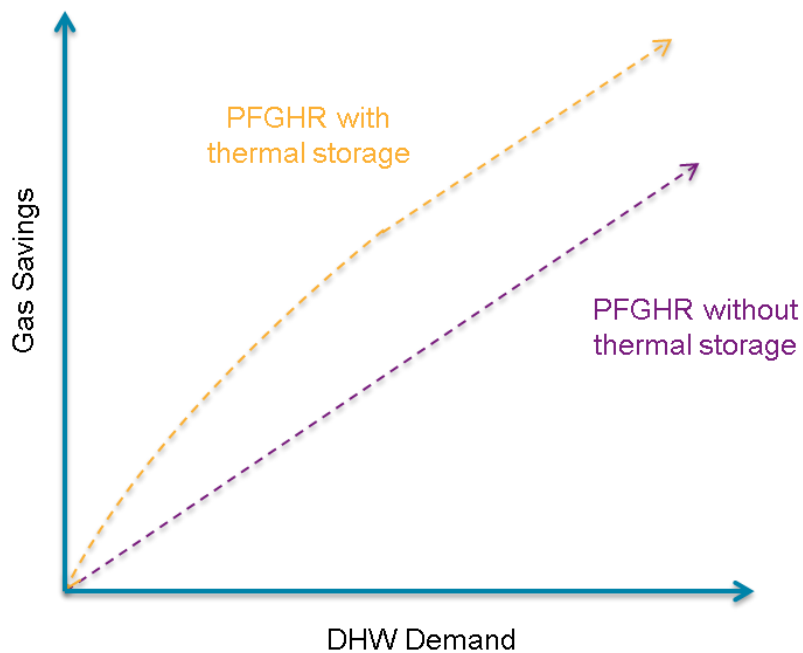
- An assessment of the theoretical efficiency which could be achieved under certain operating conditions and assumptions was carried out by Enertek International, using evidence gathered during the course of this project, manufacturer and lab-test data and desk-based analysis of boiler and PFGHR operation given certain thermal demand assumptions.
- Typical domestic hot water and space heating usage patterns within the new-build and existing UK housing stock
- Views from multiple PFGHR players, including manufacturers and suppliers

## 3.2 Summary of PFGHR Performance Analysis

For a table of assumptions used within this section, please see Appendix A.

### **Gas savings increase as demand for domestic hot water increases**

Despite the lack of available in-field performance data, we have been able to draw out a number of conclusions from this research. Perhaps the most obvious relates to the fact that the amount of gas savings which can be achieved by using available PFGHR designs today is closely linked to the demand for domestic hot water (DHW). As the demand for DHW increases, so do the gas savings. For PFGHR systems which do not employ thermal storage, the amount of gas savings is essentially proportional to the demand for DHW (as illustrated in the chart below). For PFGHR systems with thermal storage, the gas savings are even greater since additional energy is captured in heating season during space heating cycles. Naturally, however, as the demand for DHW increases, the additional benefit from thermal storage is diminished. The rate at which this 'diminishing return' occurs depends on the volume of the thermal store within the PFGHR system, the DHW demand, and the extent to which DHW demand 'overlaps' with the space heating periods. Figure 11 is for illustrative purposes only.



**Figure 11: Chart indicating gas savings versus DHW demand for PFGHR systems with and without thermal storage**

Source: Delta-ee analysis

### **PFGHR systems with additional thermal storage can achieve greater energy efficiencies**

Another clear conclusion from our research is that PFGHR systems which incorporate additional thermal storage save more gas than PFGHR systems which do not incorporate any additional storage. This is illustrated in Figure 11 above. Furthermore, PFGHR systems with larger thermal stores will save more gas than those with smaller thermal stores; this is illustrated within the charts later in this chapter.

Our research indicates that **boilers using PFGHR systems without thermal storage typically save approximately 9% of gas used to provide domestic hot water.**

The gas savings that can be achieved when using **PFGHR with thermal storage can vary significantly depending on the volume of the thermal store, space heating demand and usage patterns, but will typically fall in the range of 19 to 20% for a new-build dwelling, and 20 to 35% for a larger property with higher space heating demands.**

## A typical case: new-build property with ~2,000 kWh of annual DWH demand

For the purpose of identifying the 'typical' gas savings which can be achieved through using PFGHR, we have used the following assumptions:

- **An existing property** (since the largest untapped potential for PFGHR is within the existing building stock)
- **Annual DHW demand of 2,000 kWh** (deemed to be close to the average for a property in the UK, though actual values vary according to the occupancy of individual dwellings).
- **Annual space heating demand of 12,000 kWh** (deemed to be close to the average for a typical existing property in the UK).

### PFGHR without thermal storage

For a PFGHR system without additional thermal storage (and a PFGHR system with additional thermal storage but operating in summer, i.e. without space heating) the **typical gas savings are deemed to be approximately 9% on gas used to provide DHW.**

This 9% figure has been reached following in-depth analysis carried out by Enertek International (Enertek). Enertek has previously carried out laboratory testing of PFGHR products, and by using this previous insight, alongside anecdotal evidence provided by PFGHR manufacturers and suppliers, and by considering the components used within different PFGHR system designs, it has been concluded that 9% represents a sound view of the gas savings that PFGHR technologies can provide when operating in DHW-mode.

However, it should be noted that the actual savings will be dependent on the efficiency of the boiler to which the PFGHR unit is coupled, the usage pattern of the boiler, and the type of PFGHR.

**For a property with an annual DHW demand of 2,000 kWh, a 9% gas saving equates to a total annual gas saving of ~230 kWh** (when assuming a boiler DHW conversion efficiency of 73%).

### PFGHR with thermal storage

As mentioned above, a PFGHR system with additional thermal storage will also benefit from approximately 9% gas savings when operating in 'summer' mode. However, there will be additional gas savings in 'winter' mode due to the flue gas heat recovery that also occurs when the boiler is operating in space heating mode. For a typical existing dwelling, the **annual gas savings for a PFGHR unit with thermal storage are deemed to be approximately 31% on gas used to provide DHW.**

This 31% figure has also been reached following analysis conducted by Enertek. As mentioned previously, it has not been possible to collect 'real-life' data relating to operational performance of PFGHR systems. Therefore, it has been necessary to carry out some indicative analysis using accepted assumptions on heating cycles (during seasons when space heating is required) and domestic hot water usage patterns (also referred to as 'tapping cycles'). For a more detailed explanation of the method used to determining the gas savings for PFGHR products with thermal storage, please refer to 'Section 3.3 Methodology' later in this chapter.

Actual savings may vary significantly from one property to the next, and will be dependent on: the volume of thermal storage, total domestic hot water demand, the heating season (i.e. how

often the boiler operates in space heating mode), and the extent to which DHW demand overlaps with periods of space heating.

**For an existing property with an annual DHW demand of 2,000 kWh, a 31% gas saving equates to a total annual gas saving of ~850 kWh (when assuming a boiler DHW conversion efficiency of 73%).**

### **Best-case scenario:**

While the figures outlined earlier in this section give a good representation of the gas savings which could be achieved using PFGHR systems within typical dwellings, there are some households where much more significant gas savings could be achieved. These will tend to be dwellings with:

- **High domestic hot water demand**, and
- **High space heating demand** (in the case of PFGHR systems with thermal storage)

### **PFGHR without thermal storage**

As mentioned earlier in this chapter, for PFGHR systems without thermal storage, the amount of gas savings is proportional to the demand for DHW. Therefore, gas savings increase as DHW demand increases.

Therefore, while a typical household is assumed to have an annual DHW demand of 2,000 kWh, **for households with double the DHW demand, (4,000 kWh), gas savings of over 450 kWh could be achieved each year.**

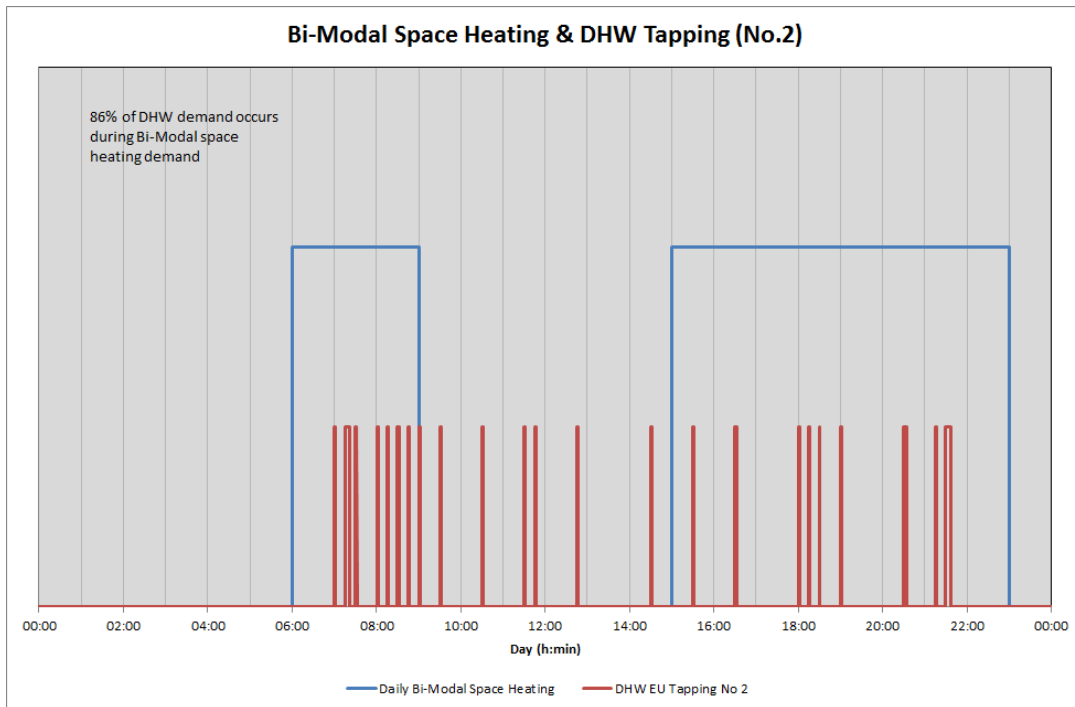
### **PFGHR with thermal storage**

Even greater gas savings can be achieved through using a PFGHR system with thermal storage in a household with both high DHW demand and high space heating demand. For example, a **household with 4,000 kWh of DHW demand and an annual space heating demand of 18,000 kWh is estimated to have the potential to save over 1,100 kWh of gas each year.**

### 3.3 Methodology

Regionally the UK the heating season varies between 30 and 40 weeks, averaging 242 days, or 66 % of the year.

Assuming daily space heating is bi-modal over the heating season, and that DHW demand matches that of EU tapping cycle no. 2 (this is a benchmark DHW demand test used in EN13203-2 for determining DHW efficiency; the test represents the energy equivalent of heating 100.2 litres to 60 °C raised from 10 °C, similar to typical demands of new build properties and smaller dwellings.) then 86 % of the DHW demand could occur during space heating, as illustrated in Figure 12. Thus between 49 % and 64 % of the yearly DHW demand may coincide with active space heating.



**Figure 12: Overlay of assumed bi-modal space heating and DHW Tapping Cycle (No. 2)**

Source: Enertek International

Using the following assumptions for a condensing appliance, to determine the available energy in the flue, and DHW demand EU tapping cycle no. 2, the relationship between active space heating demand (kW) and PFGHR Volume (litres) can be evaluated, Figure 13 and Figure 14. Figure 14: Plot of daily gas savings (%) versus PFGHR store volume (litres) for different types of building using DHW tapping cycle no. 2 (for assumed annual DHW demand of 4,000 kWh per year)

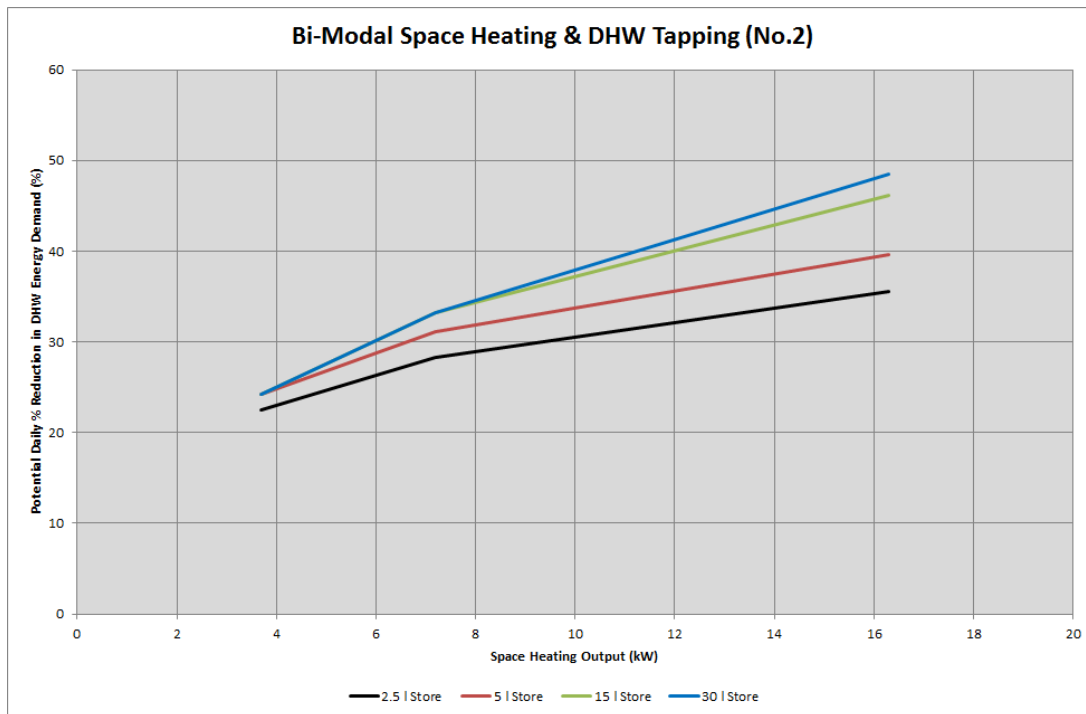
Source: Enertek International

- Flue gas CO2 % = 9.2 %

- Flue gas temperature at entrance to PFGHR = 55 °C
- Flue gas temperature at exit of PFGHR = 45 °C
- DHW inlet temperature to PFGHR = 10 °C
- Water outlet temperature from PFGHR = 40 °C
- PFGHR heat exchanger efficiency = 50 %\*

\* This assumption is based on a conservative estimate of likely performance in the absence of any actual data upon which to base this calculation. The actual efficiency would depend upon the design of the device and the resulting flue gas temperature differential across it.

Figure 13 plots the potential daily % reduction in DHW energy demand against space heating output for PFGHR with different store volumes.



**Figure 13: Plot of daily gas savings (%) versus space heating output (kW) for different volumes of thermal storage**

Source: Enertek International

From Figure 13 it can be seen that a PFGHR with a store volume of 2.5 litres could potentially give a daily DHW energy demand saving of 36 %, provided that the active space heating demand was based on that of a large house. However this would drop to 23 % if based on new build. Likewise a PFGHR with a store volume of 15 litres could potentially give a daily DHW energy demand saving of 46 %, for a large house, but only 24 % for new build.

Figure 14 plots the potential daily % reduction in DHW energy demand against PFGHR store volume for different space heating outputs. This graph illustrates the importance of selecting the right store volume based on available space heating output. i.e. there is no advantage in

having a store in excess of 5 litre for new build with low space heating needs, or in excess of 20 litre for a large house’s heating need. However, small store volumes (2.5 - 3 litres) do appear to have a significant impact on reducing the daily DHW energy demand.

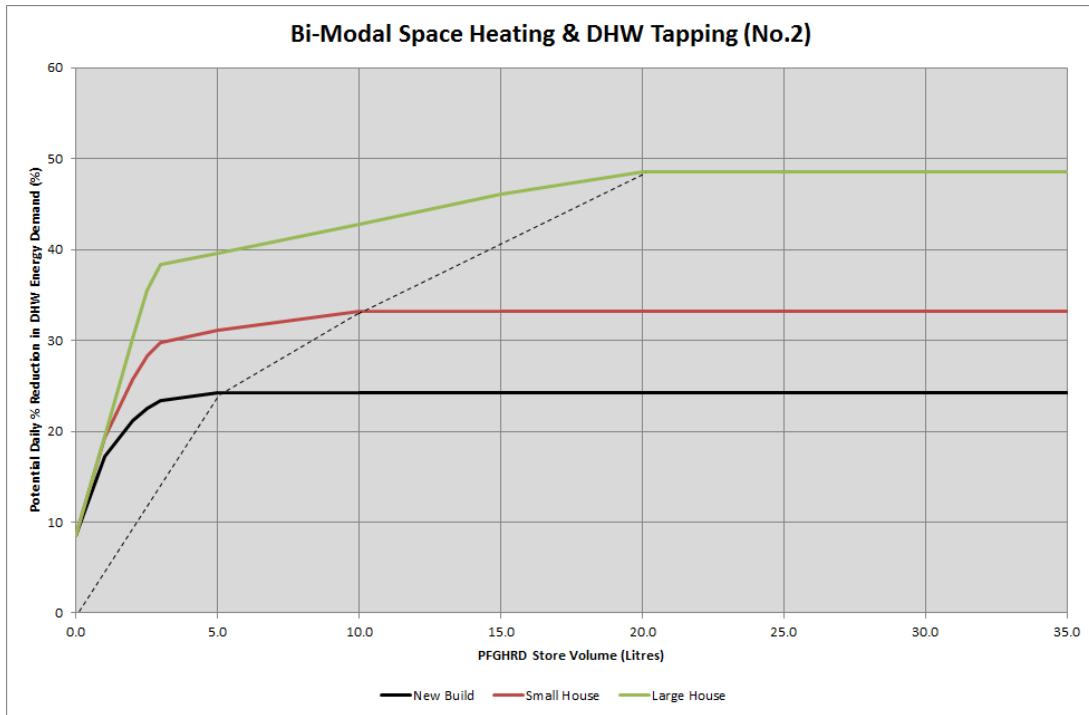


Figure 14: Plot of daily gas savings (%) versus PFGHR store volume (litres) for different types of building using DHW tapping cycle no. 2 (for assumed annual DHW demand of 4,000 kWh per year)

Source: Enertek International

Clearly the potential saving is a function of both PFGHR storage volume and active space heating demand.

Assuming a PFGHR has a 2.5 litre, store and that space heating matches that of a large house, then annual DHW efficiency may potentially be enhanced somewhere between 25 % and 31 %. For new build with a low space heating demand the annual DHW efficiency may be enhanced somewhere between 17 % and 19 %.

Assuming a PFGHR has a 15 litre, store and that space heating matches that of a large house, then annual DHW efficiency may potentially be enhanced somewhere between 33 % and 43 %. For new build with a low space heating demand the annual DHW efficiency may be enhanced somewhere between 18 % and 21 %.



## 4. Cost Analysis

PFGHR units, whether external 'bolt on' units or incorporated into the casing of a combi-boiler, typically add between £250 and £600 to the cost of an ordinary condensing boiler, and in some cases up to £1,000. These high costs do not justify purchase of a PFGHR on simple pay-back terms at present.

Total sales of PFGHR units are currently low compared to total boiler sales – between 10,000 and 20,000 PFGHR units per year, compared to a UK combi boiler market of over 1 million per year – meaning that current production costs include minimal economies of scale. There is considerable potential to reduce manufacturing, assembly and distribution costs, as well as retail margins, if total sales increased.

The price ranges outlined in this section are derived from interviews with PFGHR suppliers and manufacturers and reflect the price paid in the specification market (i.e. with some bulk-buying discount) for a heating system with PFGHR compared to an equivalent system without PFGHR (usually a condensing combination boiler).

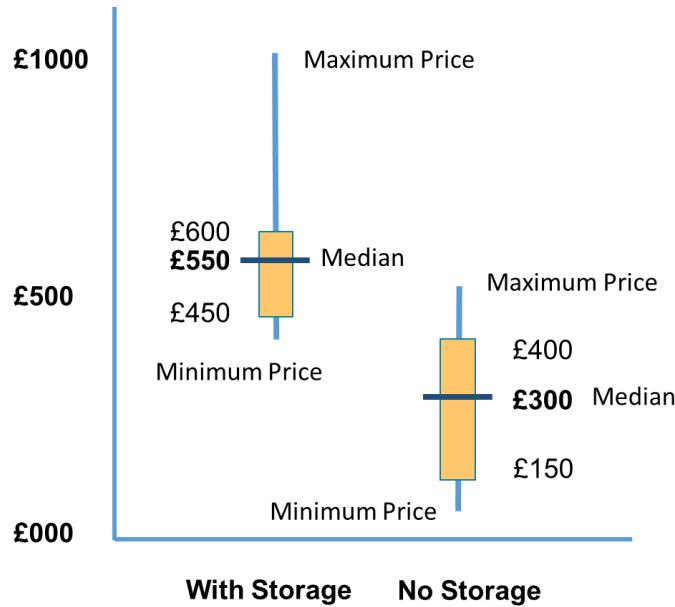
### 4.1 Typical end-user price

The additional retail cost of a PFGHR unit compared to a standard condensing boiler ranges from less than £200 to over £1,000, with the majority being **between £250 and £600**. This generally amounts to an increase in cost to the householder (or builder) of somewhere between 20% and 40%, depending on the installation costs and various other heating-system components.

PFGHR units integrated into the boiler tend to add the least cost, with the typical price differential between a standard combi boiler and a PFGHR combi boiler normally ranging between £150 and £400 (**median around £300**). These devices have **no storage** capacity and therefore only capture flue-gas heat when the boiler is operating in hot-water mode.

PFGHR units with built-in thermal storage capacity (as either condensate store or hot water) invariably cost more. These are generally bolt-on systems that are sold at the same time as combi boilers but delivered in separate packaging. There are two designs available in the UK, each sold by two or three boiler companies. The typical price of the separate **PFGHR units with storage** normally lies in the range of around £450 to £600, with a **median of around £550**.

The most expensive 'with-storage' units can exceed more than £1,000, while the cheapest integrated non-storage units add less than £200 to the combi-boiler price. The large variation in end-user costs is a function both of widely varying manufacturing costs and also the fact that sales volumes are currently very low and manufacturers' margins appear to vary significantly.



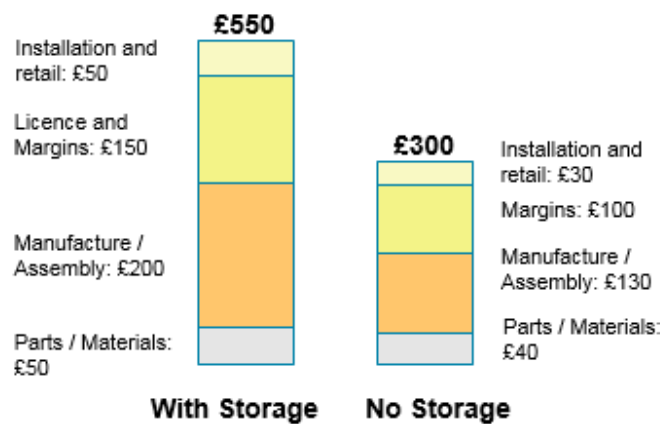
**Figure 15: Indicative range of marginal end-user costs for PFGHR units with and without thermal storage**

Source: Delta-ee Analysis

### 4.2 Cost Breakdown of PFGHR

The end-use price of any heating appliance is a function of the underlying manufacturing cost; transportation and assembly of parts; costs associated with retail, distribution and installation; and profit (and contingency) margins at every point. A licence fee may also be payable if the appliance was not designed by the manufacturer/retailer.

The figure below gives an indicative breakdown of how the £250-600 additional costs of a PFGHR unit compared to a non-PFGHR boiler break down. The variation between manufacturers (and retailers) across all these cost centres is considerable and these numbers are no more than best-estimates. See the text in the following paragraphs for a little more detail on the different components, and the final section of this chapter for how these costs could be reduced with volume or technical advances.



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**Figure 16: Indicative breakdown of PFGHR costs for external units with storage (left) and boiler-integrated units without storage.**

Source: Delta-ee Analysis

### Materials, manufacture and assembly

A PFGHR unit, whether integrated or bolt-on, is basically an additional heat-exchanger. Raw materials are generally stainless steel or, less commonly, aluminium. Manufacturers will typically purchase pre-machined parts (for example small-bore stainless steel pipes) and assemble these components in their own factory with various complex-manufacturing processes such as cutting and welding, or the whole heat-exchanger may be manufactured in one factory and then assembled into the PFGHR in a separate factory. Bolt-on units will have an additional outer shell/container; at present these are typically also stainless steel and painted white to match the combi-boiler format.

We estimate that raw material costs for a typical PFGHR unit might be around £50. Assembly at a low-volume production line, with much of the process completed by hand as is currently the case, might add £100 to £200. For integrated units, particularly those using simpler plate heat exchangers, the material costs might be lower and assembly costs should be at the low end of this range or lower.

### Cost of retail and installation

Boiler-integrated PFGHR units add a small amount of bulk (in most cases) and weight to most combi boilers and therefore increase the logistics costs associated with packaging, warehousing and transporting boilers a small amount. Bolt-on units are generally separately boxed and therefore add somewhat more to logistics of sales and delivery (although because the PFGHR is effectively a separate sale with relatively low value the risk of stocking large quantities of appliances that may not sell is lower).

The increased bulk and weight also adds a little to installation costs. More significant is the increased plumbing involved (units on the market need to be plumbed into the cold water inlet) and external units require more installation-time when fitting the flue. Estimates of increased fitting time range from one to two hours, which might add up to £100 to the installation cost if the unit is being retrofitted, particularly if the fitter is not familiar with the technology. In practise, however, most PFGHR units are sold into multi-home developments where call-out charges will not apply and the additional time/cost of the PFGHR will be absorbed into the wider cost of heating system installation. Figure 16 therefore shows an increased logistics and fitting cost of a PFGHR boiler as opposed to non-PFGHR of between £30 and £50.

### Margins and Licence

Research conducted during the course of this research has indicated that there are currently four manufacturers that have developed in-house their own boiler-integrated PFGHR products. The two external units (available from five boiler manufacturers) were designed by independent companies and are manufactured under licence or sold as complete units by the original design company. For the external units, the final price to customers will include a licence fee or an additional supplier's margin, which represents the recovery of R&D spend by the design company. Volumes are currently low so this is likely to be a relatively significant proportion of the sale price.

Normal operating margins are also charged by all of those involved in materials supply, transport (of components and complete units or boilers), manufacture and retail of the units. Depending on the specifier and installer, a margin may also be charged at the point of installation. The margin that boiler manufacturers make on sale of external PFGHR units – the sale of which is to the manufacturer additional to a boiler sale – appears to vary significantly. It seems that some boiler companies make very little, if any, margin on external PFGHR units, seeing PFGHR as a way to make sales into a small but important market (new build developments needing to hit a specific SAP target); while others make a significant margin, albeit on very low sales volumes. Manufacturers of integrated PFGHRUs also appear to make widely varying margins on PFGHR component of a boiler sale.

### Alterations to boiler and certification

Even when the PFGHR unit is bought in complete from an outside supplier there will be some additional design and certification work required to make sure that the system works as a whole and meets safety and performance requirements. Some minor alterations may also be needed to the boiler itself (or its flue) in order to work with a particular PFGHRU.

These R&D, certification, and boiler-plant costs would all be insignificant if sales volumes were very high. At current low volumes they partially explain what seems like a big variation between manufacturing costs and sales price.

## 4.3 Value of Savings to user

As demonstrated in Chapter 3, PFGHR units can typically save 1% to 5% of a typical household's gas bill over the course of an average year. The actual savings in any particular household, and with any particular PFGHR unit, will vary within this range (and, possibly, outside it). The calculations in this section are therefore indicative only, and suggest the savings that could be made in some typical homes with typical occupancy, rather than in exceptional circumstances.

The two sections below assume daily savings on DHW gas usage of 9% for all PFGHRs in 'summer only' mode (i.e. no central heating firing). During the heating season PFGHRs without storage will save the same 9% on DHW gas usage, while PFGHRs with storage will save around 31%. Assuming, as in Chapter 3, that the heating season lasts for 66% of the year, the annual savings for a PFGHR with storage are therefore around 6%. In all cases, more savings will be made by PFGHRs where more hot water is used; for units with storage even higher savings will be possible when there is a lot of heating use in combination with high hot water use.

### Average (mean) savings and payback period

For average hot water usage (assumed to be around 2,000 kWh), gas savings per year amount to around £42 per year for units with storage and £12 per year for units without, taking an indicative gas price to the homeowner of 5.0 p/kWh.

The payback on these units is typically around 13 years for PFGHR units with thermal storage and 26 years for PFGHR units without storage. The very cheapest integrated, non-storage, units tend to have the quickest payback at current prices – approximately 10 years with the assumptions above for a unit costing £100 - £150 more than a standard boiler.

### Payback period sensitivity to domestic hot water consumption

The gas savings available obviously depend fundamentally on the total hot water usage during a year, as for all units gas is only saved when the heat captured from the boiler flue is actually used as domestic hot water. Typical paybacks would double if DHW demand is only around 1000 kWh per year, or halve if DHW demand is doubled to 4,000 kWh per year.

For homes with higher hot water use, the payback on units with storage becomes better (assuming the heating load also remains high), with the average-priced storage units paying back in around 11 years at 4,000 kWh per year, compared to around 13 years for non-storage units. (A few homes with high occupancy do have hot water usage up to around 8000 kWh per year; the payback here might come down to 5 or 6 years.)

### Future payback, with cost reduction

The simple payback period calculations above are clearly highly dependent on the assumptions used. But it is the range of prices of PFGHR units that leads to the high range of payback periods. The following section suggests that the price of PFGHRs could come down significantly if higher volumes – hundreds of thousands per year, instead of thousands per year – were sold. We believe a price of £200 per unit is feasible for units with storage and £90 for units without storage. For households using 2,000 kWh per year for hot water this would bring paybacks down to **5 years for PFGHR with storage and 8 years for PFGHR without storage**, well within the expected lifetime of a boiler. For houses with 4,000 kWh per year hot water usage this would be below 5 years: a reasonably attractive proposition for householders making their own decisions about heating technology.

## 4.4 Cost Reduction Potential

Average end-user prices for PFGHRs are around £550 for with-storage external units and around £300 for integrated non-storage units. These prices reflect manufacturing and sales volumes in the hundreds or very low thousands for any one manufacturer, and there is considerable potential for costs – and therefore price – to come down.

We believe a **sales price of £200 is feasible for high-quality PFGHRs with built-in storage and under £100 for those without storage**. The vast majority of the potential cost reduction is from increasing the volume of manufacturing; opportunities for cost reduction from design improvements are more limited.

### Cost savings via increased volumes

PFGHRs are effectively heat exchangers, and there is nothing in a PFGHR unit that would not lend itself to automated production lines alongside heat exchangers and burner components for condensing boilers. The potential cost reduction from volume is very significant: estimates from manufacturers suggest that manufacturing costs could come down by more than half from around £250 to between £100 and £120 for external units if the unit sales increase from thousands per year to say 100,000 per year. This is in line with experience from cost reductions in other heating technologies that tend to show a 'learning rate' of between 12 and 15%.

Separating the *additional* costs of the PFGHR in an integrated unit is more difficult, but the manufacturing costs could come down to below £80 if we assume they are currently around £150. (In fact the manufacturing cost of comparable heat exchangers is sometimes well below

£80, so the cost reduction potential is even higher if boilers are designed for easy PFGHR as below).

### Cost savings via design improvements

Most of the manufacturing cost reductions mentioned above could come from using a more efficient (automated) production line to produce the same PFHR device. In practise, R&D will be required to **design the PFGHR for mass-production**. In order to increase the market size to hundreds of thousands, units (including designs with integral storage) will almost certainly become integrated into the boiler jacket; this will reduce manufacturing, assembly and installation cost.

There is some potential to reduce costs by simplifying the design (although this might reduce the waste heat captured) or to use alternative materials, such as plastic for some parts.

## 5. Market Potential and Barriers

### 5.1 Emerging Opportunities

In this section, we have described some of the emerging trends which could increase the opportunity for PFGHR technologies in the future. The first considers the trend of falling space heating demand, and increasing domestic hot water to space heating ratios, especially within the new-build sector where building regulations are demanding ever more stringent building fabric standards. Secondly, we consider the opportunity associated with low temperature heating circuits and whether PFGHR technologies could be used to provide energy savings on space heating in addition to that which is already captured through domestic hot water demand.

#### **1. Rising domestic hot water to space heating ratios within the UK building stock increases efficiency of gas combination boilers**

A general trend of the UK building stock is one where energy efficiency is increasing, especially within the new-build sector. As such, space heating demand is falling. Typically, the existing building stock which is more than 10 years old (the vast majority of the housing stock) has annual space heating demands ranging from 5,000 kWh per year to significantly more than 10,000 kWh per year (a significant proportion with more than 20,000 kWh per year). By comparison, new-build properties tend to have annual heating demands below 5,000 kWh.

While space heating demands are very dependent on the fabric of the building, domestic hot water demands are much more closely linked to the number of inhabitants, and the behaviour of those inhabitants (for example, whether they take showers or baths). Therefore, the long-term trend in domestic hot water usage is less likely to fall, and some estimates suggest that hot water usage is increasing as people take more frequent showers.

As a technology which saves gas when the boiler is used to supply hot water, this trend has the effect of increasing the efficiency of boilers that employ a PFGHR device. Furthermore, as this trend continues, there will likely be more emphasis in increasing the energy efficiency of domestic hot water supply, and PFGHR is a technology positioned well to meet these requirements.

#### **2. PFGHR can be used to increase space heating efficiencies in combination with low temperature heating circuits**

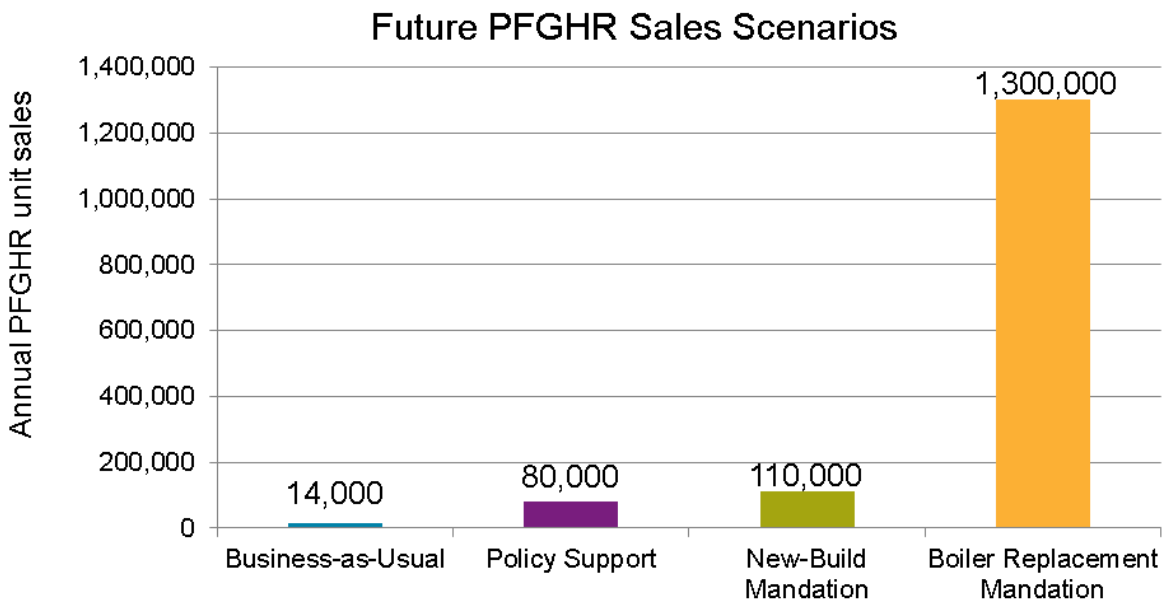
Currently, PFGHR technologies are used only to increase the efficiency of combination boilers when operating in domestic hot water mode (by pre-heating incoming cold water, as described earlier in the report). In the vast majority of the existing UK building stock, a high-temperature heating circuit is used where the boiler return temperature is approximately 60°C or higher. In this case, it is impossible for PFGHR technologies to provide any additional benefit, since the return temperature is already greater than the temperature which can be captured from the flue gases (of high-efficiency condensing boilers).

In the future, the use of low temperature heating circuits (used with underfloor heating, for example, or larger surface area radiators) is likely to increase. In such cases, there is the technical opportunity to employ PFGHR to pre-heat the returning hot water circuit if at temperatures of around 40°C or below. By doing so, it would be possible to increase the efficiency of gas boilers operating in space heating mode. It is believed that this option is not

possible using current PFGHR products on the market, but as low temperature heating circuits become more prevalent, it is possible that we shall see the emergence of PFGHR products targeting this application.

## 5.2 Future Scenarios for PFGHR Market Growth

**There is great potential for PFGHR market growth, but a significant increase in sales is unlikely to be achieved without government intervention.**



**Figure 17: Future PFGHR Sales Scenarios**

Source: Delta-ee Analysis

The market potential for PFGHR is, in principle, significant. Gas boilers represent a large majority of the UK heating market; approximately 22 million homes are heated using natural gas, from a total building stock of almost of 27.5 million. Gas combination boiler sales tend to exceed 1.3 million every year. Yet today, PFGHR sales account for only ~1% of the gas boiler market, and there is no evidence to suggest that sales will increase significantly in the period to 2025 without government intervention.

In this section, we have considered three future scenarios, alongside the ‘business-as-usual’ scenario, to illustrate how PFGHR sales could be impacted by government intervention:

1. **Introduction of policy support**, where fiscal support is provided to incentivise the adoption of boilers with PFGHR
2. **New-build mandation**, where all new-build properties connected to natural gas networks are required to install a boiler with PFGHR
3. **Boiler replacement mandation**, where all gas boilers – whether installed in new-build or replacing boilers in existing properties – are required to have PFGHR



Please note that the scenarios considered in this section are derived from limited available data, and are only intended to provide an indicative view of potential PFGHR sales volumes and overall carbon savings under different circumstances. Furthermore, macroeconomic factors, such as future residential new-build rates and future gas prices, have not been considered. Further analysis should be undertaken before drawing strong conclusions from these results, but they do serve to illustrate possible futures for PFGHR technology.

Scenarios	Annual sales	Total PFGHR units installed by 2025	Additional tonnes of CO <sub>2</sub> saved annually	Total tonnes of CO <sub>2</sub> saved per year in 2025 versus BAU	Cost per tonne of CO <sub>2</sub> saved (£ / tonne)*
Business-as-Usual (BAU)	14,000	~240,000	~600	N/A	~£465
Policy Support	~80,000	~900,000	~3,400	~28,000	~£390
New-build mandation	~110,000	~1,200,000	~4,600	~40,000	~£310
Boiler replacement mandation	1,300,000	~13,100,000	~56,000	~553,000	~£140

\* See Annex B for calculations and assumptions

We have used the following assumptions across each of the scenarios considered in this section:

- Total PFGHR installed base in 2015: 100,000 units
- No PFGHR units will be replaced in the period to 2025 (*on the basis that the large majority of existing PFGHR units, and all new PFGHR units, will not have reached the end of an assumed 15 year lifetime by the year 2025*).
- Carbon intensity UK natural gas: 185 g/ kWh
- Average annual domestic hot water demand: 2,000 kWh
- PFGHR units without thermal storage (*for consistency across each scenario and because it would likely be impractical to mandate PFGHR units with storage within the existing building stock where space is at a premium*).

### Business-as-usual scenario

Under the business-as-usual scenario, we have assumed no changes to the following market conditions:

- Retail price of PFGHR products
- Treatment of PFGHR within building regulations, including SAP

- No additional policy support for PFGHR

Since the status quo remains unchanged, it is logical to assume that the overall market for PFGHR – in terms of annual sales numbers – also remains unchanged. Therefore, in this scenario, we have assumed ongoing sales figures in the region of 14,000 units per year. Each year, the additional carbon savings attributed to the newly installed PFGHR units would be the equivalent of approximately 600 tonnes of CO<sub>2</sub> per year.

Assuming an installed base of 100,000 PFGHR units today, by 2025 the installed base would increase to approximately 240,000 units.

As we have assumed no decrease in the retail price of PFGHR, the cost per tonne of carbon saved is the same as we currently witness today – approximately £465 per tonne of CO<sub>2</sub>.

### Introduction of policy support for PFGHR

Under this scenario, we have assumed the following:

- 79,000 annual sales of PFGHR:
  - 14,000 under business-as-usual scenario, plus
  - 65,000 (equivalent to 5% of 1.3 million combination gas boiler replacements)
- The additional retail price of PFGHR (without thermal storage) reduces from £300 to £250 per unit

With this scenario, we have assumed the introduction of some modest policy support for the adoption of PFGHR technology. While we have not defined the level of support, we have assumed that a payback period of approximately 10 years for a dwelling with an average domestic hot water demand of 2,000 kWh would be achieved. In this scenario, households with higher domestic hot water demands greater than 2,000 kWh per year would achieve payback periods shorter than 10 years.

An increased volumes of sales in the order of 65,000 (above the business-as-usual case of 14,000) has been derived by assuming that 1 in 20 of the approximate 1.3 million gas combination boilers replaced each year is replaced with a unit using PFGHR. This is assumed to be a reasonable estimate of the likely uptake of PFGHR if a modest policy support was available.

In this scenario, the additional carbon savings attributed to newly installed PFGHR units each year would save the equivalent of approximately 3,400 tonnes of CO<sub>2</sub> per year. In 2025, the total CO<sub>2</sub> saved versus the business-as-usual scenario described above would be approximately 28,000 tonnes per year.

Assuming an installed base of 100,000 PFGHR units today, by 2025 the installed base would increase to approximately 900,000 units.

We have assumed that the additional retail price of PFGHR reduces marginally from £300 to £250 per unit due to economies of scale, resulting in a cost per tonne of carbon saving of approximately £390 / tonne. The price reduction is consistent with feedback we received through conversations with PFGHR manufacturers and suppliers.

## New-build mandate scenario

Under this scenario, we have assumed the following:

- All new-build properties with access to the gas grid are mandated to install a combination gas boiler with PFGHR – equivalent to approximately 110,000 units per year.
- The additional retail price of PFGHR (without thermal storage) reduces from £300 to £200 per unit

In this scenario, we have assumed that all new-build properties which have access to the gas grid are required to install a combination boiler with PFGHR technology. Based on 2014 new-build rates, the number of PFGHR units installed each year would likely rise to approximately 110,000, with additional carbon savings of approximately 4,600 tonnes of CO<sub>2</sub> per year. In 2025, the total CO<sub>2</sub> saved versus the business-as-usual scenario described above would be approximately 40,000 tonnes per year.

Assuming an installed base of 100,000 PFGHR units today, by 2025 the installed base would increase to approximately 1,200,000 units.

We have assumed that the additional retail price of PFGHR reduces from £300 to £200 per unit due to economies of scale, resulting in a cost per tonne of carbon saving of approximately £310 / tonne. The price reduction consistent with feedback we received through conversations with PFGHR manufacturers and suppliers.

## Boiler replacement mandate scenario

Under this scenario, we have assumed the following:

- All gas combination boilers, when they reach the end of their working life, are required to be replaced with a combination gas boiler with PFGHR – equivalent to approximately 1.3 million units per year.
- The additional retail price of PFGHR (without thermal storage) reduces from £300 to £90 per unit

In this scenario, we have assumed that whenever a gas combination boiler within existing buildings is due to be replaced, it is a requirement to replace the boiler with a combination boiler with PFGHR technology. Based on 2014 combination boiler sales statistics, the number of PFGHR units installed each year would likely rise to approximately 1.3 million, with additional carbon savings of approximately 56,000 tonnes of CO<sub>2</sub> per year. In 2025, the total CO<sub>2</sub> saved versus the business-as-usual scenario described above would be approximately 553,000 tonnes per year.

Assuming an installed base of 100,000 PFGHR units today, by 2025 the installed base would increase to approximately 13.1 million units.

We have assumed that the additional retail price of PFGHR reduces from £300 to £90 per unit due to economies of scale, resulting in a cost per tonne of carbon saving of approximately £140 / tonne. The price reduction is consistent with feedback we received through conversations with PFGHR manufacturers and suppliers.

## 5.3 Key barriers

There are a number of barriers present today which must be overcome if we are to see significant uptake of PFGHR within the UK market. The most obvious example is the additional upfront cost of PFGHR compared to a conventional gas boiler, but physical fit (i.e. the challenge posed by the additional size of a PFGHR), lack of awareness, and competition from other technologies are also major challenges limiting the uptake of PFGHR.

This section highlights the main barriers to widespread adoption of PFGHR, and discusses how these barriers may be reduced or eliminated in the future.

### Upfront cost of PFGHR

As discussed earlier in the report, the range of costs varies significantly across different types of PFGHR device. The additional retail price of PFGHR compared to conventional boilers can range from around £150 to over £1,000 depending on the type of PFGHR, and this is often sufficient to deter potential buyers. (The large price range can largely be attributed to the different designs of PFGHR system, with those designs which employ additional thermal storage typically priced above £500).

Based on analysis carried out for this project, we estimate that for the average house with a typical domestic hot water demand of 2,000 kWh per year, payback periods tend to exceed 10 years. It should be noted, however, that houses with a higher domestic hot water demand (for example, more than 4,000 kWh), pay-back periods could come down to below 10 years. Our analysis, and past experience, shows that significant uptake of low carbon heating technologies requires a maximum payback period of 2 to 3 years. Therefore, under current circumstances, the upfront cost of PFGHR devices will continue to limit the uptake of the technology. In the absence of other market drivers (such as SAP, as discussed earlier), there would likely be very few sales of PFGHR today (likely tens or hundreds only).

In order for the commercial proposition alone to drive sales, costs will likely need to come down significantly, by 50-70%. As discussed earlier in the report, major cost reductions will likely only be driven by a significant uptake in sales (likely 100s of thousands at least) which would allow manufacturing costs to come down and overheads to be spread more thinly.

### Physical fit

The additional space requirements for PFGHR compared to a conventional boiler is a significant challenge to overcome, especially for external, 'bolt-on' PFGHR systems, and within the existing building stock.

External PFGHR systems with thermal storage can often require an additional 300 to 400 mm in height above the boiler, and in many properties, this extra space is not available (for example, where boilers are installed within kitchens or in compact cupboard spaces).

This issue is less pressing for PFGHR devices which are more compact (i.e. those which employ an internal PFGHR configuration) and have dimensions which are more similar to conventional boilers. Nevertheless, 'physical fit' is an issue which must be carefully considered prior to selecting a PFGHR where space constraints exist.

The extent to which this issue is present among the existing UK building stock is not clear; it would benefit BEIS's further analysis to seek a more detailed understanding of physical fit constraints. However, our analysis (which is informed via interviews with boiler and PFGHR manufacturers) indicates that up to 50% of the existing building stock may not be applicable for external PFGHR systems with thermal storage. A smaller section of the building stock will not be accessible for built-in PFGHR devices. (At least one PFGHR device has the same dimensions as a non-PFGHR combination boiler).

### Lack of awareness and installer reticence

Awareness of PFGHR among end-users is very low, and boiler installers are not proactively pushing the technology. As such, within the boiler replacement market in existing homes, or the new-build owner-occupier sector, PFGHR is not normally considered or offered as an option.

For home owners, evidence gathered during this project indicates that there is very low awareness of PFGHR and understanding of the benefits that the technology can provide. This lack of awareness and lack of understanding means that PFGHR is rarely requested and so even in properties where other barriers are not present (e.g. physical fit), PFGHR is not considered.

Installers, who often act as the specifier within the boiler replacement market, are not proactively offering PFGHR products. This is also due to a lack of awareness, but – more importantly – installers normally have little incentive to promote PFGHR over conventional heating systems. The mark-up on boilers with PFGHR is normally very similar to the mark-up on conventional systems, and yet boilers with PFGHR can be more complicated installations. Therefore, there is little financial gain for installers recommending PFGHR systems. Furthermore, most installers have little or no experience installing PFGHR devices and are likely to be reticent to suggest technologies that they are unfamiliar with as this entails more risk to them with very little reward.

### Retrofit of PFGHR onto existing boilers is impractical

Retro-fitting PFGHR to existing boilers is largely impractical due to the fact that, when fitted, the PFGHR device is then considered to be a component part of the overall boiler installation, according to the relevant Regulations, and is subject to boiler design, performance and installation Standards. This eliminates the possibility of fitting an external PFGHR to a boiler without invalidating the certification unless it has been certified for use with the particular boiler model.

Since boiler companies have little benefit from allowing a third-party to couple a PFGHR device with their previously installed products, there is no incentive for boiler companies to go through the costly process of independently certifying the specific boiler and PFGHR system configuration (which would have to be carried out separately for every combination of boiler type and PFGHR type).

Furthermore, in reality, it is highly unlikely that retrofitting PFGHR units to in-situ boilers is a viable option from a commercial perspective; the cost of installation alone (likely £100 to £200+) could add as much as 100% to the price of the PFGHR unit making payback periods prohibitively long. Throughout this research, we have not come across any evidence to suggest that retro-fitting a PFGHR unit to an existing boiler has ever taken place in a 'real-life' scenario.

## 6. Conclusion & Gap Analysis

### 6.1 Overall Conclusions

#### PFGHR performance figures

As discussed earlier in the report, there is a significant gap in the availability of performance data which would be necessary to determine the effectiveness of PFGHR products to reduce gas usage when heating domestic hot water. However, during the course of this research, we have been able to come to an indicative view of the typical energy saving potential using PFGHR by considering the following:

- Typical domestic hot water and space heating usage patterns within the new-build and existing UK housing stock
- A technical assessment of the theoretical efficiency which could be achieved under certain operating conditions and assumptions (carried out by Enertek International)
- Views from multiple PFGHR players, including manufacturers and suppliers

Our analysis indicates that when operating in domestic hot water mode within new-build properties a typical combination gas boiler using:

- **PFGHR units *without* additional thermal storage can typically save 9% of the gas used to heat domestic hot water, equivalent to a boiler efficiency improvement of approximately 1 percentage point.** (Actual DHW gas savings are likely to range from around 5% to 10%)
- **PFGHR units *with* additional thermal storage can save additional gas, with total annual gas savings for heating domestic hot water typically around 31% for a typical existing building, equivalent to a boiler efficiency improvement of 5 percentage points.** (Actual DHW gas savings are likely to range from less than 15% to around 35% depending on DHW demand, space heating demand, and the volume of thermal storage.)

The above figures should be taken as indicative only; further testing of PFGHR units within real-life scenarios would be necessary to increase confidence in the actual gas savings which could be achieved when using different designs and models of PFGHR technologies.

#### Typical costs and payback periods

During the course of this research we have compiled cost information through multiple interviews with PFGHR manufacturers and retailers. Our analysis indicates that the marginal retail price for a PFGHR unit (in addition to the price of an equivalent boiler without PFGHR) varies significantly from one company to the next, and can range from around £150 to over £1,000. However, a price range of £250 to £600 captures the large majority of PFGHR products on the market today. The most significant factor which impacts the price of a PFGHR product

tends to be the design, and whether or not the unit utilises additional thermal storage; those with storage tend to cost two to three times the price of those without.

#### Typical marginal retail price for PFGHR units:

- **Without additional thermal storage: A median of £300**, with a range from £150 to £400
- **With additional thermal storage: A median of £550**, with a range from £400 to £1,000

The payback periods for PFGHR are closely linked to the domestic hot water demands of individual households; those with high hot water demands will save more gas, on average, and the PFGHR unit will pay back more quickly.

However, based on typical assumptions on domestic hot water demand (2,000 kWh per year), and using the median retail prices listed above, we have calculated that for both PFGHR with additional thermal storage, and those products without thermal storage, indicative, **simple payback periods are typically more than 10 years.**

#### Carbon savings and cost-per-tonne of carbon saved

PFGHR products have the ability to save gas which would otherwise be consumed when a combination gas boiler is operating in domestic hot water mode. By considering the carbon intensity of UK natural gas, the typical energy efficiencies of PFGHR technologies, and typical hot water demands within domestic properties, we have calculated indicative annual carbon savings which can be achieved for:

- **A PFGHR unit without additional thermal storage: Approximately 43 kg of CO<sub>2</sub> per year** (actual CO<sub>2</sub> savings are directly proportional to domestic hot water demand)
- **A PFGHR with additional thermal storage: Approximately 155 kg of CO<sub>2</sub> per year** (actual CO<sub>2</sub> savings are closely linked to domestic hot water demand, and can range from less than 125 kg per year to over 350 kg per year depending on DHW demand, space heating demand and the volume of thermal storage).

Based on these figures, the typical retail prices for PFGHR (as described above), and an assumed PFGHR lifetime of 15 years, we have calculated indicative cost-per-tonne of carbon saved figures as follows:

- **A PFGHR unit without additional thermal storage: Approximately £465 / tonne of CO<sub>2</sub> saved**
- **A PFGHR with additional thermal storage: Approximately £235 / tonne of CO<sub>2</sub> saved**

### Future cost reduction potential

However, we have also gathered views from PFGHR designers, manufacturers and retailers on future cost reduction potentials which could be achieved at high sales volumes. These are summarised as follows:

- **A PFGHR unit without additional thermal storage: Approximately £90 per unit** (down from a median value today of ~£300)
- **A PFGHR with additional thermal storage: Approximately £200 per unit** (down from a median value today of ~£550)

Based on the above, the potential *future* cost-per-tonne of carbon saved figures could ultimately be realised as:

- **A PFGHR unit without additional thermal storage: Approximately £140 / tonne of CO<sub>2</sub> saved**
- **A PFGHR with additional thermal storage: Approximately £90 / tonne of CO<sub>2</sub> saved**

### PFGHR market size today and possible future scenarios

There are currently around **14,000 PFGHR units installed in the UK every year**, with most (over 90%) going into the new-build sector. It is conceivable that government intervention could stimulate a significant uptake of the technology, and we have considered the *potential* increase in PFGHR sales which could be achieved under different scenarios, as follows:

1. **Introduction of policy support**, where fiscal support is provided to incentivise the adoption of boilers with PFGHR: **Approximately 80,000 PFGHR sales per year**
2. **New-build mandate**, where all new-build properties connected to natural gas networks are required to install a boiler with PFGHR: **Approximately 110,000 PFGHR sales per year**
3. **Boiler replacement mandate**, where all gas boilers – whether installed in new-build or replacing boilers in existing properties – are required to have PFGHR: **Approximately 1.3 million PFGHR sales per year**



## 6.2 Gap Analysis

Throughout the course of the analysis for this project, we encountered a number of gaps in available knowledge relating to the performance of PFGHR technologies and other PFGHR market factors. The most obvious was the lack of operational PFGHR performance data. This section describes potential further work which could be undertaken in order to help overcome these gaps.

### Lack of operational performance data

One of the key objectives of this project was to establish the presence of any in-field data relating to the performance of PFGHR technologies under 'real-life' operating conditions. Following conversations with many PFGHR players – including designers, manufacturers and retailers – it became clear that no such performance data has so far been collected.

The primary challenge which makes it difficult to collect such data relates to the fact that there is no evidence to suggest that PFGHR units have ever been retrofitted to existing boilers; almost all sales are within the new build sector, and where PFGHR units are installed within the existing building stock, this only occurs alongside a boiler replacement. In such a case, it is impossible to determine whether any gas savings can be attributed to the PFGHR device or to the new boiler. In reality, it would likely be a combination of both.

In order to overcome this gap, it would be necessary to carry out a field-trial by installing multiple boilers of the same design – half with PFGHR and half without PFGHR - within properties of similar fabric and occupancy levels. In order to collect representative data, a sample size of at least 10s (ideally 100s) of units would be necessary for each PFGHR product being tested, and the test carried out for a period of at least 12 months.

In terms of measurements, the following data sets would need to be collected:

- **Gas usage:** Ultimately, PFGHR products save gas which would otherwise be consumed to heat domestic hot water. Therefore, having a clear understanding of the different gas usage trend for households with and without PFGHR is crucial to help understand how much gas can be saved by deploying PFGHR.
- **Hot water usage:** As PFGHR reduces the amount of gas necessary to heat domestic hot water, it is necessary to understand the hot water demands for each household.
- **Space heating programme** (necessary for testing PFGHR products which use additional thermal storage within their design): For PFGHR products with additional thermal storage, the amount of gas which can be saved is dependent on the space heating pattern in combination with the hot water usage.

Furthermore, there is also a gap around the variation of different housing types, and different levels and volumes of domestic hot water demand. In order to bridge this gap, it would be necessary to collect monitoring data across a representative cross-section on the UK building stock. Only then would it be possible to determine accurately the number of dwellings in which a PFGHR product could be installed and achieve an attractive pay-back period.

### Uncertainty around future cost reduction

During this project, we have considered the potential for future cost reduction of PFGHR products by seeking the views of manufacturers and retailers. We believe that this analysis

provides a sound indication of the potential cost reductions which could be achieved if sales volumes increase to 100s of thousands or millions. However, in order to increase the level of confidence, it would be necessary to carry out additional research specifically focussed on exploring this topic.

For example, it is likely that step changes in cost reduction can be achieved once a certain volume of sales is reached, at which point alternative, more cost-effective manufacturing methods can be employed for certain major components. In order to consider this in detail, it would be necessary to look closely at the individual components which make up a PFGHR system, determine how they are manufactured today, and decide how they could best be manufactured more cost-effectively at greater volumes.

### **Uncertainty around available space for PFGHR within existing building stock**

One of the key uncertainties we came across during this research related to the extent to which the additional space requirement for some PFGHR products prevents installation within existing dwellings. PFGHR products which employ additional thermal storage (within the boiler casing or as a bolt-on, external device) can add up to 400 mm to the height of a conventional gas boiler. In many cases, this would prohibit the installation of a PFGHR unit using storage. (For those PFGHR designs which do not employ thermal storage, dimensions tend to be much more similar to conventional boilers, and space restrictions are not such a great concern.)

Anecdotal evidence collected during interviews for this project suggested that approximately 50% of existing residential dwellings would not be able to accommodate a PFGHR device with thermal storage. However, this figure has not been determined through any means of measurement and should be taken as indicative only.

To overcome this knowledge gap, it would be necessary to collect measurements from a representative sample (ideally over 1,000 dwellings) of the existing UK building stock.

# Appendix A: System performance assumptions

Central Scenario	Counterfactual	PFGHR system without storage	PFGHR system with storage
Upfront Costs (£)	2,500	2,800	3,050
Heat Demand (kWh / yr)	14000	14000	14000
of which space heating (kWh / yr)	12000	12000	12000
of which hot water (kWh / yr)	2000	2000	2000
Total System efficiency	89.6%	90.6%	94.3%
of which space heating	92.3%	92.3%	92.3%
of which hot water	73.2%	80.0%	106.1%
%age gas savings in DHW mode	N/A	9%	31%
DHW Fuel demand (kWh)	2732	2500	1885
SH Fuel demand (kWh)	12997	12997	12997
Total Fuel Demand (kWh)	15729	15497	14882
Emissions factor (Kg CO <sub>2</sub> / kWh)	0.185	0.185	0.185
Annual household emissions (kg)	2910	2867	2753
Annual household emissions savings using PFGHR (kg)	N/A	42.96	156.69
Gas price (£ / kWh)	0.05	0.05	0.05
Household gas bill (£ / yr)	£786	£775	£744
Household gas bill savings	N/A	£11.61	£42.35

## Evidence Gathering: Passive Flue Gas Heat Recovery Technologies

Sources with description	Counterfactual	PFGHR system without storage	PFGHR system with storage
Upfront Costs (20-24kW system)	Assumed installed price of a typical new gas combi boiler. Figure provided by DECC and confirmed by Delta-ee.	Assumed installed price of a typical new gas combi boiler with a PFGHR unit without storage. Figure provided by Delta-ee following call with multiple heating manufacturers.	Assumed installed price of a typical new gas combi boiler with a PFGHR unit with storage. Figure provided by Delta-ee following call with multiple heating manufacturers.
Heat Demand	Sum of space heating demand and DHW demand		
of which space heating	Assumed typical space heating demand figure of 12,000 kWh provided by DECC and confirmed by Delta-ee.		
of which hot water	Assumed typical DHW demand figure of 2,000 kWh reached following calls with multiple heating manufacturers, previous Delta-ee insight and referring to the following EST report: <a href="https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/48188/3147-measure-domestic-hot-water-consump.pdf">https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/48188/3147-measure-domestic-hot-water-consump.pdf</a>		
Total System efficiency	SAP efficiency figure for the biggest selling gas combi product in the UK, the Worcester Bosch Greenstar I <a href="http://www.ncm-pcdb.org.uk/sap/pcdbdetails.jsp?pid=26&amp;id=017505&amp;type=105&amp;mid=000035">http://www.ncm-pcdb.org.uk/sap/pcdbdetails.jsp?pid=26&amp;id=017505&amp;type=105&amp;mid=000035</a>	Total system efficiency for a PFGHR system without storage derived from individual efficiencies for space heating and DHW, and weighting according to assumed space heating:DHW ratio.	Total system efficiency for a PFGHR system with storage derived from individual efficiencies for space heating and DHW, and weighting according to assumed space heating:DHW ratio.
of which space heating	Derived from SAP, as above.	Space heating efficiency for boilers with PFGHR does not change.	
of which hot water	Derived from SAP, as above.	DHW efficiencies for boilers with PFGHR derived from modelling carried out by Enertek International. Based on assumptions on heating demands, and relative incidences of DHW demand coinciding with space heating demand.	
%age gas savings in DHW mode	N/A		
DHW Fuel demand (kWh)	Derived from heat demand and system efficiencies figures, above.		
SH Fuel demand (kWh)			
Total Fuel Demand (kWh)			
Emissions factor	DECC - Final energy demand emissions factors (Table 2a) <a href="https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/360323/20141001_Supporting_Tables_for_DECC-HMT_Supplementary_Appraisal_Guidance.xlsx">https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/360323/20141001_Supporting_Tables_for_DECC-HMT_Supplementary_Appraisal_Guidance.xlsx</a>		
Household emissions in 2015	Derived from emissions factor and total fuel demand figures, above.		
Annual household emissions savings using PFGHR	Annual household emissions savings derived from comparison of emissions from households with and without PFGHR devices.		
Gas price	<a href="https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/463037/Sept_15.pdf">https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/463037/Sept_15.pdf</a> Based on annual gas bill of £752 and gas consumption of 15,000 kWh per year.		
Household gas bill (£ / yr)	Derived from gas price and total fuel demand figures, above.		
Household gas bill in 2015	N/A	Household gas savings derived from comparison of gas bills from households with and without PFGHR devices.	

# Appendix B: Future scenarios assumptions

<b>Future Sales scenarios</b>				
<b>Scenario</b>	<b>Business-as-Usual</b>	<b>Policy Support</b>	<b>New-build Mandation</b>	<b>Boiler replacement mandation</b>
Installed base	100,000	100,000	100,000	100,000
Annual sales rate	14,000	79,000	107,422	1,300,000
Total Installed: 2016	114000	179000	207422	1400000
Total Installed: 2017	128000	258000	314844	2700000
Total Installed: 2018	142000	337000	422266	4000000
Total Installed: 2019	156000	416000	529688	5300000
Total Installed: 2020	170000	495000	637110	6600000
Total Installed: 2021	184000	574000	744532	7900000
Total Installed: 2022	198000	653000	851954	9200000
Total Installed: 2023	212000	732000	959376	10500000
Total Installed: 2024	226000	811000	1066798	11800000
Total Installed: 2025	240000	890000	1174220	13100000
Gas saving %	9%	9%	9%	9%
C intensity of UK NG (GCV) (g/kWh)	185.00	185.00	185.00	185.00
Avg. domestic hot water demand (kWh)	2000.00	2000.00	2000.00	2000.00
Boiler DHW efficiency (%)	73%	73%	73%	73%
Avg. gas demand for DHW (kWh)	2732	2732	2732	2732
Annual CO2 saving per unit (g/yr)	42964	42964	42964	42964
Annual CO2 saving per unit (kg/yr)	42.96	43.0	43.0	43.0
Annual CO2 saving per unit (tonne/yr)	0.0430	0.0430	0.0430	0.0430
Additional T of CO2 saved per yr	602	3,394	4,615	55,854
Total T of CO2 saved per year versus no PFGHR in 2025	10,311	38,238	50,450	562,835
Total T of CO2 saved per year versus BAU in 2025	N/A	27,927	40,138	552,523
<b>Cost Information</b>				
Gas saving per year (kWh)	232	232	232	232
Gas price (£ / kWh)	0.05	0.05	0.05	0.05
Savings per year (£)	£11.61	£11.61	£11.61	£11.61
<b>Payback (years)</b>	26	22	17	8
Assumed cost of DHW-only PFGHR	£300	£250	£200	£90
Lifetime of PFGHR (yrs)	15	15	15	15
Total annual cost of PFGHR	£4,200,000	£19,750,000	£21,484,400	£117,000,000
Cost per tonne of CO2 saved	£465.50	£387.92	£310.33	£139.65

## Appendix C: Project methodology

During the course of the research for this project, we used multiple sources of information in order to build up our knowledge of the PFGHR sector within the UK. Our primary source of information was interviews with many companies and associations who are active within the UK domestic heating industry (listed below). However, we also compiled information from publicly available material and literature, and used existing PFGHR insight known to project partners Delta Energy & Environment and Enertek International.

### Companies and associations contacted during the course of this project

#### **Boiler and PFGHR Manufacturers:**

- Alpha Heating Innovation
- ATAG Heating Technology
- Baxi
- Bosch (Worcester Bosch)
- Ideal Boilers
- Johnson & Starley
- M&G Group
- Ravenheat
- Vaillant Group
- Viessmann Group
- Zenex Technologies

#### **Associations:**

- Energy Saving Trust
- Heating and Hotwater Industry Council
- KIWA Gastec UK

#### **Housing Associations:**

- Circle Housing
- Fife Local Authority
- Guinness Partnership
- Kirklees Neighbourhood Housing
- Orbit Group

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