Review of technical information on renewable heat technologies

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1 Introduction

This report outlines the results of the review undertaken by AEA on behalf of DECC of the technical cost evidence on renewable heat technologies. The review assessed information that became available over the period February 2010 to November 2010 and focussed upon four renewable heat technologies:

- Air Source Heat Pumps (ASHP)
- Ground Source Heat Pumps (GSHP)
- Solar Thermal
- Biomass

An initial review was undertaken of the technical Renewable Heat Incentive consultation responses sent to DECC. This initial review highlighted a range of technical and policy issues. This report focuses upon the technical cost issues investigated further by AEA through reviewing the evidence base and speaking with relevant industry stakeholders. The specific areas highlighted in this report are:

1. GSHP: borehole versus slinky costs.
2. Technology learning rates
3. Technology lifetimes
4. Amendments to the cost model for the four technologies reviewed
5. Summary of technology banding and tariff recommendations

The results of this review are reflected in the cost benefit analysis of the Renewable Heat Incentive (RHI) undertaken by DECC based on the Renewable Heat model (referred to in this report as the "model") built by NERA Economic Consultants on behalf of DECC.

This report should be read in conjunction with:

- The NERA/AEA (2009)[1] and NERA (2010)[2] reports which provide background information on the previous renewable heat technology assumptions and the operations of the model
- The RHI consultation Impact Assessment[3] and
- The RHI policy Impact Assessment (published alongside this report)

The results and recommendations presented in this report reflect AEA's views based on stakeholder feedback. Therefore they do not reflect policy decisions on the final structure of the RHI which can be found in the relevant policy documents.

[1] NERA/AEA (2009): The UK Supply Curve for Renewable Heat
[2] NERA(2010): Design of the Renewable Heat Incentive
[3] http://www.decc.gov.uk/en/content/cms/consultations/rhi/rhi.aspx

2 Technical issues review

This section highlights areas where changes in the model have been recommended following the review of the RHI consultation responses. It also provides clarifications on some of the technical issues related to the technology assumptions.

2.1 GSHP: borehole and slinky costs

Several respondents highlighted that vertical heat pump borehole costs are significantly greater than horizontal 'slinky' installations. For example one stakeholder estimated that the cost of a vertical heat pump is 38% more in overall CAPEX than a horizontal equivalent installation. The typical differences in cost between the two types of installation are given in table 2.1.

Table 2.1: Cost difference vertical versus horizontal

	Vertical	**Horizontal**
11-12kW GSHP	£1480/kW	£900/kW

As part of the consultation review stakeholders provided prices of over 500 real life installations. This data exhibits a significant price range from £390/kW rated capacity to £4,250/kW for horizontal and £360/kW to £6,270/kW for vertical. The price is influenced by a number of factors:

- Geology: it is generally cheaper to drill a borehole in an area such as Cornwall that has a predominance of hard rock. Areas with clay such as parts of Oxfordshire will be more expensive as the borehole will need lining.
- Geographical location: Areas further north in the UK will need a deeper borehole or longer trench for a given kW capacity due to the lower ground temperature. This can exacerbate the average discrepancy in price.
- Sizing: There are no technical standards or regulation on installers to size the heat pump correctly for the heat load. This is likely to influence actual performance of heat pumps.
- There are opportunities to reduce the cost of boreholes should multiple installations be undertaken on the same street or as part of a new development, this could reduce the cost by 20%.

Vertical or horizontal

The type of property that is being considered for heat pumps will determine whether a horizontal or vertical heat pump is likely to be installed. The availability of sufficient land is the influencing parameter. Rules of thumb provided in the consultation responses mean that it is extremely unlikely that anyone other than a rural detached house will have sufficient space in their garden for a horizontal installation. This review also clarified that large GSHP (typically anything above 50kW) is likely to be based upon borehole systems as the land requirements for horizontal installations would be too large.

Accommodating the vertical versus horizontal installations in the cost model

The original model provided by AEA to NERA (and which was used for setting the RHI tariffs in the RHI consultation) assumed that a horizontal GSHP would be installed for all rural and suburban households as this is cheaper. Following the additional evidence supplied under the consultation and stakeholder interviews this assumption of the segmentation split has been reviewed. The market segmentation has been amended to assume that only rural detached properties would install a horizontal system and the rest a vertical borehole system. The implications of this change will be that the average cost for GSHP will show an increase in £/kW as there is a greater proportion of vertical installations.

2.2 Heat Pump efficiencies

Heat pumps use electrical energy to pump heat from a source (the ground, water or air) at a low temperature to a heating system (radiators or hot water tank) at a higher temperature. The efficiency of the heat pump is defined as the ratio between the electrical energy supplied and the heat energy delivered into the heating system, this is also termed the Coefficient of Performance (CoP). If one sums the total electricity supplied and heat delivered over a complete year then the resulting ratio gives the efficiency measure referred to as the Seasonal Performance Factor (SPF).

The original 2009 model efficiency values were based upon consultation with industry and they represent manufacturer's expected Seasonal Performance Factors (SPF) that were modified by AEA to allow for the type of emitter system and hot water proportion for the particular model sector.

Typically between 2 to 4 units of heat are pumped into the heating system for every unit of electricity consumed. The amount of electricity is not trivial and if it is generated by fossil sources there may be few if any carbon savings from a heat pump if the efficiency is low. Significant concerns were raised during the consultation about heat pumps in practise achieving low efficiencies. The dependence of the carbon saving on the efficiency of the system and the use of fossil fuel in the generating mix is recognised in the Renewable Energy Directive (RED) issued by the European Commission. The RED sets an efficiency threshold for heat pump systems below which the heat cannot be considered renewable for the purposes of national targets. The determination of system efficiency is therefore critical to the implementation of the RHI.

There are several variables that can substantially affect the performance of a heat pump system, some of which depend on how the system is used.

- The source temperature – varies throughout the year depending on location and type.
- The heating system temperature – depends on type of system and user requirements and preferences such as the amount of domestic hot water.
- The mechanical efficiency – depends on the design and installation of the heat pump

It is the SPF that is used in the RED to determine whether or not the delivered heat is renewable and how much can be credited to the UK Renewable Energy target. Using the current efficiency of electricity generation of 40% from Eurostat[4] only heat pump systems with a SPF of greater than 2.875 count as renewable[5].

The calculation of SPF is not trivial as it must access representative climatic data, take account of different configurations of heating and hot water systems, and accommodate different makes of pump. Consultation responses made reference to two main methodologies for the calculation of the SPF;

- SAP appendix Q developed by BRE as an addendum to the domestic property Standard Assessment Protocol.
- The German protocol VDI 4650.

The importance of a minimum efficiency requirement is recognised and is treated separately in the RHI policy proposals. However it should be noted that the technology cost model reports the representative efficiencies of what might currently be installed by good practice heat pumps and therefore assumes a range of efficiencies of 260%-385% for domestic and 350%-425% for non-domestic. The efficiencies in the model have therefore not been changed to match the RED although the tariff calculation has been amended to reflect this minimum SPF requirement. The review of the additional evidence does however recognise that with technical guidance and requirements on system efficiencies these standards could be met although this would be challenging for many installations. Further detail on the changes made is provided in section 3.

[4] http://epp.eurostat.ec.europa.eu/portal/page/portal/eurostat/home/
[5] Although the exact methodology for deriving that SPF is still to be determined.

2.3 Biomass Air Quality

Assumptions on air quality thresholds for RHI supported biomass boilers have been introduced since the initial modelling research was undertaken. Updated assumptions for air quality have increased the CAPEX for biomass boilers to reflect the additional capital cost that may be experienced by biomass installations in certain segments. Based on new evidence it was judged likely that it may become best practice to require planning conditions on larger boilers in urban areas to make particulate filters obligatory. To reflect this, a capital cost adjustment of 15% was made to the segments affected.

As in previous modelling work if the segment did not fall into one of the urban-large segments then the CAPEX was increased by 10% to reflect a market restriction as a result of future expected emissions thresholds.

The emission thresholds associated with this assumption are:

- 30mg/MJ particulate
- 150mg/MJ NOx

2.4 Technology learning rates

The technology cost model considers two forms of learning rate:

1. Index for CAPEX this was originally based upon technology learning rates reported by Element Energy (2008)[6]
2. Index for Efficiency/COP (only for heat pumps as for biomass and solar no significant improvements are expected over the next 10 years). The original heat pump efficiencies were based upon discussions with stakeholders in 2008/2009.

The indices tables are presented in the tables below:

Index for Capex

Technology	Sector	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Biomass DH	Non-domestic	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Biomass DH	Domestic	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Biomass boile	Non-domestic	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Biomass boile	Domestic	1.0	1.0	1.0	0.9	0.9	0.9	0.9	0.9	0.9	0.8	0.8	0.8	0.8
Liquid biofuels	Non-domestic	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Liquid biofuels	Domestic	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
ASHP	Non-domestic	1.0	1.0	0.9	0.9	0.9	0.9	0.8	0.8	0.8	0.8	0.8	0.8	0.8
ASHP	Domestic	1.0	1.0	0.9	0.9	0.9	0.9	0.8	0.8	0.8	0.8	0.8	0.8	0.8
GSHP	Non-domestic	1.0	1.0	0.9	0.9	0.9	0.9	0.8	0.8	0.8	0.8	0.8	0.8	0.8
GSHP	Domestic	1.0	1.0	0.9	0.9	0.9	0.9	0.8	0.8	0.8	0.8	0.8	0.8	0.8
Solar Thermal	Non-domestic	1.0	1.0	0.9	0.9	0.9	0.8	0.8	0.8	0.8	0.7	0.7	0.7	0.7
Solar Thermal	Domestic	1.0	1.0	0.9	0.9	0.9	0.9	0.8	0.8	0.8	0.8	0.8	0.8	0.8

Index for Efficiency / COP

Technology	Sector	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Biomass DH	Non-domestic	-	-	-	-	-	-	-	-	-	-	-	-	-
Biomass DH	Domestic	-	-	-	-	-	-	-	-	-	-	-	-	-
Biomass boile	Non-domestic	-	-	-	-	-	-	-	-	-	-	-	-	-
Biomass boile	Domestic	-	-	-	-	-	-	-	-	-	-	-	-	-
Liquid biofuels	Non-domestic	-	-	-	-	-	-	-	-	-	-	-	-	-
Liquid biofuels	Domestic	-	-	-	-	-	-	-	-	-	-	-	-	-
ASHP	Non-domestic	-	-	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0	1.1
ASHP	Domestic	-	-	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0	1.1
GSHP	Non-domestic	-	-	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0	1.1
GSHP	Domestic	-	-	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0	1.1
Solar Thermal	Non-domestic	-	-	-	-	-	-	-	-	-	-	-	-	-
Solar Thermal	Domestic	-	-	-	-	-	-	-	-	-	-	-	-	-

As part of this report AEA reviewed these assumptions in light of new stakeholder feedback. For all of the renewable heat technologies the UK market represents a relatively small proportion of the global market. It is therefore expected that there will be a limited cost reduction from economies of scale as

[6] Element Energy (2008) The growth potential for Microgeneration in England, Wales and Scotland.

many are already mass produced in Europe or Asia. There is however potential for a reduction in installation costs as UK experience grows and competition increases. Discussions with suppliers and consultees found that because of the large number of variables and uncertainties that may influence the future CAPEX there was no evidence to substantiate a change to the original figures. The following text summarises the situation for each of the four technologies.

Biomass: the biomass market is using an established technology that has been proven particularly in countries such as Germany and Austria.

Efficiency improvement: biomass boilers are highly efficient typically around 90%, there is limited scope for future improvements in the technology performance.

Cost: the leading boiler manufacturers are based in Europe and are already producing significant numbers per annum. There are also a significant number of UK based boiler suppliers and there has been little reduction in cost over the course of the Bio-Energy Capital Grants Scheme. Therefore AEA expect the costs to remain at similar levels over the next ten years. For domestic boilers a reduction in installer cost is expected which is reflected in the current CAPEX reduction.

Solar thermal: 80% of the UK's solar thermal panels are currently manufactured in Europe. Imports from China may increase in the future which is expanding its manufacturing capabilities and has a high domestic demand.

Efficiency improvement: efficiencies are not expected to improve significantly over the coming decade

Cost: Stakeholders reported little scope for technology cost reduction, there could be a potential reduction in installation cost as greater numbers are installed. However the level of reduction is hard to quantify. The original indices which show a reduction by 20% in the next decade have therefore not been modified.

Ground Source Heat Pumps

Efficiency improvements: discussions with industry confirmed that an average improvement of 0.1 COP per annum resulting in a 1.0 COP increase over the next ten years is realistic.

Cost: There has been reduction in price over recent years which is reflected in the indices, these remain unchanged from original.

Air Source Heat Pumps

Technology improvements: discussions with industry confirmed that an average improvement of 0.1 COP per annum resulting in a 1.0 COP increase over the next ten years is realistic.

Cost: There has been a reduction in price over recent years which is reflected in the indices, these remain unchanged from original. The UK market represents a very small proportion of the total number being sold with mass production in south east Asia that are widely sold in the UK. The cost reductions are from technological advances reducing the cost of manufacturing and an increase in the installer base in the UK lowering costs.

However it should be noted that CAPEX reductions over time for heat pumps are uncertain. Further reductions in cost will be influenced by COP standards required under the RHI and any technical standards introduced. Suppliers confirmed that higher technical standards would push innovation and a market response, however a consequence of this could be that the price may not decrease compared to future use of 'lower efficiency' heat pumps.

2.5 Technology lifetimes

As highlighted and explained in section 3 of this report the original technology lifetimes have been reviewed in light of consultation responses and additional evidence. The key conclusions of this review were:

- Biomass boiler lifetimes have been increased from 15 to 20 years. This ensures compatibility with the Renewables Obligation and reflects advertised boiler lifetimes.
- GSHP lifetimes were originally 23 years and 20 years. Following discussions with stakeholders it was clarified that typical lifetimes for the above ground components were twenty years. The groundworks have a longer lifetime but this has not been factored into the model. Therefore GSHP lifetimes have been revised to 20 years.
- AHSP feature that same core technology as GSHP in terms of the heat pump unit. This has an average lifetime of between 15-25 years with examples of some units operating up to twenty five years. As this part of the technology is similar it was felt that there should be consistency between ASHP and GSHP. Therefore ASHP lifetimes have been increased from 18 years to 20 years.

3 Amendments to cost model

This section summarises the changes made to the technology cost model from the previous version supplied by AEA in 2009. There are two distinct types of change that have been made:

1. A revision to the model following feedback received from the consultation responses and stakeholder discussions facilitated by AEA.

2. An amendment to the assumptions used in the model following further investigation by AEA, DECC and NERA. These changes reflect better information that has become available compared to when the model was originally created.

All amendments are highlighted in bold text. Where the change is in bold red text this is as a result of consultation responses, bold black text indicates an amendment to the model assumptions as described under point 2 above. Please note that all costs have been updated to 2010 prices from the original, only where an additional change was made has this been highlighted (although the full price adjustments for all segments have been reflected in the revised RHI analysis). No comments have been made on the total installed cost as this variation is caused by Capital Cost or Opex changes.

3.1 ASHP cost model values and amendments

	Customer segment	Variable	Unit	Original values	2010 values
1	Domestic	Capital Cost	£/kW	650-1650	**650-1450**
2	Domestic	Opex	£/kW/year	4-9	4-9
3	Domestic	Size of installation	kW	6-14	6-14
4	Domestic	Efficiency	%	250-275%	**260-285%**
5	Domestic	Lifetime	years	18	**20**
6	Domestic	Load Factor	%	10-24%	**10-16%**
7	Domestic	Total installed cost	£ '000s	4-23	**7-12**
8	Commercial/public-small	Capital Cost	£/kW	545	**446**
9	Commercial/public-small	Opex	£/kW/year	6	**12.6**
10	Commercial/public-small	Size of installation	kW	55	55
11	Commercial/public-small	Efficiency	%	350%	350%
12	Commercial/public-small	Lifetime	years	20	20
13	Commercial/public-small	Load Factor	%	35%	35%
14	Commercial/public-small	Total installed cost	£ '000s	30	**25**
15	Commercial/public-large	Capital Cost	£/kW	610	**452**
16	Commercial/public-large	Opex	£/kW/year	1	**2**
17	Commercial/public-large	Size of installation	kW	300	300
18	Commercial/public-large	Efficiency	%	400%	400%
19	Commercial/public-large	Lifetime	years	20	20
20	Commercial/public-large	Load Factor	%	35%	35%
21	Commercial/public-large	Total installed cost	£ '000s	183	**134**
22	Industrial small	Capital Cost	£/kW	610	**452**
23	Industrial small	Opex	£/kW/year	1	**2**
24	Industrial small	Size of installation	kW	300	300
25	Industrial small	Efficiency	%	400%	400%
26	Industrial small	Lifetime	years	20	20
27	Industrial small	Load Factor	%	35%	35%
28	Industrial small	Total installed cost	£ '000s	183	**134**
29	Industrial-large	Capital Cost	£/kW	610	**452**
30	Industrial-large	Opex	£/kW/year	1	**2**
31	Industrial-large	Size of installation	kW	300	300
32	Industrial-large	Efficiency	%	400%	400%
33	Industrial-large	Lifetime	years	20	20
34	Industrial-large	Load Factor	%	35%	35%
35	Industrial-large	Total installed cost	£ '000s	183	**134**

(Note: The above table reflects Air to Water system costs for the domestic sector and Air to Air system costs for the non-domestic sector).

Reasons behind amendments, only commented upon where a change is made (excluding total installed cost as this is largely influenced by CAPEX or OPEX each of which is explained):

1. Revised data received as part of the consultation responses and from speaking to stakeholders indicated that the upper range of the price was too high. This has therefore been adjusted down as show in the table.

4. Efficiency increased by 10% to reflect the rapid improvements in efficiency experienced in the domestic sector between 2009 and 2010 values. This improved efficiency is reflected in the learning rates (section 2).
5. Technology lifetime increased following discussions with suppliers and reflects the need for consistency for the heat pump component with GSHP (above ground components) as the actual heat pump unit is essentially the same technology.
6. Recalculated in line with reconsidered sizing of certain segments based upon the annual demand figures.
8. Cost figures reduced following analysis of detailed quotations provided by stakeholders. The internal cost components have been removed from the price as including this represents an overall improvement to the building ventilation system. The same approach applies to segments **15**, **22** and **29**.
9. OPEX cost increased, also applies to segments **16**, **23** and **30**. Original was based on 0.5 days of a skilled worker whose day rate = £660/day in 2009. Stakeholders suggest an additional 1 day of unskilled worker which AEA assume to be on half day rate of skilled worker so overall cost doubles. The additional time is required for the non-domestic sector to cover for F-gas regulations which require annual checks in addition to cleaning maintenance. As this is a fixed price the Opex increase for the larger installations represents a smaller fraction of the overall price.

3.2 GSHP cost model values and amendments

	Customer segment	Variable	Unit	Original values	2010 values
1	Domestic	Capital Cost	£/kW	771-1899	**940-1829**
2	Domestic	Opex	£/kW/year	5-9	5-9
3	Domestic	Size of installation	kW	6-11	6-11
4	Domestic	Efficiency	%	315-385%	315-385%
5	Domestic	Lifetime	Years	23	**20**
6	Domestic	Load Factor	%	13-24%	13-24%
7	Domestic	Total installed cost	£ '000s	5-21	9-18
8	Commercial/public-small	Capital Cost	£/kW	1420-1580	**900-1046***
9	Commercial/public-small	Opex	£/kW/year	4	4*
10	Commercial/public-small	Size of installation	kW	55	55*
11	Commercial/public-small	Efficiency	%	360-425%	360-425%*
12	Commercial/public-small	Lifetime	Years	20	20*
13	Commercial/public-small	Load Factor	%	35%	35%*
14	Commercial/public-small	Total installed cost	£ '000s	78-86	**50-58***
15	Commercial/public-large	Capital Cost	£/kW	500	**900**
16	Commercial/public-large	Opex	£/kW/year	1	1
17	Commercial/public-large	Size of installation	kW	600	**300**
18	Commercial/public-large	Efficiency	%	365-425%	365-425%
19	Commercial/public-large	Lifetime	Years	20	20
20	Commercial/public-large	Load Factor	%	35%	35%
21	Commercial/public-large	Total installed cost	£ '000s	423-458	**270**
22	Industrial small	Capital Cost	£/kW	1420-1560	**900-1046***
23	Industrial small	Opex	£/kW/year	4	4*
24	Industrial small	Size of installation	kW	55	55*
25	Industrial small	Efficiency	%	400-425%	400-425%*
26	Industrial small	Lifetime	Years	20	20*
27	Industrial small	Load Factor	%	35%	35%*
28	Industrial small	Total installed cost	£ '000s	78-86	**50-58***
29	Industrial-large	Capital Cost	£/kW	500	**900**
30	Industrial-large	Opex	£/kW/year	1	1
31	Industrial-large	Size of installation	kW	600	**300**
32	Industrial-large	Efficiency	%	365-425%	365-425%
33	Industrial-large	Lifetime	Years	20	20
34	Industrial-large	Load Factor	%	35%	35%
35	Industrial-large	Total installed cost	£ '000s	423-458	**270**

*For all values marked with an asterix please see section 3.2.1 for further discussion on the costs of small non-domestic GSHPs.
Note: All costs reflect ground to water systems

Reasons behind amendments, only commented upon where a change is made (excluding total installed cost as this is largely influenced by CAPEX or OPEX each of which will be explained):

1. Capital cost of domestic increased the lower scale of the range as better data was forthcoming during the consultation responses. An average of the prices provided by stakeholders was

used to derive the typical cost of a horizontal installation (£940/KW) and vertical (£1480/KW). The only installations that are likely to install a horizontal installation are detached rural properties.

5. Domestic lifetimes decreased from 23 to 20 years to reflect consistency across all heat pump lifetimes. It should be noted that **ALL** GSHP lifetimes are based just upon the above ground lifetimes. The groundworks of boreholes and slinky systems have an estimated lifetime of 50 years (refer to section 2.7.1).
8. The lower cost of £900/kW assumes no additional cost for wet system as it is assumed that for non-domestic application the existing air system could be used. Same change applies to **22** . The higher price of £1046 assumes including additional cost of wet system which was only assumed to be required in small non-domestic installations.
15. Increase in Capex of large scale ground source heat pumps. The previous value of £500/kW represented confusion over the presentation of heating and cooling capacities. The updated figures of £900/kW reflect the total costs of a system in relation to just the heating capacity. The same change also applies to **29**.
17. Size of large GSHP reduced from 600 to 300kW following discussions with stakeholders over the size of typical large GSHP installations, this change also applies to **31**.

3.2.1 Amendment to the small and medium non-domestic GSHP costs

The AEA cost model includes segments for GSHP for:

- Domestic: Typical sizes 6kW and 11kW
- Small commercial/public/industry : Typical size 55kW
- Large commercial/public/industry: Typical size 300kW

Based on these costs the RHI model calculates cost per unit of heat output for each size category. As installation size increases there are four factors that act together to reduce costs;

a) the fixed cost associated with getting drilling machinery on site
b) economies of scale for heat pumps up to 50kW,
c) sizes of modular units required; and
d) increased load factors for commercial units

(a)+(b): The impact of establishment costs: To illustrate the impact of the fixed costs, considering just the cost of the groundworks a domestic installation of 5kW will typically require one borehole of 100m. The fixed costs of getting equipment on site of £3000 are high (£3000 per borehole). For a small commercial 50kW installation with 12 boreholes the fixed cost of £3000 is small (£250 per borehole), a larger installation of 200kW will expect establishment costs of £60 per borehole. This change in the fixed cost per borehole has an influence upon the specific capital cost of the heat pump installation itself expressed as £/kW which drops substantially between 5kW rated capacity and 150kW.

(c): The impact of modularisation: larger heat pump installations are typically built up of modular units that will be packaged as one installation by the installer. For the larger installations (300kW+) the cost model assumes that these will be built up of 55kW modules. However installations just above the largest individual module size (e.g. 55KW) may need to be constructed from two or more smaller modules which do not have the same economies of scale. Such installations will have higher costs than assumed from the above "typical" installation size. Analysis of stakeholder feedback indicated that smaller modular units of 30KW could for example be employed in the non-domestic sector for installations just below 100KW[7].

[7] There is limited evidence to substantiate the market size of modules since GSHP installations are commonly referred to as the total heating or cooling capacity rather than the module size. However, given the impacts of economies of scale and that many non-domestic installations are likely to install GSHP to cover a proportion of the heat load is estimated that around 60% of the installations below 100KW could use 55kW modules and 40% could use 30kW modules.

Above 100kW it is expected that economies of scale, load factors and site establishment costs will have evened out.

(d): Load factors: A further factor that influences costs between domestic and non-domestic GSHPs is the assumed load factor of the equipment. In the model the load factor for domestic installations is set as 13-19% whereas for commercial installations it is set at 35%

Recommendation: To reflect the differences in the above factors whilst maintaining a reasonable number of bands and ensuring that the RHI tariffs do not result in overcompensation of installations it is recommended that the RHI tariffs are set as follows:

- Domestic tariffs: based on 12KW installation as analysis of typical domestic heat loads finds that the majority of heat loads in this sector fall under 20kW.
- Non-domestic small band (0-100KW): Based on costs of 30KW modular using with the following costs characteristics:
- Non-domestic large band (100KW+): based on 55KW modular unit.

The assumptions used for the 30KW units are set out below:

Table 3.2 Cost model values for a vertical 30kW GSHP

Customer segment	Variable	Unit	2010 values
Commercial/public/industry-small	Capital Cost	£/kW	1228-1496
Commercial/public/industry-small	Opex	£/kW/year	7
Commercial/public/industry-small	Size of installation	kW	30
Commercial/public/industry-small	Efficiency	%	360-425%
Commercial/public/industry-small	Lifetime	years	20
Commercial/public/industry-small	Load Factor	%	35%
Commercial/public/industry-small	Total installed cost	£ '000s	37-45

3.3 Biomass cost model values and amendments

	Customer segment	Variable	Unit	Original values	2010 values[8]
1	Domestic	Capital Cost	£/kW	330-550	**633-894**
2	Domestic	Opex	£/kW/year	11-18	**19.2**
3	Domestic	Size of installation	kW	12-20	**12**
4	Domestic	Efficiency	%	85%	85%
5	Domestic	Lifetime	years	15	**20**
6	Domestic	Load Factor	%	7-12	**8-17%**
7	Domestic	Total installed cost	£ '000s	7-10	**8-11**
8	Commercial/public-small	Capital Cost	£/kW	345-655	**370-788**
9	Commercial/public-small	Opex	£/kW/year	5-8	5-8
10	Commercial/public-small	Size of installation	kW	110-180	110-180
11	Commercial/public-small	Efficiency	%	81%	81%
12	Commercial/public-small	Lifetime	years	15	**20**
13	Commercial/public-small	Load Factor	%	20%	20%
14	Commercial/public-small	Total installed cost	£ '000s	37-117	**42-141**
15	Commercial/public-large	Capital Cost	£/kW	317-423	**365-509**
16	Commercial/public-large	Opex	£/kW/year	16-21	17-22
17	Commercial/public-large	Size of installation	kW	350-1600	350-1600
18	Commercial/public-large	Efficiency	%	81%	81%
19	Commercial/public-large	Lifetime	years	15	**20**
20	Commercial/public-large	Load Factor	%	20-45%	20-45%
21	Commercial/public-large	Total installed cost	£ '000s	111-678	**170-611**
22	Industrial small	Capital Cost	£/kW	345-423	**397-509**
23	Industrial small	Opex	£/kW/year	17-21	18-22
24	Industrial small	Size of installation	kW	100-1000	**100-730**
25	Industrial small	Efficiency	%	81%	81%
26	Industrial small	Lifetime	years	15	**20**
27	Industrial small	Load Factor	%	20-60%	**20-82%**
28	Industrial small	Total installed cost	£ '000s	35-423	**40-302**
29	Industrial-large	Capital Cost	£/kW	275-423	**316-509**
30	Industrial-large	Opex	£/kW/year	14-21	14-22
31	Industrial-large	Size of installation	kW	350-5000	**350-3640**
32	Industrial-large	Efficiency	%	81%	81%
33	Industrial-large	Lifetime	years	15	**20**
34	Industrial-large	Load Factor	%	20-60%	**20-82%**
35	Industrial-large	Total installed cost	£ '000s	96-2120	**170-1204**

Reasons behind amendments, only commented upon where a change is made (excluding total installed cost as this is largely influenced by CAPEX or OPEX each of which will be explained):

1. Cost increased by 10% to reflect the use of better quality biomass boilers and market restrictions. Additional variations are caused by changes in wet system costs and resizing of some biomass boiler sizes[9].
2. OPEX values not increased but a reduction in the range occurs because of the boiler resizing.

[8] All changes to biomass values were based upon improved information collected by AEA rather than consultation responses.
[9] Although not reflected in the above values previous RHI modelling included a 10% cost adder for air quality considerations based on earlier advice by AEA (see section 2.3)

3. All 20kW systems resized to 12kW which is typically the smallest available capacity. Gas/oil combi boilers are oversized to provide larger instantaneous hot water loads. Conversely, biomass boilers do not provide instantaneous hot water but feed a hot water tank. Where appropriate the boilers were resized it was to meet the target 20% load factor. This change was a correction of an earlier inconsistency in the model rather than as a result of consultation responses.
6. Biomass boiler lifetime increased from 15 to 20 years. Load factor increased, recalculated in line with resizing and annual demand.
8. Non-domestic CAPEX increased by 10% as under point 1. The exception to this is if the boiler is located in an urban area in which case the cost is increased by 15% to reflect fitting of air quality filters. The filters typically represent 30% of the biomass boiler equipment costs which are on average 50% of the total CAPEX including installation. Same change applied to **15**, **22** and **29**.
24. Biomass boiler resized inline with counterfactual capacity, same change applied to segment **31**.
27. Load factor upper range increased from 60% to 82%, resized inline with the counterfactual. Same change made to segment **34**.

3.4 Solar Thermal cost model values and amendments

A number of consultation responses suggested that there should not be a cut off point for solar thermal above 100kW. AEA reviewed a number of data sources and consulted stakeholders to determine the typical applications of solar thermal in the scale above 100kW. There is limited UK activity in this sector at present with the greatest interest in the following applications:

- Heating for flats
- Swimming pools
- Hotels

The table below includes the addition of the cost segment above 100kW.

	Customer segment	Variable	Unit	Original values	2010 values
1	Domestic	Capital Cost	£/kW	1600	1600
2	Domestic	Opex	£/kW/year	17	17
3	Domestic	Size of installation	kW	3	3
4	Domestic	Efficiency	%	N/A	N/A
5	Domestic	Lifetime	Years	20	20
6	Domestic	Load Factor	%	8	8
7	Domestic	Total installed cost	£ '000s	4.5	4.5
8	Non-domestic	Capital Cost	£/kW	1350	1350
9	Non-domestic	Opex	£/kW/year	7	7
10	Non-domestic	Size of installation	kW	32	32
11	Non-domestic	Efficiency	%	N/A	N/A
12	Non-domestic	Lifetime	Years	20	20
13	Non-domestic	Load Factor	%	7	7
14	Non-domestic	Total installed cost	£ '000s	44	44
15	Medium Scale	Capital Cost	£/kW	N/A	**1170**
16	Medium Scale	Opex	£/kW/year	N/A	**7**
17	Medium Scale	Size of installation	kW	N/A	**150**
18	Medium Scale	Efficiency	%	N/A	N/A
19	Medium Scale	Lifetime	Years	N/A	**20**
20	Medium Scale	Load Factor	%	N/A	**8**
21	Medium Scale	Total installed cost	£ '000s	N/A	**175**

15. CAPEX of medium scale solar based upon an estimate provided by the stakeholders on UK installations. STA figures provided are for DH connected schemes.
16. OPEX, based upon estimate provided by stakeholders
17. Based upon information supplied by stakeholders. Range of typical UK installations is at present focussed upon 100-350kW with more towards the lower end of that scale with a typical size of 150kW.
19. Assumed same as for individual 32kW non-domestic schemes.
20. The assumed load factor is based upon the application type. The majority of installations in this size range are expected to be residential developments and hotels which will have a slightly higher load factor than commercial installations. Very limited information available from UK installations of this size. It is recommended that subject to further information about UK installations becoming available that the performance data and levels of support are revisited at the next review point.

3.5 Counterfactual changes

In addition to the renewable heat costs AEA also reviewed previous assumptions used on the conventional heating technologies.

The review resulted in three changes made to the counterfactual technologies since the original data review (2009).

1. The efficiency of oil boilers in the domestic and small commercial/public segments has been increased from 80% to 93%. This change reflects the use of condensing oil boilers rather than non-condensing boilers as was originally assumed. The updated efficiency figures were obtained from SEDBUK[10]. SEDBUK reports figures in GCV and based upon laboratory tests for seasonal performance. Assuming a reduction in performance of 5% but conversion to NCV the average boiler efficiency was calculated as 93%.
2. The counterfactual boiler efficiencies for medium/large commercial and industrial scale boilers (300kW and greater) have been amended to 90% for gas (down from 94%) and increased for oil to 89% (up from 80%).This amendment is consistent with values reported by the European Commission[11] (2007).
3. The lifetimes of industrial counterfactual boilers is increased from 15 to 20 years. Industrial boilers are typically better maintained than domestic and commercial boilers.

[10] www.sedbuk.com.
[11] http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2007:032:0183:0188:EN:PDF

4 Technology banding and tariffs

This section summarises by technology the views of AEA on the RHI banding and tariff structure based upon our technology knowledge and consultation responses. Following a review of typical domestic heat loads AEA recommend introducing a domestic band of 0-20kW for all technologies. Very few heat loads above this size will be domestic and if so their heat loads will be different to a typical house. Introducing a domestic band also accounts for the fact that non-domestic properties will experience different load factors.

Technology	Banding	Tariff levels
Biomass	AEA suggests that another band is introduced and that RHI tariffs are based on the following bands: • 0-20kW - Domestic • 0-200 kW – Non-domestic • 201 kW-1 MW – Non-domestic • 1 MW+ Non-domestic This structure is proposed as 200kW represents a generic threshold above which boilers tend to run on wood chips and below which generically on pellets[12]. In addition above 200kW the application type tends to be installations running with a higher load factor.	The individual tariffs for bands need to be selected to minimise the step changes. There is great variation in biomass project costs for a given size (which is generally valid due to site specific costs). AEA therefore recommended additional band minimises the step change and hence reduces the potential impact of 'gaming'.
ASHP	Introduce a domestic band of 0-20kW. As the technology is modular in size the increase in cost for larger installations is broadly linear.	It is recommended that tariffs are set with an assumed minimum threshold of seasonal performance factor of 2.9. Although there are currently no technical standards or guidelines for heat pump installers to follow the 2.9 seasonal performance factor is regarded as achievable by manufacturers.
GSHP	Revise the banding levels to: • 0-20kW Domestic • 0-100kW – Non-domestic • 100kW+ As described in section 3.2.1, there are additional costs for small non-domestic installations. These are from the site establishment costs and the smaller size of heat pumps modules that are used.	Given the significant discrepancy between the price of a 'slinky' vs 'borehole' system. AEA recommend that two separate tariffs are considered for slinky and borehole installations. Larger installations of above 100 kW will almost all be borehole due to space requirements for a horizontal system of this size.
Solar	Recommended that a band for medium/large scale solar of greater than 100 kW is introduced.	

[12] AEA recognise that there are a significant range in the applications of biomass boilers and fuel type by size. There is no clear line in the sand between which to differentiate a small and large installation, as such a generic approach based upon AEA's experience of the UK biomass market has been undertaken. AEA's experience draws upon industry knowledge and over 600 non domestic installations supported by the Bio-energy Capital Grants Scheme.

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