RHI Phase II – Technology Assumptions

Key Technical Assumptions for Selected Technologies

Report for Department of Energy Climate Change

AEA/R/ED57097
Issue Number 3
15th February 2012

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Appendices

1 Introduction

The following report contains the results of the data gathering and technology assessment carried out by AEA for DECC as part of the RHI Phase II project and used to inform the modelling work to be carried out by NERA. This work covers both non-domestic applications and domestic buildings.

2 Non-domestic Technologies

The key technologies that AEA were asked by DECC to review were:

- Large Biomass (direct air heating / kilns) – this was subsequently split into direct use of biomass and biomass direct air heating;
- Air to Air (ATA) heat pumps – limited to an assessment of usage patterns with respect to heating and cooling;
- Air to Water (ATW) heat pumps;
- Conversion of existing plant to renewable heat;
- Biogas > 200kW for heat.

Lower priorities included large solar thermal >200kWth, heat from waste (solid recovered fuel) and deep geothermal.

2.1 Biomass Conversion

Two key routes for biomass conversion have been considered. Firstly where boiler plant can be converted to biomass (by replacing the burner and modifying the boiler accordingly) and secondly where fossil fuel burners can be replaced with biomass burners as part of an industrial process (such as drying).

2.1.1 Boiler conversion

The focus of AEA's work was on conversion of conventional fossil fuel fired boiler plant to wood pellets. Conversion of boilers to bio-liquid has not been considered as DECC requested they should not be included.

2.1.1.1 Conversion of Conventional Boilers to burn Wood Chips

AEA were unable to find anyone currently offering products in the UK market place to enable conversion of conventional boiler plant to woodchip although it is understood that limited bespoke applications might exist[1]. Whilst this is technically possible, it would require a very dry fuel to enable effective combustion and result in a significant level of de-rating of the appliance likely to be unacceptable to the end user (due to the lower calorific value of the fuel). To allow combustion without a grate would also require a small particle size this could also result in poor combustion (lack of burn out of suspended particulates) and higher particulate emissions.

[1] A UK bio-energy company provided information to AEA after the completion of this study. They are looking at replacing the whole furnace of a rotary drier. This is a large application 15MW, with a specific capital cost of around £185/kW.

This is only likely to be feasible on large installations which are bespoke installations and very limited in numbers (this is the only project of this nature that AEA are aware of). The attraction particularly for this company was that this system would allow combustion of cheap biomass material (so whilst a higher capital cost per kW may be initially incurred compared with a pellet burner system, fuel costs will be much lower during the lifecycle of the system).

2.1.1.2 Conversion of Conventional Boilers to Biogas

Biogas conversion has been covered in the later section on biological biogas in boiler (Section 2.6.5), this considers the total cost of conversion to biogas including modifications/replacement of the burner (the burner costs are very small in comparison with capital cost associated with the digester plant).

2.1.1.3 Conversion of Conventional Boilers to Wood Pellet

There are very few companies that offer technology for conversion of boiler equipment to pellet fuel, and there are a number of issues associated with conversion of a boiler from a fossil fuel to a biomass fuel, these include:

- Boiler suitability for conversion – not all boilers can be converted to run on a pellet fuel (this is mainly due to the construction of the boiler, such as internal dimensions which affect the limit on flame length etc.)
- Ash removal – although pellet fuels do not produce large amounts of ash it still exceeds the quantities from oil and gas. Only coal boilers are designed for ash removal, other fossil boiler types may need the removal of the burner in order to manually remove ash.
- Boiler de-rating – conversion of a boiler to pellet leads to the de-rating of the boiler. The extent depends upon design.
- Spatial constraints – many existing fossil fuel boilers are installed in locations where there is not enough space to allow conversion to a pellet fuel. This is aggravated by the necessity in some cases to fit abatement equipment to remove dust.
- System life – As the conversion equipment is often being installed on existing plant which may be reaching the end of its useful life, in many cases it is more economic to replace the system with a new biomass system.
- Emissions – The emissions from a biomass system are dependent on both the burner and the boiler unit. This would make ensuring each installation meets the proposed emission limits difficult due to the number of permutations of boiler and burner units. It would also require each individual installation to undergo emissions testing before accreditation.

From the evidence gathered it seems that conversion of conventional fuel burners in boiler units is unlikely to occur unless they are coal fired systems. This is primarily due to ash removal issues (there have been some examples of conversion of oil systems to pellet in Ireland; this has not been particularly successful).

Although boiler conversion could be technically applied to large commercial and industrial hot water boilers in small numbers (there are few companies in the UK that offer boiler conversion technology), it should be noted that solid fuel use in the GB in the commercial sector represents less than 0.2% of fuel consumption (which includes coal systems) and therefore a very small proportion of the market place.

2.1.2 Burner Conversion for Direct Heat

The other route for conversion considered is where pellet systems are installed to replace gas, oil or coal fired systems where direct hot air is being provided to a process. The only market segments where this technology could be deployed are industrial large and small high temperature applications (this classification also includes drying processes).

When considering the market segments it has been assumed that electrical heating is required as part of an electro-chemical reaction or some other process related reason and therefore cannot be displaced by burner conversions – the category of industrial applications using electricity has therefore been set to unsuitable for modelling purposes..

2.1.2.1 Counterfactual Assumptions

It was assumed there is no counterfactual capex as the burner is being converted. The opex is assumed to be 2.5% of a burner cost for a 1MW burner (£9,100) this would be £0.23/kW, for a 50kW burner (£1,100) this would be £0.55/kW.

Setting the counterfactual efficiency will depend on the actual process and the exhaust temperature from the process. An efficiency of 90% (on a NCV basis) has been used based on experience from industries that have been reviewed as part of the EU ETS heat benchmark study carried out by AEA.

2.1.2.2 Key Technology Assumptions

Technology assumptions have been developed based on market data[2]. Whilst there is virtually no market at present, given an incentive we would expect new entrants from the established Swedish and Italian markets. In the longer term the technology may well develop to encompass recuperative systems that could increase the suitability. The key assumptions for burner conversion in large industrial high temperature market segment are presented in table 2-1.

2-1 Large industrial – High temperature

Characteristic	Key assumptions
Capex	• Capex estimate is based on a multiple unit size of 350kW – as multiple burners may be installed in industrial processes, with separate fuel feed and shared hoppers depending on the location of the burners on the plant. • Assumed 3 x 350kW units with one hopper. Capex £44/kW in rural and suburban environments. • Urban environments will require additional flue gas treatment equipment, with a total capex estimated at £77/kW
Opex	• Opex assumes that 2.5% of capex = £1.1/kW per year (Rural and Suburban) and £1.9/kW per year (Urban)
Efficiency	• 90% as per the counterfactual (discussed above).
Load factor	• Assumed process load factor of 60%.
Size	• 1,050kW (burners can be installed as modular units of 350kW units each).
Lifetime	• Burner lifespan of 15 years.
Space restriction	• It has been assumed that there will be some market restriction when considering space required – this will be for the pellet fuel storage and also integration of the fuel feed into existing process equipment which may be restrictive in some cases. This will be exacerbated in urban locations.
Heat grade and match to application	• It has been assumed that current applications are likely to be limited and dependant on the use of recuperative/regenerative burners (it is assumed that non-recuperative biomass burner units will not replace recuperative fossil fuelled burners) – also issues around using the burners to achieve the correct firing temperature and the contaminants in the combustion gases for example ash contamination of clays and pigments used in ceramics. It should also be considered that fossil fuel fired burners might be installed in combination with renewable burners, both supplying heat into a single process – this could be considered as co-firing.

[2] Limited information from the UK market for equipment at this scale was compared with data from Swedish suppliers of similar equipment via a web survey and found to be representative.

Environmental and other impacts	• It has been assumed that the proposed RHI biomass boiler emission limits will apply to conversions. To be consistent with boilers in rural and suburban areas it is assumed that emissions will not restrict deployment, whereas in urban locations it is considered that flue gas particulate abatement technology will be required.

The key assumptions for burner conversion in small industrial high temperature market segment are presented in Table 2-2. Technology assumptions and costs have been developed based on market data gathered from suppliers.

Table 2-2 Key assumptions small industrial high temperature

Characteristic	Key assumptions
Capex	• Capex estimate is based on a single unit size of 50kW for small applications. • Capex £224/kW - rural and suburban environments • Capex £364/kW - urban environments allowing for flue gas abatement technology.
Opex	• Opex assumes that 2.5% of capex = £5.6/kW per year (Rural and Suburban) and £9.1/kW per year (Urban)
Efficiency	• 90% as per the counterfactual (discussed above).
Load factor	• Assumed process load factor of 60%.
Size	• A size of 50kW has been selected these could be installed as modular units (multiple burners providing process heat).
Lifetime	• Assumed life span of 15 years.
Space restriction	• It has been assumed that there will be some market restriction when considering space required – this will be for the pellet fuel storage and also integration of the fuel feed into existing process equipment which may be restrictive in some cases. This will be exacerbated in urban locations (more so than larger sites which are less spatially constrained).
Heat grade and match to application	• Evidence suggests that the market for small direct heat will be niche, the evidence gathered shows the technology could be installed into applications such bakery ovens. The grade of heat achieved is therefore suitable for this type of application, as with large applications there may be issues with recuperative / regenerative equipment in some cases and issues around contaminants in the combustion gases. • As for larger systems, it should also be considered that fossil fuel fired burners might be installed in combination with renewable burners, both supplying heat into a single process – this could be considered as co-firing. The oven application appears to be available as systems that are 100% fired by biomass (without reliance on fossil burners).
Environmental and other impacts	• In rural and suburban areas it is assumed that emissions will not restrict technology deployment, in urban locations it is considered that flue gas abatement technology will be required.

2.2 Direct Use of Biomass

Direct use of biomass is limited to niche industrial applications such as cement, asphalts, lime and sand dryers where a feedstock is combusted directly as part of an industrial process. Our understanding is that biomass will be less suitable for other high temperature applications due to issues around firing temperature, contamination of the product and availability of efficient equipment.

The capital cost of this technology is low as much of the required capital equipment is already in place requiring only the addition of storage and feeders.

This application will be largely co-firing. Discussions with cement industry representatives (Mineral Products Association) indicated that it is very unlikely that kilns will switch to 100% biomass direct use, both for fuel security reasons (due to the amount of energy that would be required) and because the temperatures that are required for the process need to be carefully controlled (clinker production requires a temperature of 1450^{o}C ±50^{o}C). The temperatures that can be achieved using biomass will vary depending on the exact fuel type (moisture content etc.) and the system in which it is burnt.

A major element of industrial direct use of biomass is in the form of usage of waste (based on solid recovered fuel, SRF) for heat production via direct firing of waste to deliver heat for an industrial process. In the UK, this use of waste is most prevalent in the cement industry, where waste materials are used to displace fossil fuels in the calcination process. Many cement kilns are permitted to utilise a variety of waste materials including, tyres, MBM[3], sewage sludge pellets, Refuse Derived Fuel/Solid Recovered Fuel (of which a proportion of the fuel is considered biomass) and residual solvent waste.

Co-firing of biomass in the cement industry is also well established. In 2010 the cement industry used waste derived fuels for 38% (2.8TWh) of the energy input and 16% (1.2TWh) of the total was biomass in the waste, sludge pellets etc. Biomass feedstock is currently used in these applications on the basis that it is more economical to do so. RDF (with biomass content) will often be priced at a slightly lower price point than conventional feedstock making them more commercially attractive. The Mineral Products Association also stated that there was concern in the industry over the effect on feedstock prices if other end users are incentivised by the RHI as this might divert feedstock from the sector.

The industry also indicated that they buy the waste-derived fuel at a cost which is set by the fuel producer at a slightly lower rate than the reference fuel (i.e. they are not charging a gate fee). Table 2-3 identifies cement works situated in the UK with permission to operate utilising RDF/SRF fuel.

Table 2-3: UK Cement Works Permitted to Utilise RDF/SRF Waste Fuels

Scheme Name	Feedstock	Form of energy recovery	Waste Fuel Capacity [tonnes per annum]
Cement works 1	RDF	Direct Firing	c.70,000[4]
Cement works 2	RDF	Direct Firing	c.130,000
Cement works 3	RDF	Direct Firing	c.17,000
Cement works 4	SRF	Direct Firing	up to 250,000
Cement works 5	SRF	Direct Firing	c. 18,000

Waste materials have been able to penetrate this market largely due to the energy intensive nature of cement production together with the comparatively low retrofit costs for kilns to

[3] Meat and Bone Meal
[4] Denotes maximum capacity for the use of waste fuel based on environmental permit, actual utilisation rates will be dependent upon availability of fuel and may be less than this figure.

meet the Waste Incineration Directive (WID) due to the high-temperature nature of the calcination process.

AEA found no other examples of the direct use of waste in industrial processes other cement production, although we understand there may be applications in aggregate drying and lime calcination.

Following guidance from DECC during the RHI Phase II study, AEA and NERA were advised that co-firing was not to be included under the current RHI work.

2.3 Biomass Direct Air Heating

Direct warm air heating is used for heating large, open, industrial and commercial spaces such as workshops, warehouses, retail sheds, garden centres and sports centres, the market size is estimated at 8.5GW of installed capacity. The forced air method of heating provides a more rapid heat-up and an economic method of transferring adequate heat to the large volumes typical of these applications. Using conventional convective heat transfer methods such as radiators would require an extensive water distribution system and multiple radiators giving a cost that is often not justified by the low occupancy.

2.3.1.1 Counterfactual Assumptions

AEA has considered a single unit size for the small and large applications as current practice is to install multiple units where a larger heat load exists. It is assumed that the counterfactual case will be a warm air cabinet system operating on either gas or oil.

Counterfactual have been assumed as £35/kW with an O&M cost of 2.5%, annual efficiency of 91% based on ECA performance criteria. It is assumed that larger space heating loads will not be provided using electric heating units, as using oil or gas would be more cost effective, therefore an electric counterfactual has not been considered. In smaller locations it is assumed that electric system will be either providing radiant heat[5] or will not be replaced as they are much more compact.

2.3.1.2 Key Technology Assumptions

Table 2-4 shows key assumptions that have been used for biomass direct air heating; these have been derived based on discussions with manufacturers.

Table 2-4 Key assumptions for biomass direct air heating

Characteristic	Key assumptions
Capex	• Capex of £285/kW based on consultation responses, this includes the unit, fuel handling and hopper.
Opex	• Opex based on 2.5% of the capex.
Efficiency	• Efficiency 77% based on consultation responses.
Load factor	• Assumed the same heating load as a biomass boiler.
Size	• Size based on average size unit 200kW.
Lifetime	• Lifetime assumed to be 20 years.
Space restriction	• No specific space restrictions would be envisaged in industrial or large public or private sector applications in rural and suburban environments • Some space restrictions are likely to exist in urban locations.

[5] Radiant heating technology will not be replaced by direct air heating as they are used to provide direct radiant heat in specific locations (such as factories with high air change rates where it is not effective to use warm air technology).

Heat grade and match to application	• Within the warm air space heating segment considered, it provides a good match with the grade of heat necessary – all segments have been classed as having a high suitability.
Environmental and other impacts	• This type of technology will not be restricted by environmental sensitivity in rural areas; • Biomass direct air heating technology would be less suitable in suburban and urban environments. Feedback from installers was that automatic fed systems (opposed to batch fed equipment) would be capable of meeting the proposed RHI emission limits, AEA have not considered batch stoked system in this analysis.

2.4 ATW Heat Pumps Commercial

DECC received significant response from key heat pump manufacturers and suppliers as part of a call for evidence in May 2011. This call for evidence information was reviewed as part of this study and has helped form many of the assumptions for ATW and ATA commercial heat pumps. The commercial heat pump call for evidence illustrates that the heat pump industry is strongly supportive of commercial ATW systems receiving RHI support. Industry feels that without support the market will not reach its full potential.

The AEA approach has assumed good practice is followed in terms of heat pump selection and installation. As part of this approach to facilitate the ability of the heat pump system to achieve satisfactory seasonal performance factors AEA has included the cost differential of low temperature emitters for ATW heat pumps as part of the capex for older commercial buildings (commercial buildings which are either post 1990 or pre 1990 in the model segmentation).

The emitters were assumed to be fan convector units with an average installed cost derived from a building services pricing handbook.[6] The units were de-rated to compensate for the lower temperature of the heating circuit.

2.4.1.1 Key Technology Assumptions

Table 2-5 presents the key commercial ATW heat pump assumptions that have been derived based on the data collected from consultation responses and stakeholder engagement (as listed above).

Table 2-5 Key commercial ATW heat pump assumptions

Characteristic	Key assumptions
Capex	• Two reference technology sizes: 50kW @ £807/kW and 300kW @ £574/kW both of these costs include low temperature radiators/fan coils as a cost adder.
Opex	• £920 per annum or £19/kW per year. Based average of manufacturer responses (for 50kW system) • £1,250 per annum or £4.2/kW per year. Based upon average of manufacturer responses for 250kW and 350kW systems.
Efficiency	• 3.20 seasonal performance factor (efficiency of 320%), COP of heat pumps 4.13 (efficiency of 413%). Manufacturer evidence suggests there is no real change in efficiency as size increases
Load factor	• 35%, this also aligns with ATA and GSHP commercial load factors from previous RHI research.
Size	• 50kW and 300kW. To match previous model sizes. ATW commercial heat pumps are modular and typically can be sized to match the building heat

[6] SPON'S – Designers and Contractors Price Guide.

	demand. Up to 50kW modules are generally available at any 5kW interval i.e a 40 or 45kW module.
Lifetime	• 20 years
Space restriction	• Rural and sub-urban, no space restriction was identified. • Urban, some commercial premises may experience space restrictions
Heat grade and match to application	• May not be suitable for all of Post 1990 properties, new properties with better thermal insulation enable low temperature heat delivery • Pre 1990 commercial buildings likely to have worse thermal efficiency and therefore low temperature heating may not offer sufficient comfort. This means a more restricted market for these applications.
Environmental and other impacts	• Rural locations, no constraints on noise • Urban and sub-urban environments have restricted deployment due to concerns over noise. Permitted development rights and technical development will ameliorate this but there is a definite barrier that must be overcome.

2.5 ATA Heat Pumps Commercial

As outlined in section 2.4, significant information was provided by manufacturers as part of a call for evidence. This information was reviewed alongside existing modelling assumptions used previous studies 2009 and 2010.

2.5.1 Split between heating and cooling

AEA have spoken to manufacturer's regarding the market structure for heat pump reversible systems versus the chiller market. This discussion centred round whether there was much potential for the ATA reversible market to expand or whether specific barriers exist which prevent the ATA market expanding. The UK cooling market has changed quite significantly over the last 20 years with a shift from chiller systems to reversible ATA systems. However there is still a quite substantial chiller market. The current features of the UK cooling market are:

- Chillers are preferred over heat pumps on large construction projects where a significant volume of cooling is required, for example, shopping centres. These installations are therefore generally driven by functionality in terms of the provision of significant cooling capacity.
- The medium and small commercial market has become dominated by reversible ATA systems. Typically offices and schools are now generally installing reversible heat pump systems rather than chillers.

It was commented that the chiller market is gradually decreasing and that incentives may have the effect of shifting the capacity threshold between ATA reversible and chillers.

Discussions suggested that in general it is more economic to go for an ATA heat pump system over a chiller. However, there are a few exceptions to this rule. Larger shopping centres for example will typically install a chiller/ centralised boiler system then each unit will be supplied with heat and chilled water from this central plant. In this example a chiller will be the most suitable type of technology to install. However, it was commented that in many cases large department stores within such complexes would then commission a heat pump supplier to install a separate internal heating/cooling system.

Aside from the large scale situations normally an ASHP system will win over a chiller in terms of economics due to the much greater efficiency. Despite this and the significant track record of commercial ASHP some ignorance exists in the market place. Many people do not understand the difference. In some cases a hotel for example may have a chiller and is familiar with transporting water around the building rather than refrigerant. In such an example they may simply decide to replace the existing system with a like for like replacement. There is also some concern in the market place over refrigerant leaks (which some manufacturer's regard as over exaggerated).

2.5.1.1 Market view on incentives for the Commercial ATA sector

The industry call for evidence provided a useful insight to the views of manufacturers in relation to the commercial ATA market and whether this warranted support by government. In general manufacturers were not in favour of incentives for this market. The ability to deliver heat via a ventilation system naturally lends itself to the provision of heating and cooling. Some manufacturers believe that it is therefore important to consider the renewable contribution of cooling capable heat pumps. In manufacturer's experience the customer purchase decision is due to the cooling capability and therefore they do not believe reversible systems are a sensible market to incentivise.

As part of the industry consultation a number of manufacturers commented on the heating only (non-reversible) market size. This is at present extremely small as the May 2011 Call for Evidence established that no reliable information exists on the UK market size at present. The main manufacturers have very limited information on this market at present. However, it was commented that they expect the market size to grow in the future as building designers adapt their designs. It was felt that the market for heating only will be driven by incentives and product features.

2.5.1.2 Recommendations for ATA

AEA's view is that commercial reversible heating and cooling systems do not require subsidy as this is an established market c.£300 million per annum which represents 1 GW of capacity or 2.9 TWh pa.

The Phase 1 modelling used the costs and performance of commercial ATA systems as representative of all ASHP in the commercial sector. We felt this was an accurate assumption as there was no evidence to suggest that ATW would take a significant proportion of the commercial market. Since then we have seen a significant increase in the interest from manufacturers in targetting the boiler/ chiller market using the RHI as a competitive edge – hence new ATW segments have been added.

The growth projections from the manufacturers for ATW in the recent consultation are very ambitious and exceed our original estimates for all ASHP in phase 1. We therefore retained the original estimates for ATA and added the ATW with a 30% overlap which would assume they compete with each other for some of the market.

The commercial heating only segment will remain very small and introduce compliance risks such as modifying systems once installed to provide cooling.

2.5.1.3 Key Technology Assumptions

Commercial/Industrial ATA has already been included in previous modelling, Table 2-6 documents the changes to previous DECC and CCC assumptions.

Table 2-6 Key assumption changes for ATA commercial heat pumps

Characteristic	Key assumptions
Capex	• No change from previous assumptions
Opex	• No change from previous assumptions
Efficiency	• 320% seasonal efficiency or SPF of 3.2 based upon manufacturer data, COP of heat pumps 4.13 or efficiency of 413%. Other manufacturer evidence suggests there is no real change in efficiency as size increases
Load factor	• No change from previous assumptions
Size	• No change from previous assumptions
Lifetime	• No change from previous assumptions
Space restriction	• No space restrictions for any sectors
Heat grade and match to application	Consistency across all non-process heating segments to apply the following: • May not be suitable for all Post 1990 properties, new properties with better thermal insulation enable low temperature heat delivery • Pre 1990 commercial buildings likely to have worse thermal efficiency and therefore low temperature heating may not offer sufficient comfort – some restriction of market was applied. This means a restricted market for these applications.
Environmental and other impacts	• Rural locations, no constraints on noise or for industrial installations • Urban and sub-urban environments may have specific restrictions on noise particularly if located adjacent to residential dwellings (applied to commercial)

2.6 Biogas Heat >200kW

2.6.1 Approach to Biogas >200kW

Biogas has been considered as specific areas where the technology can be segmented, these are:

- Biological biogas – where the biogas is used and directly combusted using a burner for high temperature applications – such as in kilns. The size of biogas installations as well as other considerations means that lower temperature applications are more likely to use CHP systems than boiler-only systems (where this grade of heat can be supplied by heat recovery from a reciprocating engine). The SKM[7] work supports this assumption and shows very little uptake of heat only boiler installations. It will depend on the relative profitability of heat and electricity subsidy.

- Thermal biogas – where gasification is use to generate a synthetic gas which can be used in high temperature applications. These will be large applications 10MW+ gasification systems, there are none currently installed in the UK, and AEA would expect very limited deployment in the UK by 2020 (perhaps 3 units). These are likely

[7] SKM Enviros (2011) Report to DECC: Analysis of characteristics and growth assumptions regarding AD Biogas combustion for heat, electricity and transport and biomethane production and injection to the grid.

to be CHP applications utilising reciprocating engines, unless high grades of direct heat are required (direct firing) above the temperatures that can be provided from the CHP exhaust.

Therefore the focus of this work has been around biological biogas (from AD) in industry.

2.6.2 Existing Biological Biogas Market

Previously AEA reviewed 46 plants generating in 2010, 17 met the criteria for useful heat and could be classified as CHP, 16 were generating electricity only and 13 were generating heat only. No plants were generating significant quantities of biomethane for injection into the gas grid. The capacities and energy generation are summarised in the Table 2-7.

Table 2-7 Summary of electricity and heat production from AD schemes in 2010

Scheme type	Number of plant generating in 2010	Capacity, Mwe	Capacity, MWth	Electricity Generation, MWh	Estimated Heat Production, MWh	Estimated heat utilisation, MWh
CHP	17	19.23		60,680	65,240	38,403
Electricity	16	8.80		30,239	34,269	15,497
Heat	13	0	0.34	0	1,660	1,660
Total	**46**	**28.03**	**0.34**	**90,919**	**101,169**	**55,560**

The heat only schemes were small on-farm schemes, and it was assumed that all the heat they generated was utilised. For electricity only schemes there was insufficient evidence to define the heat as 'useful heat', but it was estimated that about 40% of the heat generated would be used for process heating including heating the digester. For CHP schemes evidence was found that some of the heat rejected from electricity generation could be defined as useful heat despite the main use being for heat treatment of digestate and feedstock and digester heating which would not be eligible.

2.6.3 Approach to Biological Biogas

It is assumed that AD plants could be installed at larger industrial sites to provide biogas for high temperature process use, this could take two forms:

1. Direct heat into an industrial process.
2. Firing biogas in a boiler to raise steam (it is recognised that these processes may wish to use biogas directly, as they might not have the requirement for low grade heat that would be generated by CHP with reciprocating engine).

To maintain consistency with the SKM report it is assumed that lower temperature applications in large scale industrial sites would use CHP (which is being considered outside this piece of work). This is based on SKM conclusions and our own observations from other project work. Clearly if the incentives drive in one direction this may change but power generation offers secure revenue and is insensitive to variation in demand from the heat consumer. It is not considered that there will be any small high temperature applications that would use this technology due to the mismatch between the physical size and cost of the digester equipment and the heat using equipment. For the same reason it is also very unlikely that there will be any implementation of this technology in commercial/public buildings.

2.6.4 Biological Biogas Direct Heat

2.6.4.1 Counterfactual Assumptions

The counterfactual for direct heat would be either an oil or gas burner; the efficiency of the process will depend on the temperature of operation of the specific process and may vary considerably. We have assumed that the efficiency will be 90% - i.e. 90% of the heat will be released into the furnace.

The opex is assumed to be 2.5% of capex per annum. It is assumed that high temperature electrical direct heating applications are used for electro-chemical or other highly specialised processes and therefore cannot be substituted with a different fuel source.

2.6.4.2 Key Technology Assumptions

Table 2-8 details the key assumptions that have been made for biogas direct heat, these assumptions have been based on the SKM Enviros study for DECC, internal AEA data, DECC consultation responses and specific manufacturers contacted for further information by AEA.

Table 2-8 Key assumptions for biogas direct heat >200kWth

Characteristic	Key Assumptions
Capex	• Capex estimate is based on AD costs from consultation documents – cost for a 3.64MW net (4.54MW gross) thermal plant is £2,361/kW – this includes: o Anaerobic digester plant costs. o An allowance for the burner units (although this cost is a very small element). o A system with the capability to utilise waste and has been taken from the SKM analysis. o The cost of a boiler to provide heat for the AD system (parasitic heat).
Opex	• Opex figure £121.1/kW per year (based on AEA data) this is between the reported SKM data and consultation responses that AEA reviewed.
Efficiency	• Efficiency is difficult to calculate as it will depend on the feedstock of the AD plant and solubility of the material being processed. The amount of gas produced will also vary significantly depending on feedstock and the heat required by the process dependant on the size of digester and if pasteurisation is required. Assuming that: o Typical volatile solids removal from a Stirred Tank Reactor treating a sewage sludge/refuse would be expected to be 50-60% of Volatile Solids in the feedstock (up to 90% VS removal can be achieved from waste which have a high solubility) o Biogas collection is assumed to be in the order of 98%. o Of the biogas then produced around assume that 11% of the biogas is used for heating the digester and pasteurisation – this is from the SKM report. o Burner efficiency as with the counterfactual is assumed to be 90% (this depend on the process, as all the fuel is converted into heat and released into the kiln and it depends on the remaining heat in the exhaust of the process) – 90% was thought to be an average value from information gathered by AEA. • Therefore an overall AD system efficiency is c.43.2%
Feedstock mix	• Based on consultation responses a feedstock mix of 50% food waste, 25% maize silage and 25% animal manures. This is suitable for a stirred tank system as covered by the capex and opex data. A balanced feedstock is necessary to prevent over acidification of the digester, which can happen where too much food is used. Variable feedstock may also be required to balance feedstock quantities supplied into the digester.

Load factor	• The load factor is assumed to be 90% - as the AD plant will operate continuously, there may be variation in biogas output depending on variation in the feedstock.
Size	• A size of 4.54MW thermal gross has been selected to align the analysis with the biomass system market segmentation – installation sizes will vary depending on application. This has been entered in to the data model as 3.64MW which is the Net output once digester and other parasitic heat have been removed.
Lifetime	• Typically a major overhaul would be required after 20 years; this might include repairs de-scaling of the digester – this is in line with SKM estimates from AD report.
Space restriction	• It is assumed for large industrial sites rural locations will not be spatially constrained and urban locations most spatially constrained with limited space for the digesters.
Heat grade and match to application	• Biogas can deliver a high grade of heat and burners can either be modified to burn biogas (typically there would be expected to be some de-rating when burning biogas, this can typically be overcome by modifying the gas train and burner) or specific biogas burners fitted. Biogas would also be expected to burn in a clean manner and can be operated with recuperative and regenerative combustion equipment. One potential limitation is that some high temperature applications will be using a batch firing process; this may limit the compatibility in some cases (or require a gas holder to store biogas between batch firing). As for larger process systems that might convert to biomass burners, it should also be considered that fossil burners might be installed in combination with renewable burners, both supplying heat into a single process – this could be considered as co-firing. The oven application appears to be available as systems that are 100% fired by biomass (without reliance on fossil burners).
Environmental and other impacts	• In rural locations it is assumed that there will be very few environmental restrictions; urban locations are likely to be most restricted with potential issues around vehicle movements and possible permitting issues (planning and environmental permitting).

2.6.5 Biological Biogas – High temperature heating – Combustion in boilers for steam

2.6.5.1 Counterfactual Assumptions

The counterfactual for direct heat would be either an oil or gas fired steam boiler; the efficiency of the boilers will be 89% for oil and 90% for gas (based on previous RHI assumptions for steam boilers).

The counterfactual opex is based on previous assumptions. It is assumed that high temperature electrical direct heating applications are used for electro-chemical or other highly specialised processes and therefore cannot be substituted with a different fuel source.

2.6.5.2 Key Technology Assumptions

Table 2-9 details the key assumptions that have been made for biogas combustion in boilers, these assumptions (as for biogas direct heat) were based on the SKM Enviros study for DECC, internal AEA data and DECC consultation responses.

Table 2-9 Key assumptions for biogas combustion in boilers >200kWth

Characteristic	Key Assumptions
Capex	• Capex estimate is based on AD costs from consultation documents – costs for a 3.64MW net (4.54MW gross) thermal plant is £2,361/kW – this

	includes: ○ Anaerobic digester plant costs. ○ An allowance for a steam boiler unit to provide process heat (this is also used to provide AD digester heat (via a heat exchanger)). ○ A system with the capability to utilise waste and has been taken from the SKM analysis.
Opex	• Opex figure £121.2/kW per year (based on AEA data) this is between the reported SKM data and consultation responses that AEA reviewed.
Efficiency	• Efficiency is difficult to calculate as it will depend on the feedstock of the AD plant and solubility of the material being processed. The amount of gas produced will also vary significantly depending on feedstock and the heat required by the process dependant on the size of digester and if pasteurisation is required. Assuming that: ○ Typical volatile solids removal from a Stirred Tank Reactor treating a sewage sludge/refuse would be expected to be 50-60% of Volatile Solids in the feedstock (up to 90% VS removal can be achieved from waste which have a high solubility) ○ Biogas collection is assumed to be in the order of 98%. ○ Of the biogas then produced around assume that 11% of the biogas is used for heating the digester and pasteurisation – this is from the SKM report. ○ A biogas steam boiler efficiency of 90% has been assumed – this is in line with previous assumptions for counterfactual assumptions for natural gas steam boilers (from RHI Phase 1). • Therefore an overall AD system efficiency is c.43.2%
Load factor	• The load factor is assumed to be 90% - as the AD plant will operated continuously, there might be the requirement for a gas holder for process that are batch firing process.
Size	• A size of 4.54MW thermal gross has been selected – installation sizes will vary depending on application. This has been entered in to the data model as 3.64MW which is the Net output once digester and other parasitic heat have been removed.
Lifetime	• Typically a major overhaul would be required after 20 years; this might include repairs de-scaling of the digester – this is in line with SKM estimates from AD report.
Space restriction	• Space restriction are not an issue for rural locations • Space restriction may be an issue for suburban location • Space restriction for Urban systems are likely to be an unsuitable as these locations with be more spatially constrained
Heat grade and match to application	• Biogas can be combusted in boilers to raise steam for industrial processes without any technical restrictions. Industrial process loads which utilise a batch process or have low load conditions over given period (such as a weekend) may be less suitable (or additional gas storage may be required).
Environmental and other impacts	• In rural locations it is assumed that there will be very few environmental restrictions; urban locations are likely to be most restricted with potential issues around vehicle movements and possible permitting issues (planning and environmental permitting).

2.7 Deep Geothermal

AEA contacted the REA and deep geothermal developers to gather evidence on geothermal heat. AEA has also reviewed the ARUP report[8].

[8] "Review of the generation costs and deployment potential of renewable electricity technologies in the UK" Arup for DECC.

There is only currently one plant in the UK (in Southampton), this provides hot water for district heating from the Sherwood Sandstone aquifer at 76°C from a depth of approximately 1,800 m. The estimated capacity of this geothermal project is 2.76MW_{th} and was constructed in 1987. In 2011 this project has received £200,000 funding from DECC to part fund the refit of the Southampton deep geothermal well.

DECC are also funding the following current projects:

- £500,000 to Keele University, to drill a 1.2km borehole to provide geothermal heat for their proposed sustainable campus
- £400,000 to a Newcastle/Durham University project to fund the drilling, hydraulic testing and geophysical logging of a 2km deep borehole at 'Science Central', a large development in central Newcastle.

AEA were informed that the likely approach to development of heat only plants would be development of large 6-7MW_{th} systems serving large public sites, such as hospitals or universities. It was suggested that schemes connected to district heating may be less likely due to the cost of district heating infrastructure.

It was suggested that the large initial heat only schemes would still require connection by heat transfer pipework from the drilling site/heat production site (this would not be expected to be at the same site due geological restrictions or spatially constraints).

Capital costs are highly variable depending on local geological constraints and specific project details (e.g. depth of boreholes required). It was also suggested that the cost of system should be reduced once initial projects are established; this may be in part due to better understanding of geology in a local area and also as drilling equipment is available in the UK (assuming some UK companies invest in this equipment).

The information collected during this project is presented below. It is understood that the number of projects will be very limited but significant in size (similar to thermal biogas).

Characteristic	Data collected
Capex	• Typical Capital costs (2 wells at 3.2 – 3.3Km) Estimated capacity 6-7MWth • £10m - Drilling costs • £550-600k – Logging/pumping tests – these are required to ascertain the heat yield and pumping rates that can be achieved before "break-through" and temperature drop of 0.5°C occurs, typically they expect an extraction rate between 40-50 litres/s. Note: drilling of the first well and this cost is all at risk, as financial close cannot be reached until this has been completed (£6-7m at risk) and it is understood how much heat can be extracted and over what time period. • £750,000 – re-injection, pumping equipment – this must be replaced every 5 years. • £2m – energy centre, civil works (typically underground as it is likely to be in an urban environment). • Contingency c.10-12%. • Total Cost: £14.6 million for 6-7MW_{th} at a specific capital cost £2,250/kW-£2,500/kW.
Opex	• 1% of the total capex would be expected to be enough to cover the

	fixed opex of a scheme – this would include replacement of the pumping and re-injection equipment every 5 years
Efficiency	• 99%
Load factor	• 55%
Size	• 6-7MW_{th}
Lifetime	• 20 years

Growth in the sector will be highly dependent on successful schemes being demonstrated in the UK. Assuming that maybe 4 could be realised, would give a range of heat provided in the order of between 0.22-0.55TWh in 2020 between a central and optimistic view.

2.8 Solar Thermal >200kW

Based on the previous work carried out by AEA and stakeholder engagement, there were found to be very few applications for large scale solar thermal technology >200kW_{th} that can be developed without connection with district heating system. From the review carried out by AEA have not come across any further evidence to suggest this has changed.

Without a heat distribution network it will be very difficult to justify such projects and as such that means there will be very limited application, if any by 2020.

2.9 Waste for Heat

The following forms of waste are utilised for the recovery of energy as heat:

- Municipal Solid Waste (MSW) arising from household and small commercial collections conducted by local authorities. Sometimes referred to as "black bag waste" this waste stream will have undergone little or no processing before energy recovery takes place.
- Commercial and Industrial (C&I) waste. Besides typical mixed wastes, this also includes streams of materials such as textiles, animal by-products and tyres. As with MSW, C&I wastes will have undergone minimal pre-processing before energy recovery takes place.
- Refuse-derived Fuel (RDF). Refers to waste that has undergone successive processing stages such as shredding, blending or drying to deliver a fuel with more uniform properties and greater usability than unprocessed waste. RDF can be used as a replacement for solid fossil fuels in industrial processes. RDFs are not standardised, allowing them to be customised for particular consumers but meaning that the properties of individual RDFs can vary significantly.
- Solid Recovered Fuel (SRF). SRF is a sub-set of RDF, defined in the UK as a fuel derived from non-hazardous waste that meets European standards[9] and criteria for particle size and biological activity. SRF is generally produced from MSW and/or C&I waste within a dedicated Mechanical-Biological Treatment (MBT) or Mechanical-Heat Treatment (MHT) facility. Production of SRF is expected to grow as local authorities develop MBT/MHT facilities as a means of diverting biological waste away from landfill.
- Treated Waste Wood, this is wood that has typically been recovered from C&I or Construction/ Demolition waste streams that has been treated with preservatives.

[9] CEN/TS 15359:2006

Facilities utilising the above waste feedstocks will need to comply with the EU Waste Incineration Directive[10] (WID). Compliance with WID requires that the facility meet certain plant design, operation and monitoring requirements to control environmental hazards specific to the thermal treatment of waste, such as the release of dioxins and furans into the environment.

Facilities utilising waste for the production of heat can be broadly divided into the following categories:

- Energy from Waste (EfW) facilities. These are plants that are fuelled exclusively by waste with the principal objective of recovering energy in the form of heat or power or both as in the case of CHP .
- Industrial processes directly utilising waste within a combustion-based production process.

Facilities using unprocessed waste materials (such as raw MSW) are generally able to charge the waste producer a gate fee for receiving and processing the waste material. Facilities using processed waste such as RDF or SRF can expect to receive much lower gate fees and in some cases expect to pay to receive this material but at a lower price than fossil or biomass fuel alternatives.

As a result, facility operators will have an incentive for the use of waste feedstocks in the form of lower fuel costs compared to fossil or biomass fuel alternatives. However, this will be countered by the additional cost of meeting more stringent environmental regulation in the form of the WID. These competing concerns mean that the argument for the use of waste feedstocks is strongest for large energy users and/or processes that are already subject to similar levels of environmental regulation, where WID compliance introduces limited additional cost.

In addition to direct firing of waste, waste may also be used for the production of heat for space heating or process use. A review of major EfW facilities in the UK conducted by AEA indicated that use of energy recovery from waste is dominated by recovery of energy as electrical power. This has been due to the relative ease with which electricity could be supplied to consumers via the national grid compared to exporting heat, which requires the development of dedicated distribution infrastructure. Even so, policy moves to optimise the amount of energy recovered from waste means that modern plants are generally configured to operate in a CHP mode.

Table 2-10: Current Existing and Proposed EfW and CHP/Heat Stations in the UK utilising Waste Feedstocks

Scheme Name	Feedstock	Form of energy recovery	Waste Fuel Capacity [tonnes per annum]
East London Sustainable Energy Facility, ELSEF (Proposed)	SRF	CHP	c. 90,000
Eastcroft Incinerator, Nottingham	MSW	CHP	160,000
INEOS Chlor, Runcorn	SRF/RDF	CHP	up to 750,000

[10] DIRECTIVE 2000/76/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 4 December 2000 on the incineration of waste

(Under construction)			
Sheffield Energy Recovery Facility	MSW	CHP	225,000
Shetland Heat Energy and Power	MSW and C&I waste	Heat-only	22,000
Slough Heat and Power	SRF/RDF	CHP	250,000

Table 2-10 above identifies major existing and proposed EfW CHP/Heat Stations generating heat in the UK. The review found that the majority of facilities identified generated heat in tandem with electrical power, operating as CHP. Only one facility identified (Shetland Heat Energy and Power) was found to generate only heat (where the lack of connection to the mainland electricity system means load balancing is difficult). As such, facilities producing heat indirectly from waste typically do so under CHP operation not heat only operation.

With the increasing availability of SRF expected in coming years there is speculation that SRF might serve as an alternative to virgin biomass in medium sized heat-only installations (e.g. medium scale industrial applications). AEA were unable to find any examples of this approach having been already adopted and, while such an approach may be viable in the future, it is not possible to project how this market might develop on the basis that there is limited historic information available on the appetite of operators to accepting the additional regulatory burden associated with WID compliance compared to operation using fossil fuels or biomass fuels. Furthermore UK SRF producers are currently focussing on securing supply contracts with large consumers (including those outside the UK) to meet SRF production capacity. It is expected that only as the market matures will producers seek to engage smaller consumers.

Evidence that where heat is generated from waste feedstocks this is either where waste directly fired for heat (e.g. cement production) or used within facilities operating as CHP. A review of facilities in the UK utilising waste for the production of heat revealed the presence of only one facility, located in Shetland, that combusted waste solely for the production of heat.

In light of the above, it is proposed that direct firing of waste be dealt with in conjunction with biomass direct firing. Beyond this, it is expected that the vast majority of heat from waste will be derived from CHP sources and that heat-only facilities will not form a major form of supply in the immediate future.

3 Domestic Technologies

The key domestic technologies that AEA were asked by DECC to review were:

- Renewable domestic technologies in new build
- Air to Air heat pumps
- Biomass stoves with back boilers

3.1 Domestic Air to Air (ATA) Air Source Heat Pump

3.1.1 Current deployment and market conditions

In Southern European countries such as Italy domestic air to air heat pumps are a major market driven by the need for cooling. This is in contrast to the UK where the commercial market is by far the dominant player and the domestic heat pump market is very small (BSRIA, 2010). Due to the infancy of the market, the manufacturers contacted by AEA did not have sufficient reliable information to comment on the market size. The domestic market as it exists is largely driven by the demand for air conditioning.

The UK domestic ATA market is driven by the high end residential market where there is a demand for comfort cooling. One major UK supplier commented that they do not actively promote the domestic ATA market as 90% of properties never require a cooling[11] load and therefore ATW systems are much more appropriate. AEA appreciate that this view is not necessarily representative of all UK suppliers and installers.

One example that differs from the more standard splits system is an internally wall mounted unit with ventilation holes drilled in the building exterior for air extraction and rejection. Such systems are not currently marketed or sold by the major manufacturers in the heat pump industry, who are somewhat sceptical of this technology solution due to the lower efficiencies reported for ”through the wall” systems. With this in mind we have not included this type of technology in the model as a separate technology nor modified any assumptions of cost or performance. We feel that it is more robust for modelling to use the split systems marketed by the major suppliers.

AEA’s research has found that the market has changed from previous studies and split systems with internal wall mounted units within habited rooms linked an external unit are more commonplace. This means that there is no physical restriction upon the size of property that could be heated by an ATA unit. This was confirmed by manufacturers.. This change is reflected in the revised suitability approach as shown in section 4 which does not rule out ATA systems being installed in larger domestic properties. However, AEA do not believe that the domestic ATA market will be particularly attractive to a large proportion of the domestic housing stock particularly given the prevalence of wet heating systems which are used in 84% of households. Electric heating systems are often installed due to the low purchase price compared to alternative heating options. Therefore take up in properties with electric heating will be restricted as if finance were no object they might upgrade to a wet heating system. A consumer with the capital to afford an ATA system to replace electric heating would therefore consider what other heating options (renewable or conventional) they could afford with their capital.

[11] All ATA heat pumps will be able to provide cooling. The cooling function could be disabled in the control panel which would represent no cost saving to the customer to have heating only. Due to the infancy of the market above there is very little data on the current market status of the technology in the UK. UK domestic properties generally do not require cooling and therefore this is a luxury market.

3.1.2 ATA heat pump performance

AEA reviewed information from a range of commercially available ATA systems. AEA reviewed eleven different products (of 3-4kW) for ATA single split heat pumps as part of the background research for this work. Across the eleven products from different leading manufacturers the average COP at A7 was 4.3.

Using the seasonal efficiency data[12] for commercial ATA heat pumps this was 0.9 lower than the rated COP. The modelling has assumed that the same ratio of rated to seasonal efficiency would also apply to the domestic sector. Therefore 0.9 has been deducted from the efficiencies to reach a seasonal average i.e. 4.3-0.9 = 3.4 (fuel efficiency of 340%).

The provision of hot water could be provided by an air to water heat pump, however it is more likely that an electric immersion heater will be installed to provide the domestic hot water requirements, this is rated with a COP of 1.0 (efficiency of 100%).

The calculation of seasonal COP was derived from the following equation:

$$\frac{\textit{Total heat demand (kWh/yr)}}{\textit{(Space heating demand (kWh/yr) / Space heating COP) + (Water heating demand (kWh/yr) / Hot water production COP)}}$$

Based on this calculation, and considering flow temperature of space heating circuit for different type of domestic market segments AEA have calculated the heat pump performance figures stated in Table 3-1. The range presented for each sector reflects the difference in heat loads between rural, suburban and urban heat loads.

Table 3-1 Air to Air Seasonal Performance

Sector	Space heating efficiency	Hot water production efficiency	Total Seasonal efficiency
New Build	340%	100%	170% -176%
Post 1990	340%	100%	178% - 244%
Pre-1990 cavity wall insulation	340%	100%	196% - 261%
Solid wall	340%	100%	217% - 275%

3.1.2.1 Counterfactual Assumptions

Counterfactual assumptions remain the same from previous AEA work on Phase I of the RHI for domestic market segments. These are given in Appendix 1.

3.1.2.2 Key Technology Assumptions

The key assumptions that have been derived based on communication with industry for domestic air to air heat pumps are presented in Table 3-2.

It should also be noted that the installed costs of an electric immersion heater have been included in the capex. Most heating systems with a hot water tank will be fitted with an immersion heater. We assumed that it would be installed at the same time as the heat pump. Although there could be some additional benefit (as typically an immersion heater would be installed with some heating systems), this would be expected to be negligible.

[12] Available at the time of research (late 2011), wider reporting of seasonal efficiencies is becoming available with the introduction of Eco-Design requirements.

Table 3-2 Key assumptions for domestic air to air heat pumps.

Characteristic	Key Assumptions
Capex	• £325/kW for smaller sizes up to 6kW – Average of 11 major manufacturer prices available from online retailers. This includes installation cost derived from SPON's price estimating guide. • £375/kW for 6-20kW reflecting need for multi-split installations differential between (smaller units, as outlined above) 5kW and 10kW unit c.a. £50/kW • To cover the production of domestic hot water, a total installed cost of £435 was added to flats (2kW immersion heater) and £560 to non-flat properties (3kW immersion heater). These costs are installed costs. • It is assumed that the potential removal of a wet heating system to accommodate an ATA system would be cost neutral given scrap value of the components.
Opex	• Fixed £52/annum based upon AEA estimates of information provided by a range of manufacturers.
Efficiency	• Based upon seasonal efficiency of 340% for space heating and 100% for electric immersion heater. Seasonal efficiency range is 170%-275% (SPF (1.7-2.75) dependent upon ratio of space heating to hot water requirements.
Load factor	• Technology sized for load factor between 10-21% - to align with previous research i.e UK heat supply curve and review of renewable heat technologies.
Size	• 3.5-20kW. The size is just that of the heat pump and does not count the immersion heater size.
Lifetime	• 20 years in common with all heat pumps as they use the same core components, No reason to change assumptions for heat pumps from AEA's 2010 report to DECC 'Review of renewable heat technologies'
Space restriction	• No identified space restrictions except for flats (this assumption has been made on typical ATA technology i.e. split models). • Some flats may be restricted from installation due to layout, assumed that heat pumps can be wall mounted on exterior or on balcony.
Heat grade and match to application	• No restriction for all flats with electric counterfactual- as ATA offers a straightforward technology substitution with no requirement for a wet heating system • No restriction for all new build properties as the technology can be easily specified from the outset and can easily provide small space heating loads • All segments with wet heating system would be regarded as being more restrictive, as this would need to be removed and could be regarded as a 'hassle' factor. • All segments that are non-new build are less attractive as the heat pump is likely to be larger and a wet heating system becomes more attractive. • Properties requiring a heat pump of 16kW or greater are considered to be most restricted, the high heat demand means a different technology is likely to be more suitable.
Environmental and other impacts	• No restrictions if the heat pump is 12kW or less (small heat load) and in rural location • Sub-urban or urban environments may face noise restrictions/planning requirements and therefore be more restricted (again 12kW or less). • If a large heat pump is required, greater than 16kW+ these proprieties are least suitable. With a heating demand of this size a wet system would be more appropriate, there are also risks that a 3 Phase connection may be required.

3.2 Domestic Air to water (ATW) Air Source Heat Pump

3.2.1 ATW heat pump performance

In order to consider the heat pump performance the heat distribution system connected to the heat pump must be considered (i.e. the type of emitters) as a whole. As such it was assumed that low temperature emitters would have to be installed to achieve good heat pump efficiency.

The standard COP criteria as reported by manufacturers is typically against the EN14511 standard test conditions i.e ambient air temperature of 7°C and a flow temperature of 35°C. To better reflect the conditions heat pumps may actually perform in situ AEA have considered the heat pumps COP at:

- Weighted average winter temperature conditions (for space heating), this was calculated to be 5.2°C (based upon the West Midlands as a coherent data set at the geographical centre of England and Wales). This is derived from the number of degree days in a specific month to provide a weighting factor which was multiplied by the average monthly temperature.
- Mean ambient temperatures (based upon Met Office data for the last twenty years) for the domestic hot water production. Mean temperature: 9.2°C
- Temperature flow conditions (dependent upon housing age). It was assumed that low temperature radiators would need to be installed to ensure a reasonable level of efficiency for all properties. The additional cost of the low temperature radiators £275/kW has been included in the cost data. These are based on average quoted prices for commonly available modern fan convectors plus an allowance for installation taken from a pricing handbook. It is unlikely that existing radiators designed for boiler system use would be suitable. It is possible in some circumstances depending on the extent of over sizing but as a modelling assumption it is safer to assume a change to make the achievement of the RED threshold secure.
- For each domestic market segmentation we have the total heat requirement which is composed of a varying proportion of domestic hot water production and space heating, this has been used to calculate the overall system performance.

Based on the above assumptions the seasonal COP figure was then calculated using the same formula described in section 3.1.2.

Based on this calculation, and considering flow temperature of space heating circuit for different type of domestic market segments AEA have calculated the heat pump performance figures stated in Table 3-3. The range presented for each sector reflects the difference in heat loads between rural, suburban and urban heat loads.

Table 3-3 Air to Water Seasonal Performance

Sector	Flow temperature °C (max)	Space heating efficiency	Hot water production efficiency	Total Seasonal efficiency
New Build	35	400%	240%	313-317%
Post 1990	45	350%	240%	298-325%
Pre-1990 cavity wall insulation	45	350%	240%	307-331%
Solid wall	45[13]	350%	240%	316-335%

As heat demands (space to water heating split) for each domestic sector vary, the seasonal performance figures for COP are affected, the significant hot water requirements of new build offsets the higher space heating COP.

The assumptions on emitter type and flow temperatures are broadly in line with MCS guidance for emitter selection.

3.2.1.1 Counterfactual Assumptions

Counterfactual assumptions remain the same from pervious AEA work on Phase I of the RHI for domestic market segments.

3.2.1.2 Key Technology Assumptions

The key assumptions that have been derived based on communication with industry for domestic air to water heat pumps are presented in Table 3-4.

Table 3-4 Key assumptions for domestic air to water heat pumps.

Characteristic	Key Assumptions
Capex	• Three different price brackets, less than 7kW= £965/kW), 10kW= £850/kW and >10kW=£650/kW- Correlation between responses 2011 and 2010 data from BSRIA via REA. • Low temperature radiators added to the cost £275/kW in order to achieve required efficiencies • Wet system conversion costs factor in substitution of conventional radiators with low temperature radiators.
Opex	• Fixed £52/annum based upon AEA estimates of information provided by a range of manufacturers.
Efficiency	• 298% to 335% depending upon building age and hot water/space heating split. Lower flow temperatures (35°C) used for new build. Higher efficiency for new build arises from the use of 35°C as the emitter temperature compared to 45°C for other properties. The efficiency takes into account the split of hot water versus space heating by segment.
Load factor	• Technology sized for load factor between 10-21% - to align with previous research i.e UK heat supply curve and review of renewable heat technologies.
Size	• 6-20kW: size range increased to reflect increased range of heat loads.

[13] This will not be realistically possible in many older solid wall properties. For example it would not tend to be recommended to install ATW heat pumps into domestic properties above 14kW. Other technologies would be better suited. To reflect this suitability of heat pumps into this category of property is lower.

Lifetime	• 20 years, no reason to change assumptions from 'Review of renewable heat technologies'
Space restriction	• No identified space restriction except for flats • Some flats may be restricted from installation due to layout, assumed that heat pumps can be wall mounted on exterior or on balcony.
Heat grade and match to application	• For all new build properties as the technology can be easily specified from the outset and provide small space heating loads at low temperature • For post 1990 and pre-1990 properties with cavity wall as these buildings have a reasonable level of thermal efficiency thereby allowing the heat pumps to run at lower temperatures and provide comfort. • Solid wall, heat losses are likely to be too high to operate at a reasonable degree of comfort and/or if heat pump is 16kW or greater. The suitability of a heat pump to the heat grade is low and other technologies may be better suited to this type of property unless substantial insulation works are carried out on the house's fabric.[14]
Environmental and other impacts	• If heat pump is 12kW or less (small heat loads) and in rural location there is no restriction. • Heat pumps less than 16kW, but located in a sub-urban or urban environment and therefore may face noise restrictions/planning requirements. • A large heat pump greater than 16kW+ it is likely more than a single outdoor unit will be required and there could be issues with the electricity connection.

3.3 Biomass Stoves with Back Boilers (BSBB)

Biomass stoves with back boilers can be split into two specific categories:

1. Log burning stoves with back boilers
2. Pellet burning stoves with back boilers

These are quite different pieces of equipment in the way they operate, pellet systems have control systems that control the mix of combustion air and fuel offering higher levels of automation and combustion control. Log systems are hand stoked in batches and rely on much high levels of manual intervention.

3.3.1 Current deployment and market conditions

3.3.1.1 Overall Stove Market

There is a buoyant stove market in the UK. The Stoves Industry Alliance suggested that the market had doubled over the last 5 years. Current estimates for **total stove sales** in the UK are c.160,000 -200,000 units/year (including multi-fuel appliances)[15]. The overwhelming majority of these are log burning stoves that heat only the room in which they are placed and have no boiler fitted. Stoves with boilers fitted are thought to represent some 10% of total sales.

HETAS estimate that the current population of stoves in general is 1 to 1.5 million each burning on average 1 dry tonne of wood per year. This indicates that sales are well in excess of stock replacement and increasing.

[14] Refurbishing Dwellings – A Summary of Best Practice, The Energy Saving Trust, Publication ref CE189
[15] This figure was corroborated by HETAS and includes stoves which are room heaters only and stoves fitted with back boilers. This also includes multi-fuel stove system which can burn coal as well as biomass fuels.

Anecdotally we understand that most manufacturers and distributors are working at full capacity to supply the demand. However a short review of European suppliers shows over a hundred brands which, with the simple nature of the products, would suggest there is little constraint in supply.

Overall deployment of stove equipment may be constrained by the capacity of the installer trades.

3.3.1.2 Biomass Stoves with back boilers (BSBB)

It is estimated from discussions with HETAS and distributers that around 1/3 of sales are wood-only appliances (with the other appliances able to burn both wood and other fuels such as coal). Further to this estimate, it was estimated that around c.10% of stoves sold are fitted with back boilers. Biomass Stoves with back boilers (BSBB) therefore has a current market of 16,000 – 20,000 units/year. The majority of this market would be expected to be log burning stoves with back boilers.

Wood usage for a BSBB would be higher than the average at say 3 dry tonnes per year giving approximately 1.5 TWh/year. As explained below most of this will be DHW.

Considering an average BSBB capacity of 18kW, this amounts to an installed capacity of 320MW/year (mostly log stoves with back boilers).

This level of sales and the increasing trajectory suggests that there could be a risk of the RHI subsidising log fuelled BSBB a technology that is already successful delivering 1.5TWh pa without incentives.

3.3.2 Market sectors

Typically boiler stoves fuelled by logs have outputs 12 - 30kW total with 3- 12kW as a space heating from the stove casing. The hot water temperature is comparable with fossil fuel boilers. This means they are suitable for most domestic properties.

BSBB are essentially conventional stoves modified to give some hot water output. This is done in a number of ways;

- A small heat exchanger clipped to the flue of a conventional stove, possibly a retrofit, capable of fulfilling the DHW needs of the property.
- A small heat exchanger more permanently incorporated around the flue.
- A heat exchanger fitted to the back of the combustion chamber.
- A heat exchanger surrounding the combustion chamber.

In AEA's expert opinion only the last option is capable of delivering sufficient output to supply whole house heating. We do not have information as to the proportion of each type sold.

Currently they are most popular in off gas network rural areas where the combination of ready access to wood and high and increasing heating oil prices make stoves generally a cost effective complement to an existing heating system. Boiler equipped stoves are a small part of this market.

3.3.3 Technical issues associated with the deployment of log fuelled BSBB

From the stakeholder engagement (Hetas, Stoves Industry Alliance (SIA), manufacturers, distributors and consultation responses supplied by DECC) we understand that there are a number of issues relevant to the inclusion of this technology in the RHI:

- **MCS accreditation** – feedback from manufacturer stakeholders is that the cost of gaining MCS approval for log fuelled BSBB and log stove units in general is commercially prohibitive. However, it is possible that a sufficiently high tariff level could overcome this barrier (although the stakeholders we talked to were sceptical of this).
- **Emissions and air quality impacts** – there are likely to be issues with the meeting the proposed RHI emission limits (NOx = 150g/GJ; Dust = 30g/GJ) for all log fuelled BSBB appliances. To define this problem further AEA carried out a review of the emissions performance of recent (2010/11) CAA-exemption applications for stove and similar appliances. This analysis found that, of 103 stove appliances, only 10% would meet the particulate emission limits that have been proposed (30g/GJ) under the RHI at full load operating conditions. The appliances reviewed do not necessarily have back boilers, but in our expert opinion all will exhibit combustion under the same conditions – i.e. manually controlled, batch-fed, natural draught - and are therefore representative. Log stoves are in contrast to pellet fuelled stoves which generally meet the RHI air quality thresholds.

  Testing coordinated by IEA Task 32 has shown that emissions immediately following fuelling can be an order of magnitude greater than mid cycle. User behaviour also has a major impact.

  The batch fed nature of the combustion makes it extremely difficult to impose abatement equipment on the flue because of the variation of the nature of the emissions through the burning cycle from loading to de-ashing. As a result AEA is not aware of any commercially available equipment. Some filters are being trialled in Germany but have not reached the market as yet.

  Further information on this topic can be found in the LACORS handbook for local authorities.[16]
- **GHG emissions**. Stakeholders have argued that reduced embodied energy should be factored into GHG emission calculations. Based on AEA's work in developing the BEAT model for EA and Defra we can say that there is no doubt that local fuel supplies would have a lower carbon footprint than nationally traded fuels. However the footprint for biomass generally is low so any benefit from local sourcing is marginal. There is a counter argument that the increased levels of nitrogen oxides and unburned organic material resulting from the use of BSBB would negate this but it is difficult to quantify and as stated the effect is marginal.
- **Multi-fuel stoves** – most log fuelled appliances on sale in the UK are available as multi-fuel versions (able to burn other fuels such as coal) and wood only. The difference is in the design of the fire grate – coal requires a mechanism to agitate the grate bars and remove the much larger quantity of ash. The difference in cost is minimal (approximately £100 - £200) and many choose the multi-fuel option for fuel security (costs are discussed in the section below). To prevent fraud multi-fuel systems could be excluded but multi-fuel grates can also be fitted retrospectively which would make policing of any exclusion very difficult. The alternative to exclusion would be direct monitoring (e.g., a requirement to send fuel receipts when claiming the RHI). Both alternatives would be very difficult to administer in practice.

[16] New Guidance for Councils on Biomass and Air Quality. LACORS 2010, http://www.lacors.gov.uk/lacors/NewsArticleDetails.aspx?id=21913

Wood pellet fuelled stoves with or without a back boiler are unsuitable for use with any fuel other than the grade of wood pellets specified by the manufacturer and so do not have the complication in compliance of multi-fuel operation.

- **Primary heat source –** it is difficult for a stove to be the primary heat source with no dependence on a secondary source of heat, for the principal reason that water heating must be provided also during summer when the space heating output from the stove casing is not needed. Additional space heating may also be required if the house is not occupied over winter periods, as the majority of stoves require some frequent manual intervention. As a result it is inevitable that users will fit a secondary heat source. This can be a simple immersion heater for summer hot water or the retention of an existing oil boiler. Where a boiler is retained heat can be lost through the stove flue. The retention of a boiler makes "deeming" an unreliable method of estimating output as it is impossible to know how the heat is sourced. These problems are in common with biomass boilers but are made more difficult by the complication of the space heating from the casing of the stove.

  Hot water represents approximately 25% of the total heat demand and summer use approximately half of this. The quality of heat is not in itself the problem but rather the necessity for an auxiliary.

  These issues introduce complications when considering implementation of RHI payments for BSBB. DECC would need to define how much heat output from a renewable energy system would constitute a primary heat source when considering if a BSBB can be classed as a primary heat source.

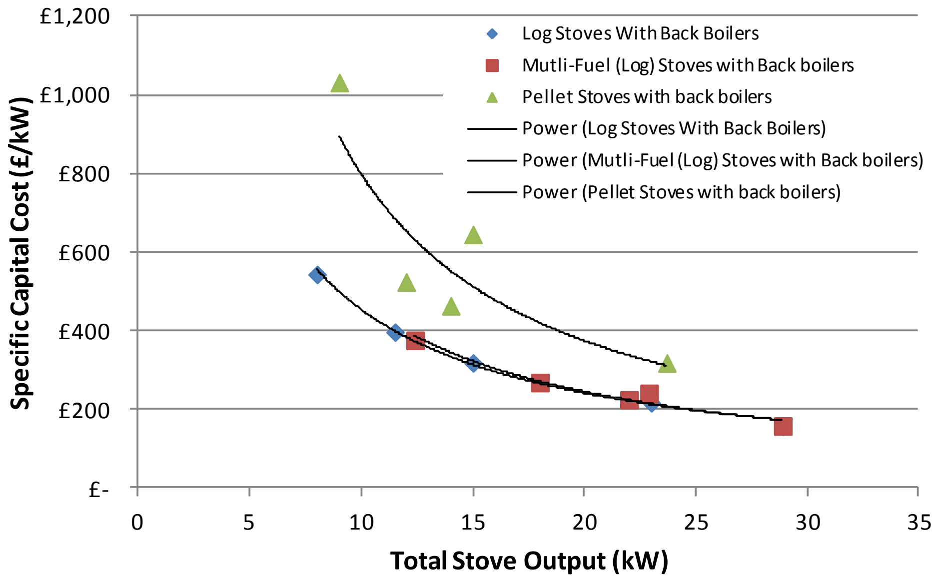
- **Costs** - AEA has surveyed prices for a several models and found them to be extremely variable, depending more on aesthetic appeal than output. Should these units be included then we have carried out analysis to determine a reasonable cost and have installation costs provided by HETAS.

3.3.4 Wood Pellet fuelled boiler stoves may be more suitable

There are only 5 pellet stoves that have been tested for CAA exemption which we have data for, but all of these would meet the proposed emissions requirements easily at full load conditions.

Therefore, one potential approach to support stoves with back boilers would be support pellet fuelled appliances under the biomass boilers tariff for domestic properties. From a previous review of pellet stoves with back boilers by AEA the costs were found to be in the order of £850/kW for an 8kW unit, these costs fall steeply and a 15kW unit might be expected to cost around £500/kW as depicted in Figure 4-1. This cost is slightly higher than equivalent cost for an 8kW biomass system which is around £633/kW.

Figure 3-1 Biomass stoves with back-boiler costs (pellet, log and multi-fuel)



However pellet stove with back boiler pricing is very variable and shows little correlation with size (as shown in Figure 4-1). The aesthetic appeal and reputation of the manufacturer seem to be more important. In view of this we suggest it would be acceptable if such equipment received the same level of support as a biomass boiler at the same output with the consumer paying the premium for aesthetic value.

On the basis of the above biomass pellet boiler stoves can be considered as biomass boilers for the purposes of modelling but some modification to the wording of the description in the legislation will be needed to include pellet boiler stoves.

The cost of log stove systems can be seen to be substantially lower with a cost of £425/kW for an 8kW system and costs around £200/kW for larger systems. The cost of multi-fuel systems is marginally more than that of log only systems. This would indicate if log systems were to be supported a separate tariff is likely to be needed.

3.4 New Build

Following the review of new build domestic heat loads, AEA have considered the application of a range of renewable technologies to the new build market:

- Biomass boilers
- Solar Thermal
- ATA heat pumps
- ATW heat pumps
- Ground Source heat pumps (GSHP).

As part of this work AEA has reviewed the cost of different technologies, appropriate size of the technology, operating costs and suitability to the new build segment. The following tables set out where new assumptions have been made, assumptions for ATA and ATW systems are described in the previous sections.

Domestic Biomass (already included in previous modelling, table documents the changes to previous DECC and CCC assumptions)

Characteristic	Key Assumptions
Capex	• Assume the same specific cost for CAPEX biomass systems. It is assumed that there will be limited cost reduction for new build properties and it is

	unlikely that biomass system will be bought in bulk by developers.
Opex	• Opex figures adjusted as required for different biomass system sizes.
Efficiency	• No change from previous assumptions
Load factor	• Load factors have been adjusted to meet the new domestic heat load
Size	• New sizing created for new build and also solid wall properties – aimed for a target capacity factor of 20%. In some cases the biomass boiler size is limited by available technology, smallest technology available is assumed at 8kW (new build).
Lifetime	• No change from previous assumptions
Space restriction	• Flats assumed not suitable, they would need to have community or district heating. • Urban detached and also suburban semi-detached assumed to be more spatially constrained. • All other domestic building types assumed to be not spatially constrained.
Heat grade and match to application	• Properties that are electrically heated are less suitable as they will need a new wet heating system. • All other properties can have biomass integrated into the wet heating systems.
Environmental and other impacts	• Assumption left as they are from the previous RHI analysis. • Semi-detached / terraced properties excluded due to air quality concerns in urban areas only.

Domestic Ground Source Heat Pumps (already included in previous modelling, table documents the changes to previous DECC and CCC assumptions)

Characteristic	Key Assumptions
Capex	• As per original DECC 2010 figures –with 15% reduction on CAPEX due to cheaper drilling costs of installing multiple GSHPs in a housing development. This follows discussions with manufacturers and is based on the cost savings achievable from, having drilling rigs and contractors on site. A recent quote for a ground source system also provided to AEA confirms this assumption.
Opex	• As per 2010 'Review Technical Information on Renewable Heat Technologies'.
Efficiency	• Heat pump efficiency updated based on calculated SPF values. 329-363%. This assumes different space heating and hot water production efficiencies.
Load factor	• Adjusted to meet the heat requirements required for different building types
Size	• No change from previous assumptions, new build selected based on the available technology size.
Lifetime	• No change from previous assumptions
Space restriction	• Flats have been assumed as zero suitability as they are likely to part of a community heating system. Physical connections to each flat from the ground loop would be impractical.
Heat grade and match to application	• Selected based on the likely heating system that is currently installed and current emitter temperature.
Environmental and other	• No specific environmental constraints for different domestic sectors.

impacts	

Domestic Air Source Heat Pumps Air to Water (already included in previous modelling, table documents the changes to previous DECC and CCC assumptions)

Characteristic	Key Assumptions
Capex	• 10% reduction in Capex compared to retrofit . This reflects a facilitation of the installation, possible discounts from having other contractors on site and ordering in bulk.
Opex	• As per 2010 'Review Technical Information on Renewable Heat Technologies'.
Efficiency	• Heat pump efficiency updated based on calculated SP efficiency values 313-317% (SPF 3.13- 3.17). The range reflects only the variation in the model segments and the different emitters used not the range of equipment available on the market. • We do not use EST field trial figures, although we have reviewed them. This is because they represent early stage installations rather than those we would expect to see under the RHI when the lessons have been learned. • This assumes different space heating and hot water production efficiencies.
Load factor	• Adjusted to meet the heat requirements required for different building types
Size	• No change from previous assumptions, new build selected based on the available technology size – size for new build 6kW.
Lifetime	• No change from previous assumptions
Space restriction	• No identified space restriction except for flats, some flats may be restricted from installation due to layout, assumed that heat pumps can be wall mounted on exterior or on balcony.
Heat grade and match to application	• For all new build properties as the technology can be easily specified from the outset and provide small space heating loads at low temperature
Environmental and other impacts	• No restriction if heat pump is 12kW or less (small heat load), this is the case for all new build properties in urban areas. Some restrictions in a sub-urban or urban environment and therefore may face noise restrictions/planning requirements.

Domestic Air Source Heat Pumps (Air to Air) (already included in previous modelling, table documents the changes to previous DECC and CCC assumptions)

Characteristic	Key Assumptions
Capex	• 10% reduction in Capex compared to retrofit (see This reflects a facilitation of the installation, possible discounts from having other contractors on site and ordering in bulk. Remaining CAPEX is the same as for retrofit installations.
Opex	• As per 2010 'Review Technical Information on Renewable Heat Technologies'.
Efficiency	• Heat pump efficiency updated based on calculated SPF values. 170-176%. This assumes different space heating and hot water production efficiencies. Hot water production is assumed to be provided by an electric immersion heater.
Load factor	• Adjusted to meet the heat requirements required for different building types

Size	• Size 3.5kW and 6kW depending upon space heating requirement.
Lifetime	• 20 years
Space restriction	• No identified space restriction except for flats • Some flats may be restricted from installation due to layout, assumed that heat pumps can be wall mounted on exterior or on balcony.
Heat grade and match to application	• No restriction for all flats with electric counterfactual- as ATA offers a straightforward technology substitution with no requirement for a wet heating system • No restriction for all new build properties as the technology can be easily specified from the outset and can easily provide small space heating loads • All segments with wet heating system would be regarded as being more restrictive, as this would need to be removed and could be regarded as a 'hassle' factor.
Environmental and other impacts	• No restrictions if the heat pump is 12kW or less (small heat load) and in rural location • Sub-urban or urban environments may face noise restrictions/planning requirements and therefore be more restricted (again 12kW or less).

Solar Thermal (already included in previous modelling, table documents the changes to previous DECC and CCC assumptions)

Characteristic	Key Assumptions
Capex	• Capex figures are per original DECC figures – a 10% cost reduction has been applied on the basis of cost savings from bulk discounts and also savings of installing at the time of construction.
Opex	• As per original DECC figures
Efficiency	• Heat pump efficiency updated based on calculated SPF values.
Load factor	• 7% as used in previous modelling for CCC and DECC
Size	• No change from previous assumptions, new build selected based on the available technology size.
Lifetime	• No change from previous assumptions
Space restriction	• Flats have been assumed as zero suitability as they are likely to part of a community heating system. Some may have their own system, uptake likely to be very small.
Heat grade and match to application	• Suitability as per original DECC work.
Environmental and other impacts	• No specific environmental constraints for different domestic sectors.

4 Suitability and technical potential

To maintain consistency of approach the methodology used was the same as in the recent project for the Committee on Climate Change, CCC. The description from the final report[17] is reproduced below.

Following this extract we give a description of changes that have been made for this work and the results of an examination of data carried out to gain insight into the impact of the various ways of deriving a single figure for use as a measure of suitability for modelling.

In assessing the suitability of low-carbon heat technologies for different end-user applications we have grouped constraints into three categories;

- ***Physical space**: the space required for installation of the primary elements such as boiler and fuel store, solar panels, ground coils, thermal storage, etc. as well as feasibility of taking fuel deliveries.*
- ***Heat grade:** the match of the heat grade available from the technology to the application. For example, low temperature heat from a heat pump is not suitable for a high temperature industrial application, and heat pumps also are unlikely to provide sufficient heat output for large domestic loads (notably, uninsulated dwellings).*
- ***Other factors**: the most relevant considerations are environmental factors, including air quality limitations and noise in urban environments.*

We have assessed each of the technology and end-user combination, awarding a grade of 0, 1, 2, or 3 to represent unsuitable, low, medium and high suitability, respectively, to each of the above categories. We then combine the three assessments to determine a final suitability rating, discussed in more detail below.

4.1.1.1. ***Assumptions for the physical space factor***

Space limitations are particularly important in the domestic sector. We have applied the following principles:

- *Flats often are too small to fit individual low-carbon heat installations. A more realistic assessment of potential is to consider the potential for communal heating equipment.*
- *Volume (e.g., the smaller area available to fit collectors or external heat pump parts).*
- *Urban and suburban domestic properties heated by biomass have reduced suitability to reflect the requirement for fuel storage and delivery. Rural properties are not thought to present a problem.*
- *Off grid properties are assumed to have more space than those on the gas grid irrespective of their location. In practice most are in rural areas where space is less likely to be a problem.*
- *Suitability of smaller properties (flats, terrace and semis) that use technologies with storage is reduced compared to the same technology without storage, reflecting the substantial footprint for the water accumulator.*
- *To reflect the difficulty of locating ground loops, ground source heat pumps are excluded from urban smaller properties, except for new build where it is assumed some form of provision can be made at design stage. Larger properties are allowed but have reduced suitability as they are assumed able make allowance within the boundaries of the premises.*
- *Industrial sites are assumed to have more space available than domestic or commercial and we assume that space will not be a limitation for any technology.*

[17] Low Carbon Heat Scenarios for the 2020's, NERA and AEA, 2010. Available from www.theccc.org.uk

4.1.1.2. ***Assumptions for the heat grade factor***

We have assessed primary heating systems, rather than secondary or complementary heating options. For example, heat pumps used to supply combustion air preheat for furnaces are not included in the assessment, nor are small air-to-air split heat pump units that provide occasional heating and cooling for domestic or small commercial premises. (See below for a discussion of air-to-air heat pumps).

The starting point for the assessment is a consideration of the ability of the existing system to accept the new heat generation technology. Thus only combustion systems are suitable for high temperature applications, and heat pumps are less suitable in dwellings with high heat losses.

Other principles used for the assessment include:

- *Replacing electricity is always assumed to be more difficult than other fuels. This is because electricity is usually selected for some specific technical or economic factor in spite of its very high cost. Substituting for this factor may be more complex than replacing oil or gas.*
- *New build has much lower heat demand than existing buildings. We assume that building regulations require incorporation of renewables. Both these factors tend to increase the suitability (the impact of FiTs and drive for electricity over heat has not been considered here).*
- *Older properties are less suitable for low temperature sources as they require large outputs into conventional radiator systems. In particular, heat pumps may not be able to respond adequately to low temperatures, with a resulting loss in comfort. We assume that heat pumps are unsuitable for uninsulated dwellings, but can be used in a proportion of insulated homes.*
- *Air-to-Air heat pump systems are assumed to operate through whole house ventilation systems(we assumed that some form of air management system would be necessary to move heat around the house to avoid uncomfortable gradients. We have subsequently revised this after speaking to industry to allow multi split refrigerant flow systems). This makes them unsuitable in older domestic properties where such systems are difficult to implement and would in any case be unable to carry the volume of heat necessary.*
- *Heat pumps of all types are assumed to be unsuitable for all process heat applications as they cannot provide adequate temperature[18]. There are some exceptions to this, such as the drying of confectionary, but we assume these are not significant enough to influence the outcome of the model and can be disregarded.*

4.1.1.3. Assumptions for environmental factors

The environmental factors we have considered include impacts on air quality and noise pollution.

Individual biomass boilers are excluded from terraced and semi-detached houses in urban areas as a proxy for air quality concerns. Larger properties and flats (treated as blocks) are allowed, as pollution abatement should be possible.

[18] There are undoubtedly some applications that require less than the 45°C that would bring HP into RED but we feel for the purposes of modelling they are so few that we can exclude them. Many industrial sites have an abundance of this grade of heat which is typically rejected from cooling processes.

Urban domestic properties are assumed to be less suitable for ASHP due to external noise. Commercial and industrial applications are assumed to be capable of mitigating noise to the point where it does not reduce the suitability.

4.1.2. Implications for the Potential for Low-Carbon Heat

To assess the implications of the suitability analysis for the potential for low-carbon heat we aggregated the three suitability scores in each segment to represent a share of the total heat load in the segment that could be served by the technology. We have used a number of different rules for this, to produce different scenarios for suitability.

First, in all scenarios, a zero in any category takes precedence and the application is marked as unsuitable for the technology. For the individual scenarios, we apply the following algorithms:

- ***Low scenario**: The overall suitability is determined by the lowest score of the three factors. This means that the highest hurdle determines the suitability and could be seen as a pessimistic assessment.*
- ***High scenario**: The overall suitability is determined by the average of the three factors. The assumption in this case is that favourable circumstances for one or two of the factors can help overcome difficulties on other dimensions. This is likely to be an optimistic assessment.*
- ***Central scenario**: This scenario falls between the low and high scenario, calculating a weighted average by attaching twice as much weight to the factor with the lowest score as to the other two factors.*

Once we have calculated the values as described, we interpret the result as the proportion of heat load in each demand segment that can be served by each technology. We apply these proportions to the heat load projections outlined in section 2, and this yields the technical potential for individual low-carbon heat technologies.

4.1 Additional work for this project

We developed sets of suitability scores for each of the new technologies introduced in this work according to the methodology above and these are described in the appropriate technology sections of this report.

In this work we also considered an additional “very low” scenario where each of the constraints represented by the suitability scores was considered to act in series i.e. the potential was reduced successively by each constraint. This was constructed by multiplying the scores, dividing by 9 and expressing as a percentage. This method is typical of modelling work in other areas in established markets carried out by AEA. This is likely to represent the lowest probability, i.e. the worst case scenario.

4.1.1 Qualitative examination of the impact of the scenarios on potentials

To gain some insight into the impact on the potential of the various scenarios we compared the largest segments in the domestic, commercial and industrial sectors and prepared a qualitative commentary which is given below.

Tables of fifteen of the largest heat load segments in each sector are given by Tables 4-1 to 4-3.

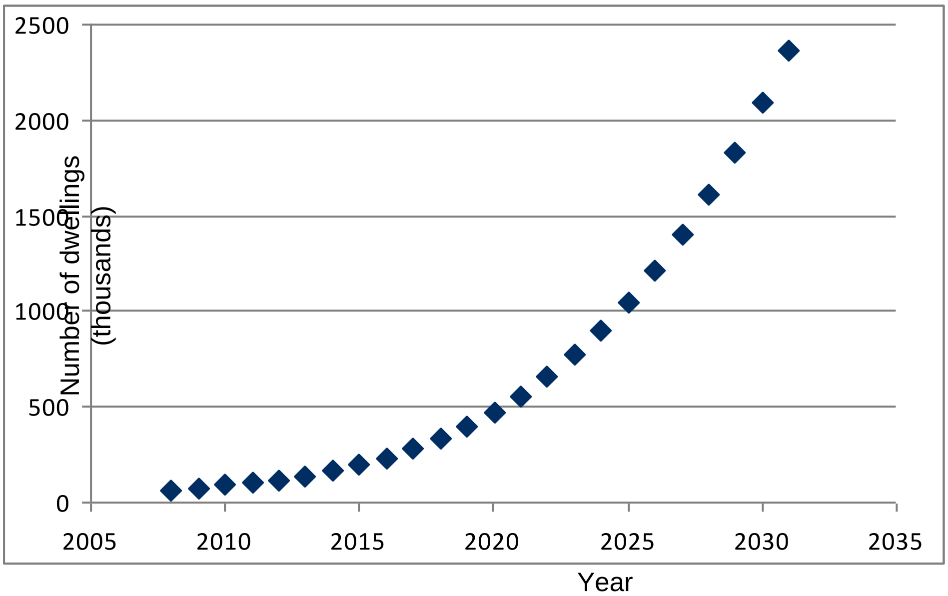
4.1.1.1 Domestic

The largest heat demands are in domestic, gas, other houses, Pre 1990 and dwellings with solid wall insulation (SWI). Both the “very Low” and the “Low” scenarios restrict the demand for heat pumps quite severely, particularly for GSHP in suburban and urban areas which is to be expected. The “very Low” scenario is very restrictive (down to 11% in some cases) however and has an impact that whilst probably correct today intuitively seems too large for 2020 and 2030 when other measures will have been taken and technology will have advanced. The “Low” scenario seems a better measure but may be an overestimate of the current situation as the minimum score is 33% due to the 1, 2, 3 scoring. The “High” scenario gives potential that seem unrealistically high, particularly for heat pumps. On balance “Low” seems to be the most appropriate. If extensive measures were taken to increase the rate of insulation take up, education, refurbishment programmes etc then it may be possible to increase the potential to the central scenario.

4.1.1.2 Heat pumps and Sold Wall Insulation (SWI)

The growth in the uptake of solid wall insulation is a key factor in suitability for heat pumps in older houses. Current uptake of insulation is very low at 102,000 houses (DECC domestic energy use stats). If we assume an ambitious rate of uptake of 20% increase per annum falling progressively to zero in 2050 at full replacement then we would expect to get 2 - 2.5 million properties by 2030 or a little under 1/3 of the potential which is somewhat less than the “Low” score for SWI with heat pumps. The “very Low” however probably restricts the potential more than is reasonable over the period.

Figure 4-1 *Estimated growth of dwellings with solid wall insulation installed until 2030.*



4.1.1.3 Commercial

The largest commercial demands are pre 1990 in urban and suburban areas. The “Very Low” scenario is extremely harsh on HPs especially GSHPs in urban areas where intuitively we know that the suitability is higher because of the availability of car parks etc and the demand for summer cooling improves the attractiveness of heat pumps. We feel the “Low” scenario or “central” scenarios give a better indication here. As with the domestic sector the high index gives an unreasonably high estimate for heat pumps given the multiple barriers.

Solar is also restricted severely by the “Very Low” index and intuitively there should be more than this suggests even if the match to the heat load is not ideal in many circumstances. The “Low or Central” scenarios seem the most appropriate.

The model has relatively little granularity in the commercial sector. We are aware that there is a wide range of building types and occupancy and these will have a large effect so any assessment is necessarily very qualitative and based on AEA experience.

4.1.1.4 Industrial

The largest loads in the industrial sectors are all rural and all process heat - both low and high temperature. All scenarios are in agreement with a substantial but reasonable restriction in demand for high temperature process heat with the “High" scenario giving an over optimistic estimate in our opinion. There is less of a differential between the scenarios in this sector which is very dependent on the suitability of heat grade.

4.1.2 Selection of scenarios

On the basis of the examination above we feel that a realistic potential lies between the Low scenario and the central scenario with the central being achieved if extensive measures are put in place to improve suitability.

Table 4-1*Top fifteen domestic heat loads*

Technology	Customer segment	Fuel counterfactual	Sub-segment	Location	Building Age	Heat demand in segment, 2010	Scores: Space restriction	Scores: Heat grade match to application	Scores: Environmental and other impacts	Scenarios: Very Low	Scenarios: Low	Scenarios: High	Scenarios: Central
ASHP ATA	Domestic	Gas	Other House (semi-, terraced)	Suburban	Pre-1990	53.88	3	2	2	44%	67%	78%	75%
ASHP ATW	Domestic	Gas	Other House (semi-, terraced)	Suburban	Pre-1990	53.88	3	2	2	44%	67%	78%	75%
Biomass DH	Domestic	Gas	Other House (semi-, terraced)	Suburban	Pre-1990	53.88	0	0	0	0%	0%	0%	0%
Biomass boilers	Domestic	Gas	Other House (semi-, terraced)	Suburban	Pre-1990	53.88	2	3	3	67%	67%	89%	83%
GSHP	Domestic	Gas	Other House (semi-, terraced)	Suburban	Pre-1990	53.88	1	1	3	11%	33%	56%	50%
Solar Thermal	Domestic	Gas	Other House (semi-, terraced)	Suburban	Pre-1990	53.88	2	2	3	44%	67%	78%	75%
ASHP ATA	Domestic	Gas	Detached	Suburban	Pre-1990	24.97	3	2	2	44%	67%	78%	75%
ASHP ATW	Domestic	Gas	Detached	Suburban	Pre-1990	24.97	3	2	2	44%	67%	78%	75%
Biomass DH	Domestic	Gas	Detached	Suburban	Pre-1990	24.97	0	0	0	0%	0%	0%	0%
Biomass boilers	Domestic	Gas	Detached	Suburban	Pre-1990	24.97	3	3	2	67%	67%	89%	83%
GSHP	Domestic	Gas	Detached	Suburban	Pre-1990	24.97	3	1	3	33%	33%	78%	67%
Solar Thermal	Domestic	Gas	Detached	Suburban	Pre-1990	24.97	3	2	3	67%	67%	89%	83%
ASHP ATA	Domestic	Gas	Other House (semi-, terraced)	Rural	Solid-wall	20.60	3	1	3	33%	33%	78%	67%

ASHP ATW	Domestic	Gas	Other House (semi-, terraced)	Rural	Solid-wall	20.60	3	1	3	33%	33%	78%	67%
Biomass DH	Domestic	Gas	Other House (semi-, terraced)	Rural	Solid-wall	20.60	3	3	3	100%	100%	100%	100%
Biomass boilers	Domestic	Gas	Other House (semi-, terraced)	Rural	Solid-wall	20.60	3	3	3	100%	100%	100%	100%

Table 4-2 *Top fifteen Commercial heat loads*

Technology	Customer segment	Fuel counterfactual	Sub-segment	Location	Building Age	Heat demand in segment, 2010	Scores: Space restriction	Scores: Heat grade match to application	Scores: Environmental and other impacts	Scenarios: Very Low	Scenarios: Low	Scenarios: High	Scenarios: Central
ASHP ATA	Commercial / Public	Gas	Large private	Urban	Pre-1990	6.94	3	1	2	22%	33%	67%	58%
ASHP ATA	Commercial / Public	Gas	Small private	Urban	Pre-1990	6.94	3	1	2	22%	33%	67%	58%
Biomass boilers	Commercial / Public	Gas	Large private	Urban	Pre-1990	6.94	2	3	2	44%	67%	78%	75%
Biomass boilers	Commercial / Public	Gas	Small private	Urban	Pre-1990	6.94	2	3	1	22%	33%	67%	58%
Biomass DH	Commercial / Public	Gas	Large private	Urban	Pre-1990	6.94	3	3	3	100%	100 %	100%	100 %
Biomass DH	Commercial / Public	Gas	Small private	Urban	Pre-1990	6.94	3	3	3	100%	100 %	100%	100 %
GSHP	Commercial / Public	Gas	Large private	Urban	Pre-1990	6.94	1	1	3	11%	33%	56%	50%
GSHP	Commercial / Public	Gas	Small private	Urban	Pre-1990	6.94	1	1	3	11%	33%	56%	50%
Solar Thermal	Commercial / Public	Gas	Large private	Urban	Pre-1990	6.94	2	1	3	22%	33%	67%	58%
Solar Thermal	Commercial / Public	Gas	Small private	Urban	Pre-1990	6.94	2	1	3	22%	33%	67%	58%
ASHP ATW	Commercial / Public	Gas	Large private	Urban	Pre-1990	6.94	2	1	2	15%	33%	56%	50%
ASHP ATW	Commercial / Public	Gas	Small private	Urban	Pre-1990	6.94	2	1	2	15%	33%	56%	50%
ASHP ATA	Commercial / Public	Gas	Large public	Urban	Pre-1990	6.79	3	1	2	22%	33%	67%	58%

ASHP ATA	Commercial / Public	Gas	Small public	Urban	Pre-1990	6.79	3	1	2	22%	33%	67%	58%
Biomass boilers	Commercial / Public	Gas	Large public	Urban	Pre-1990	6.79	2	3	2	44%	67%	78%	75%

Table 4-3 Top fifteen industrial heat loads

							Scores			Scenarios			
Technology	Customer segment	Fuel counterfactual	Sub-segment	Location	Building Age	Heat demand in segment, 2010	Space restriction	Heat grade match to application	Environmental and other impacts	Very Low	Low	High	Central
ASHP ATA	Industrial	Non net-bound	Large, high-temp. process	Rural	Post-1990	5.39	3	0	3	0%	0%	0%	0%
ASHP ATA	Industrial	Non net-bound	Small, high-temp. process	Rural	Post-1990	5.39	3	0	3	0%	0%	0%	0%
Biomass boilers	Industrial	Non net-bound	Large, high-temp. process	Rural	Post-1990	5.39	3	3	3	100%	100%	100%	100%
Biomass boilers	Industrial	Non net-bound	Small, high-temp. process	Rural	Post-1990	5.39	3	3	3	100%	100%	100%	100%
GSHP	Industrial	Non net-bound	Large, high-temp. process	Rural	Post-1990	5.39	3	0	1	0%	0%	0%	0%
GSHP	Industrial	Non net-bound	Small, high-temp. process	Rural	Post-1990	5.39	0	0	0	0%	0%	0%	0%
Liquid biofuels	Industrial	Non net-bound	Large, high-temp. process	Rural	Post-1990	5.39	3	3	3	100%	100%	100%	100%
Liquid biofuels	Industrial	Non net-bound	Small, high-temp. process	Rural	Post-1990	5.39	3	3	3	100%	100%	100%	100%
Solar Thermal	Industrial	Non net-bound	Large, high-temp. process	Rural	Post-1990	5.39	3	0	3	0%	0%	0%	0%
Solar Thermal	Industrial	Non net-bound	Small, high-temp. process	Rural	Post-1990	5.39	0	0	0	0%	0%	0%	0%
Biological Biogas	Industrial	Non net-bound	Large, high-temp. process	Rural	Post-1990	5.39	3	2	3	67%	67%	89%	83%
Biomass Conversion	Industrial	Non net-bound	Large, high-temp. process	Rural	Post-1990	5.39	2	1	3	22%	33%	67%	58%
ASHP ATA	Industrial	Non net-bound	Large, high-temp. process	Rural	Pre-1990	4.88	3	0	3	0%	0%	0%	0%

ASHP ATA	Industrial	Non net-bound	Small, high-temp. process	Rural	Pre-1990	4.88	3	0	3	0%	0%	0%	0%
Biomass boilers	Industrial	Non net-bound	Large, high-temp. process	Rural	Pre-1990	4.88	3	3	3	100%	100%	100%	100%
Biomass boilers	Industrial	Non net-bound	Small, high-temp. process	Rural	Pre-1990	4.88	3	3	3	100%	100%	100%	100%

Appendices

Appendix 1 - Counterfactual assumptions from Phase 1

Counterfactual – Natural Gas

Table 4.4: Summary technology assumptions for natural gas heating

Customer Segment	Variable	Unit	Values
Domestic	Capital Cost	£/kW	125-150
Domestic	Opex	£/kW/year	9
Domestic	Size of installation	kW	20
Domestic	Efficiency	%	94%
Domestic	Lifetime	years	15
Domestic	Load factor	%	3%-10%
Domestic	Total install cost	£'000s	3-3
Commercial / Public -- Small	Capital Cost	£/kW	93
Commercial / Public -- Small	Opex	£/kW/year	3
Commercial / Public -- Small	Size of installation	kW	50-180
Commercial / Public -- Small	Efficiency	%	94%
Commercial / *Lifetime subsequently*	Lifetime	years	15
Commercial / *changed to 20 years*	Load factor	%	20%
Commercial / Public -- Small	Total install cost	£'000s	5-17
Commercial / Public -- Large	Capital Cost	£/kW	65
Commercial / *Efficiency subsequently*	Opex	£/kW/year	1
Commercial / *changed to 90%*	Size of installation	kW	350-3,600
Commercial / Public -- Large	Efficiency	%	94%
Commercial / *Lifetime subsequently*	Lifetime	years	15
Commercial / *changed to 20 years*	Load factor	%	20%
Commercial / Public -- Large	Total install cost	£'000s	23-234
Industrial -- Small	Capital Cost	£/kW	30-65
Industrial -- Small	Opex	£/kW/year	0
Industrial -- S *Lifetime subsequently*	Size of installation	kW	96-1,000
Industrial -- S *changed to 20 years*	Efficiency	%	94%
Industrial -- Small	Lifetime	years	15
Industrial -- Small	Load factor	%	20%-82%
Industrial -- Small	Total install cost	£'000s	3-65
Industrial -- Large	Capital Cost	£/kW	30-65
Industrial -- L *Efficiency subsequently*	Opex	£/kW/year	0
Industrial -- L *changed to 90%*	Size of installation	kW	350-3,600
Industrial -- Large	Efficiency	%	94%
Industrial -- L *Lifetime subsequently*	Lifetime	years	15
Industrial -- L *changed to 20 years*	Load factor	%	20%-82%
Industrial -- Large	Total install cost	£'000s	11-237

Counterfactual – Off-grid

Table 4.5: Summary technology assumptions for off-grid fossil fuel heating

Customer Segment	Variable	Unit	Values
Domestic	Capital Cost	£/kW	125-150
Domestic	Opex	£/kW/year	9
Domestic	Size of installation	kW	20
Domestic	Efficiency	%	80%
Domestic	Lifetime	years	15
Domestic	Load factor	%	5%-10%
Domestic	Total install cost	£'000s	3-3
Commercial / Public -- Small	Capital Cost	£/kW	93
Commercial /	Opex	£/kW/year	3
Commercial /	Size of installation	kW	50-180
Commercial /	Efficiency	%	80%
Commercial /	Lifetime	years	15
Commercial /	Load factor	%	20%
Commercial / Public -- Small	Total install cost	£'000s	5-17
Commercial / Public -- Large	Capital Cost	£/kW	65
Commercial /	Opex	£/kW/year	1
Commercial /	Size of installation	kW	350-3,000
Commercial / Public -- Large	Efficiency	%	80%
Commercial /	Lifetime	years	15
Commercial /	Load factor	%	20%
Commercial / Public -- Large	Total install cost	£'000s	23-195
Industrial -- Small	Capital Cost	£/kW	30-65
Industrial -- S	Opex	£/kW/year	0
Industrial -- S	Size of installation	kW	96-1,000
Industrial -- Small	Efficiency	%	80%
Industrial -- S	Lifetime	years	15
Industrial -- S	Load factor	%	20%-82%
Industrial -- Small	Total install cost	£'000s	3-65
Industrial -- Large	Capital Cost	£/kW	30-65
Industrial -- L	Opex	£/kW/year	0
Industrial -- L	Size of installation	kW	350-3,600
Industrial -- Large	Efficiency	%	80%
Industrial -- L	Lifetime	years	15
Industrial -- L	Load factor	%	20%-82%
Industrial -- Large	Total install cost	£'000s	11-237

Efficiency subsequently changed to 93%

Efficiency subsequently changed to 89%

Lifetime subsequently changed to 20 years

Efficiency subsequently changed to 89%

Lifetime subsequently changed to 20 years

Efficiency subsequently changed to 89%

Lifetime subsequently changed to 20 years

Efficiency subsequently changed to 89%

Lifetime subsequently changed to 20 years

Counterfactual – Electric heating

Table 4.6
Summary technology assumptions for electric fuel heating

Customer Segment	Variable	Unit	Values
Domestic	Capital Cost	£/kW	175
Domestic	Opex	£/kW/year	
Domestic	Size of installation	kW	10-23
Domestic	Efficiency	%	90%
Domestic	Lifetime	years	15
Domestic	Load factor	%	5%-9%
Domestic	Total install cost	£'000s	2-4
Commercial / Public -- Small	Capital Cost	£/kW	221
Commercial / Public -- Small	Opex	£/kW/year	1
Commercial / Public -- Small	Size of installation	kW	50-180
Commercial / Public -- Small	Efficiency	%	100%
Commercial / Public -- Small	Lifetime	years	15
Commercial / Public -- Small	Load factor	%	20%
Commercial / Public -- Small	Total install cost	£'000s	11-40
Commercial / Public -- Large	Capital Cost	£/kW	221
Commercial / Public -- Large	Opex	£/kW/year	0
Commercial / Public -- Large	Size of installation	kW	350-3,600
Commercial / Public -- Large	Efficiency	%	100%
Commercial / Public -- Large	Lifetime	years	15
Commercial / Public -- Large	Load factor	%	20%
Commercial / Public -- Large	Total install cost	£'000s	77-797
Industrial -- Small	Capital Cost	£/kW	147
Industrial -- Small	Opex	£/kW/year	0
Industrial -- Small	Size of installation	kW	96-1,000
Industrial -- Small	Efficiency	%	100%
Industrial -- Small	Lifetime	years	15
Industrial -- Small	Load factor	%	20%-82%
Industrial -- Small	Total install cost	£'000s	14-147
Industrial -- Large	Capital Cost	£/kW	147
Industrial -- Large	Opex	£/kW/year	0
Industrial -- Large	Size of installation	kW	350-3,600
Industrial -- Large	Efficiency	%	100%
Industrial -- Large	Lifetime	years	15
Industrial -- Large	Load factor	%	20%-82%
Industrial -- Large	Total install cost	£'000s	51-535

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