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Heat Generation Technology Landscaping Study, Scotland's Energy Efficiency Programme (SEEP)

BRE

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Summary

This landscaping study has reviewed the status and suitability of a number of near-term heat generation technologies that are not already significantly established in the market-place. The study has been conducted to inform Scottish Government on the status and the technologies so that they can make informed decisions on the potential suitability of the technologies for inclusion within Scotland's Energy Efficiency Programme (SEEP).

Some key findings which have emerged from the research include:

- High temperature, hybrid and gas driven heat pumps all have the potential to increase the uptake of low carbon heating solutions in the UK in the short to medium term.
- High temperature heat pumps are particularly suited for off-gas grid retrofit projects, whereas hybrids and gas driven products are suited to on-gas grid properties. They may all be used with no or limited upgrades to existing heating systems, and each offers some advantages (but also some disadvantages) compared with standard electric heat pumps.
- District heating may continue to have a significant role to play – albeit more on 3rd and 4th generation systems than the large high temperature systems typical in other parts of Europe in the 1950s and 60s – due to lower heating requirements of modern retrofitted buildings.
- Longer term, the development of low carbon heating fuel markets may also present significant opportunity e.g. biogas, and possibly hydrogen.

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Introduction

The commission

This study is one of three technology landscaping studies, commissioned by Climate X Change, which will feed in to the Research and Development (R&D) work stream of Scotland's Energy Efficiency Programme (SEEP). Climate X Change is working closely with the Scottish Government policy team working on delivering SEEP.

The three landscaping studies are:

- Heat generation technologies (this study) – undertaken by the Building Research Establishment (BRE)
- Energy efficiency and retrofit solutions – undertaken by the National Energy Foundation
- Smart energy technologies – undertaken by CAG Consultants (with Smarter Grid Solutions and Innovas)

Together the studies create a platform and common format for further developing and updating of a suite of technologies potentially of future interest within SEEP. The studies have focused on 'near-term' technologies that may be suitable for commercial application under SEEP – the guideline for this being a Technology Readiness Level (TRL) of 8 or 9. Each shortlisted technology has been assessed against common criteria which includes consideration of technical, environmental, consumer, monetary, supply chain and policy related issues.

This scope for this study is therefore near-term technological options for the delivery of heat generation solutions in the commercial, public, industrial and domestic building sectors. The study has not included technologies that are significantly well established but has rather focused on less well established technologies and/or innovative technologies that are likely to become commercially available in the lifetime of SEEP.

Scotland's Energy Efficiency Programme (SEEP)

SEEP is the "cornerstone" of Scottish Government's National Infrastructure Priority on buildings energy efficiency. It will combine existing energy efficiency and community energy programmes with new devolved powers over Supplier Obligations on energy efficiency and fuel poverty.

Alongside its draft energy strategy published in January 2017, Scottish Government is consulting on the SEEP framework[1]. A pilot phase is underway, with projects running to 2018/19. A development phase to 2022/23 will see implementation of advice and support services, an assessment and consumer protection framework. Thereafter will be a full-scale operation of SEEP, facilitated by new regulation as appropriate.

The Scottish Government's vision is a scheme which combines and consolidates interventions across all of Scotland's building stock –domestic (social and private), public, commercial and industrial – making use of delivery mechanisms shown to work and deliver value for money.

Report structure

All three studies use the same reporting structure, as follows:

- Context
- Methodology – overview of the methodology employed within the study
- Key technology areas and individual technologies – a narrative on shortlisted technologies, trends emerging from the assessment, contextual observations and identification of key data gaps. A combined MS Excel-based spreadsheet of technologies and their corresponding assessments accompanies the three reports.
- Closing remarks and future work

[1] National Infrastructure Priority for Energy Efficiency – Scotland's Energy Efficiency Programme. January 2017. http://www.gov.scot/Publications/2017/01/2195/downloads#res-1

Heat Generation

Context (Heat)

Heat is at the core of Scotland's energy system. The consumption of heat accounts for 53% of the energy consumed by Scotland's homes and businesses (see figure 1) (source: Scottish Government Draft Energy Strategy[2]). This makes heat the biggest element of Scotland's energy use and the largest source of its emissions. With the domestic sector space heating and water heating respectively accounting for 74% and 14% of total household energy use (see figure 2) (source: Scottish Government Draft Energy Strategy)

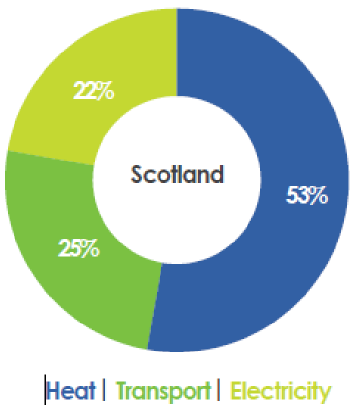

Figure 1: Energy Demand in Scotland

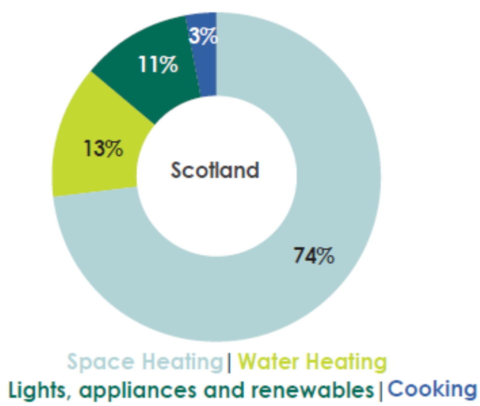

Figure 2: Household energy use in Scotland

Scotland's heating requirements are supplied predominantly from natural gas at present. The Draft Energy Strategy highlights that (in 2015) an estimated 79% of homes used natural gas as their primary heating fuel.

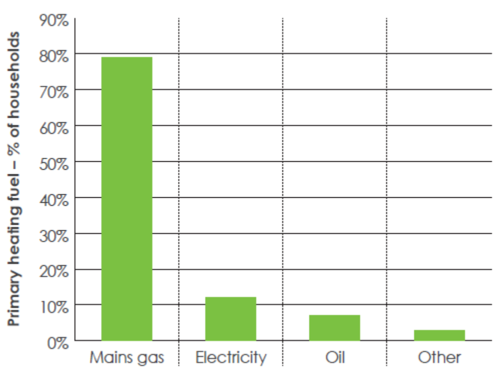

Figure 3: Household primary heating fuels in Scotland

The Scottish Government is committed to largely decarbonising our energy system by 2050, at an affordable price to consumers through maintaining and developing secure supplies of energy. The draft Energy Strategy sets out a whole-system view of energy policy, examining where our energy comes from and how we use it – for power (electricity), heat and transport. This integrated approach recognises the interactions and effects that the elements of the energy system have on each other. The draft Energy Strategy proposes a new 2030 'all-energy' target for the equivalent of 50% of Scotland's heat, transport and electricity consumption to be supplied from renewable sources. Back in 2015, the Scottish Government Heat Policy Statement set an ambition for 11% of heat demand to be met by renewable sources by 2020 and the Draft Energy Strategy reports that significant progress has been made towards this target with renewable heat currently representing 5.3% to 5.6% of non-electrical heat demand. It should also be noted that the Draft Energy Strategy also commits Scottish Government to undertaking further work to establish where, and with what investment,

[2] Draft Scottish Energy Strategy, Scottish Government, January 2017

emerging fuel sources and technologies can become viable alternatives in the future. Given the ambitious targets of the Draft Energy Strategy and the fact that SEEP aims to include "measures to make homes and places of work warmer, promoting more affordable energy for consumers, helping to tackle poverty and improve the competitiveness of the Scottish economy" then it is imperative that the Scottish Government remain appraised of the ever-changing status of new and emerging heat technologies as well as advances and innovation in transitional and/or next generation heating fuels.

Scope for this study

Scotland's Energy Efficiency Programme (SEEP) aims deliver millions of pounds in energy savings as well as supporting and creating jobs across Scotland whilst delivering a substantial Scottish market and supply chain (for energy efficiency, renewable heat services and other technologies and related expertise) which is transferable to international markets.[3] This shall typically require appropriate technologies to be available and market ready and for a support plan and associated work streams to be in place. To date these do not exist, however these three technology landscaping studies will inform these work streams by considering a range of technologies against a suite of criteria (including Technology Readiness Level (TRL), cost-effectiveness, carbon reduction, economic benefit, etc.) in support of the work of the Scottish Government's SEEP policy team and the SEEP work stream on research and development (R&D). Specifically, the studies are intended to provide the research and development work stream with an understanding of what the short-term technological options are for the SEEP to aid Scottish Government in steering the technological direction of SEEP as a long-term programme of investment.

This scope for this study is therefore near-term technological options for the delivery of heat generation solutions in the commercial, public, industrial and domestic building sectors. As a result the landscaping study has not examined technologies that are mature or that are already significantly well established but rather focusses on a less well established technologies and/or innovative technologies that are likely to become commercially available in the lifetime of SEEP. As a result, established and well understood technologies such as condensing boilers, traditional heat pumps, biomass boilers, solar thermal, etc. have been excluded from the study.

[3] DRAFT CLIMATE CHANGE PLAN The draft third report on policies and proposals 2017-2032 January 2017 - available at www.gov.scot - ISBN: 978-1-78652-743-1

Methodology

Technology Identification

A dual process was used to identify technologies suitable for inclusion within the study. This included (i) identifying near-term technologies by drawing upon BRE's existing experience and knowledge at the forefront of emerging low carbon built environment technologies and innovative products through our research, product development, performance assessment, testing, certification and demonstration activities, and (ii) undertaking desk based research and an associated literature review. This process identified a range of relevant technologies as outlined in the next section.

Assessment criteria

Following a review and gap analysis of the draft assessment criteria, a standard assessment criteria matrix was jointly finalized by the organisations undertaking the landscaping studies. This assessment criteria was subsequently approved for use by the project Steering Group. A copy of the assessment criteria is included in Appendix A.

Each technology was then assessed against the agreed criteria using a common assessment method consisting of a 1-5 scale whereby '1' equals very poor, '2' equals poor, '3' equals neutral / average, '4' equals good, '5' equals very good, or 'n/a' equals not applicable.

The majority of technologies have been assessed versus standalone gas boilers. However, in order to ensure that the research didn't overlook off-gas grid applications, various assessments (where relevant) include additional commentary on the technology performance as compared versus traditional electrically driven heat pumps (e.g. air source heat pumps). This approach was deemed appropriate because (i) gas boilers currently dominate the Scottish heat sector, and (ii) had technology "X" been compared against a gas boiler and technology "Y" been compared against a heat pump, then such an approach would not enable technology 'X' to be fairly cross-compared to technology 'Y'. The assessment method deployed overcomes this issue and ensures that all technologies can be compared against one another.

Whilst the majority of identified technologies have applications as a primary heating system it should be noted that some technologies are considered "add-on" or complimentary technologies i.e. they are unlikely to be able to meet the total space heating or domestic hot water energy demand of a property but rather they offer potential to usefully contribute to meeting part of this demand. In order to ensure that technologies such as these can be assessed relative to the performance of the other technologies, professional judgement (informed by the research findings) has been applied.

Information on the technologies identified during the project is included below however waste water heat recovery, flue gas heat recovery, hybrid solar photovoltaics and solar assisted positive input ventilation systems have also been assessed in this manner. Professional judgement has also been used to assess the comparative performance of district heating, biogas CHP and combined cooling heat and power (CCHP). This approach was deemed necessary to ensure that all of the technologies can be compared equally against one another.

Careful consideration of the scoring descriptor / context should be applied when interpreting the assessments. For example, in the vast majority of criteria a score of '1' ('very poor' as measured against the comparison technology) means 'very low' (e.g. in the case of carbon saving potential). The reader should however be aware that '1' / 'very poor' can purposely mean 'very high' (e.g. in the case of capital costs). This difference is explained further below.

Example 1: '(in-use) carbon saving potential' (NB: the scoring descriptor states: '1 (low) to 5 (high)')

This approximates the potential for a technology to reduce carbon emissions during its lifetime, compared relatively against the alternative. In this context the scoring mechanism should be interpreted as follows:

1	very poor	The technology generally presents a significantly poorer (i.e. significantly less) carbon saving potential versus the alternative technology
2	poor	The technology generally presents a poorer (i.e. less) carbon saving potential versus the alternative technology
3	Neutral / average	The technology generally presents a similar carbon saving potential to that of the alternative technology
4	good	The technology generally presents a good (i.e. increased) carbon saving potential versus the alternative technology
5	very good	The technology generally presents a significantly good (i.e. significantly increased) carbon saving potential versus the alternative technology
n/a	Not applicable	The assessment is not applicable / relevant, or insufficient data exists.

For example, a gas driven heat pump can typically operate at a higher efficiency than a gas condensing boiler. It therefore offers good potential for carbon savings versus a gas condensing boiler. An assessment result of '4' is therefore applied. An assessment result of 5 could, for example, have been applied should the technology have presented a significantly higher carbon saving potential (e.g. if it had presented a significantly higher efficiency or if it used significantly lower carbon, or renewable, fuel).

Example 2: 'Capital costs' (NB: The scoring descriptor states: '1 (high) to 5 (low)')

This approximates the capital cost for a technology compared relatively against the alternative.

It should be noted that the scoring descriptor (within the scorecard identifies that a '1' – 'very poor' – relates to a very high capital cost. Therefore in this context of this criteria the scoring mechanism should be interpreted as follows:

1	very poor	The technology generally presents a significantly higher capital cost versus the alternative technology
2	Poor	The technology generally presents a higher capital cost versus the alternative technology
3	Neutral / average	The technology generally presents a similar capital cost as the alternative technology
4	Good	The technology generally presents a higher capital cost versus the alternative technology
5	Very good	The technology generally presents a significantly higher capital cost versus the alternative technology
n/a	Not applicable	The assessment is not applicable / relevant, or insufficient data exists.

For example, the capital cost of a micro-CHP device can typically be a multiple of the capital cost of a gas condensing boiler. This is significantly higher in percentage terms and thus an assessment result of '1' has been applied.

Comments have also been added to help explain the basis of the assessments. Whilst the quantitative scoring is useful for 'at-a-glance' comparison of technologies further investigation into, and awareness of, the qualitative context is advised before conclusions are drawn.

Assessment scores are generally all of medium to high confidence. Where this is not the case, or where there are specific issues that impact on the confidence of the score, then this is explained within the respective narrative description for the individual assessment category.

The resulting assessments are provided in a Microsoft Excel Spreadsheet that should be read in conjunction with this report.

The technologies

The landscaping review identified number of near-term heat generation technologies of interest to the study. The individual technologies can generally be grouped into nine technology categories, as follows:

- Heat pumps
    - Heat generation technologies that use heat pump technology to upgrade low grade heat to a more useful temperature for building energy applications
- Solar
    - Heat generation technologies that are solar derived or solar-assisted
- Geothermal
    - heat extracted from hot rocks/aquifers, typically at depths of around 3 km or more
- Hydrogen / Fuel cells
    - Hydrogen burning appliances, and
    - Fuel cells which generate heat and electricity
- Cogeneration
    - Combined Heat and Power (CHP) technologies and derivatives thereof
- Trigeneration
    - Combined Cooling Heat and Power (CCHP) technology
- District heating
    - Modern and emerging district heating design "approaches / concepts"
- Local heaters
    - Heat emitter technologies
- Heat recovery
    - Technologies that recover heat from other building energy processes

The following individual technologies were identified before each technology was then assessed against the agreed criteria.

Category	Technology
Heat pump	high temperature heat pump gas driven heat pump hybrid heat pumps waste water heat pump solar-assisted heat pump
Solar	PV-thermal (PV-T) (hybrid solar photovoltaics) solar collector assisted, positive input ventilation
Geothermal	deep geothermal

Hydrogen/Fuel Cell	hydrocarbon fuel cell (cogeneration) hydrogen fuel cells (cogeneration) hydrogen burners / boilers
Cogeneration	biogas CHP (cogeneration) microCHP - heat led (cogeneration)
Trigeneration	Combined Cooling Heat and Power (CCHP) (trigeneration)
District heating	3rd generation district heating design 4th generation (low temperature) district heating design
Local heaters	infrared heaters electric storage heaters (high heat retention)
Heat recovery	waste water heat recovery passive flue gas heat recovery active flue gas heat recovery

Table 1: List of assessed technologies (by category)

The resulting assessments are provided in a Microsoft Excel Spreadsheet that should be read in conjunction with this report.

Additional supporting information on each of the above technologies is also provided in Appendix B.

The technologies have various applications. To provide further assistance to the reader Appendix C includes a table that summarises the typical applications in terms of on or off-gas grid applications, community/district heating applications of applications in domestic, public, commercial or industrial buildings. Additional supporting guidance is also presented regarding potential applications for realising maximum carbon savings for each of the technologies, however it should be noted that the applications listed are generalised, not exhaustive, and that additional applications offering potential for carbon savings are likely to exist.

Appendix D provides further information on the current Standard Assessment Procedure (SAP) status of the technologies with domestic applications.

A number of useful references and link to background information has also been included in Appendix E.

A glossary of terms has also been included in Appendix F.

Closing remarks and future work

The Scottish (and UK) heating market is dominated by gas boilers. Most low carbon pathways suggest that heat pumps will play a large role in decarbonising the UK economy. The Committee on Climate Change (CCC) has suggested that the overall cost-effective uptake of heat pumps in UK homes could reach 2.3 million by 2030 [4]. The current UK market for heat pumps is small; around 18,700 units per year, of which around 17,700 are estimated to be domestic[5].

High temperature, hybrid and gas driven heat pumps however, all have potential to increase the uptake of low carbon heating solutions in the UK in the short to medium term. High temperature heat pumps are particularly suited for off gas grid retrofit projects, and hybrids and gas driven products are suited to on gas grid properties. They may all be used with no or limited upgrades to existing heating systems. Each offers some advantages (but also some disadvantages) compared with standard electric heat pumps, but it is not yet clear that these advantages are sufficient to stimulate widespread uptake of the technologies. High temperature heat pumps may remain a niche market in the short term.

[4] Sectoral scenarios for the Fifth Carbon Budget, Technical report, Committee on Climate Change, Nov 2015

[5] Evidence Gathering – Low Carbon Heating Technologies - Domestic High Temperature, Hybrid and Gas Driven Heat Pumps: Summary Report, BEIS, November 2016

Their target market tends to be large, old, or listed properties (i.e. with high heat loss), often off the gas grid and with high domestic hot water demand. Hybrid heat pumps could be a competitive low-carbon transition technology, delivering the carbon saving benefits of an electric heat pump with the performance of a gas boiler when required. Gas heat pumps may help to overcome consumer inertia (as consumers are familiar with gas fired heating), however they are still very new in the domestic market and high initial capital cost. These heat pump technologies can deliver cost and carbon savings compared with a standard electric heat pump, particularly where expensive and disruptive upgrades to the heat distribution system would otherwise be required. However only gas driven products are likely to deliver a significant operational cost saving versus a new gas boiler. In terms of overall impact, it should be noted that according to the BEIS publication “Low Carbon Heating Technologies – evidence gathering” (see footnote 5) - all of the above heat pump technologies can deliver a carbon saving compared with a gas boiler. This is important in relation to assessing the likely energy efficiency, climate impacts and potential fuel poverty impacts of moving to these technologies at a point in time where gas costs are low in relation to other fuels.

At the same time it is important to note that it remains difficult to draw quantitative conclusions on the relationship between laboratory tests and in-use performance for these emerging heat pump technologies. This is predominantly due to the lack of a performance standard and limited availability of trial data. A recent BEIS comparative review of heat pumps suggests that information gathered from a number of trials has shown that the technologies each perform satisfactorily in general, however particular care is needed with equipment sizing, system design and control strategies, which require specialist expertise beyond traditional heating installations .

It is also worth noting that beyond these technical issues, a number of other barriers exist to large scale uptake of heat pumps, including perception and lack of familiarity, leading to inertia. High temperature, hybrid and gas driven products can variously help to mitigate some of these traditional barriers, as most can provide the high temperature space heating outputs that customers are used to, and can also supply domestic hot water. These systems could help overcome the consumer inertia that currently ‘favours’ conventional gas boilers. Furthermore, hybrid and gas driven products may help overcome other barriers associated with moving away from gas fired heating systems. However these technologies still suffer from high upfront cost, the need for additional space, and low customer awareness and associated lack of acceptance. These systems are new to the market and as a result there is a lack of trial information so the cost benefits and performance remain generally unproven.

In addition to heat pump technology a range of other technologies identified by this study are likely to present specific opportunities, most likely at smaller scale. It should also be noted that the promotion of district heating also has a significant role to play – albeit focused more on 3rd and 4th generation systems than the large scale high temperature systems typical in other parts of Europe in the 1950s and 60s – due to the lower heating requirements of modern and retrofitted buildings.

In the longer term the development of low carbon heating fuel markets may well present significant opportunity e.g. biogas (and also possibly hydrogen, although the widespread use of hydrogen as a heating fuel is likely to be some time away and it is also likely to have to compete with growing applications in energy storage and transport).

Appendix A – the assessment criteria

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Technology name

Technology short description

Likert				
1	2	3	4	5
Bad				Good

Technical	**Scoring**	**Score**	**Comments**
Technology readiness	TRL score 1-9		
Efficiency (product / technology efficiency)	1 (low) to 5 (high) score		
Reliability	1 (low) to 5 (high) score		
(level of) Compatability with existing systems	1 (low/poor) to 5 (high/good) score		
complexity of systems/ their integration	1 (complex) to 5 (simple) score		
risk/severity of unintended consequences	1 (high) to 5 (low) score		
		0	

Environmental	**Scoring**	**Score**	**Comments**
(in-use) carbon saving potential	1 (low) to 5 (high) score		
whole life environmental impact	1 (high) to 5 (low) score		
		0	

Policy / Regulation	**Scoring**	**Score**	**Comments**
compatability with Scottish policy	1 (low) to 5 (high) score		
compatability with current regulation	1 (low) to 5 (high) score		
compatibility with current assessment methodologies	1 (low) to 5 (high) score		
		0	

Monetary	**Scoring**	**Score**	**Comments**
capital costs	1 (high) to 5 (low) score		
life cycle costs	1 (high) to 5 (low) score		
carbon cost effectiveness (£ per tCO2 saved)	1 (low) to 5 (high) score		
(potential for) economy of scale (to drive down costs)	1 (low) to 5 (high) score		
		0	

Capacity/ Supply Chain	**Scoring**	**Score**	**Comments**
applicability	1 (low) to 5 (high) score		
existing Scottish capacity/skills	1 (low) to 5 (high) score		
Scottish content	1 (low) to 5 (high) score		
potential for cross-sector involvement/benefit	1 (low) to 5 (high) score		
scottish economic impact potential	1 (low) to 5 (high) score		
		0	

Consumer	**Scoring**	**Score**	**Comments**
user friendliness / practicality	1 (low) to 5 (high) score		
disruption	1 (high) to 5 (low) score		
customer acceptance	1 (low) to 5 (high) score		
savings on bills	1 (low) to 5 (high) score		
maintenance requirements	1 (high) to 5 (low) score		
health/wellbeing/comfort	1 (high negative imapct) to 5 (high positive impact) score		
existing consumer protection? (adequacy?)	1 (low) to 5 (high) score		
		0	

Opportunities / risks	**Scoring**	**Score**	**Comments**
Critical success factors/watch points	List/Describe		
other relvant considerations/risks/opportunities	List/Describe		
adaptability / future proofing	List / Describe		
		0	

Appendix B – Technology Summaries

Heat Pumps

High Temperature Heat Pumps

A high-temperature heat pump is similar to a conventional electric heat pump but it is capable of providing output temperatures of 65°C or higher. By way of contrast, conventional electric heat pumps generally provide output temperatures of only around 55° C. Typically a high-temperature heat pump will use two cascades, with each cascade containing different refrigerants. Some manufacturers claim that their products can achieve output temperatures of 80°C.

High temperature heat pumps are suitable for retrofit to existing properties as they can be used with existing, high temperature distribution systems (e.g. existing radiators) and are also capable of meeting hot water demand. BEIS suggested (2016) that sales are estimated at approximately 2% of total heat pump sales (which numbers a few hundred units per year). They are typically specified to heat large, old, or listed properties, often off the gas grid.

Strengths and weaknesses

As a result of reaching higher temperatures, the coefficient of performance is a little lower than conventional heat pumps, but they are less likely to require electric immersion top-up to achieve temperatures for domestic hot water. Their potential to contribute to the low carbon economy is linked to the general decarbonisation of the electricity grid.

Opportunities

High temperature heat pumps are likely to be attractive for properties off the gas grid which have radiator systems requiring higher temperatures, particularly if the hot water demand is high.

High temperature heat pumps have potential to increase the uptake of low carbon heating solutions in the UK. They are also particularly suited for off gas grid retrofit projects, because they can be used with existing high-temperature distribution systems, e.g. existing radiators.

Significant market uptake of heat pumps for space heating has been predicted over the next 15-35 years. High temperature heat pumps could provide an attractive option, as they can often operate with existing heat distribution systems and provide domestic hot water. The potential market could be 29,000-60,000 dwellings (off gas grid) per year for high temperature heat pumps. Manufacturers expressed the view that there are too many variables to make firm predictions of market potential, such as the future balance of incentive schemes and the relative prices of gas, oil and electricity which affect the competitiveness of heat pumps. Manufacturers have suggested that if current incentives and energy prices remain the same then the market is likely to remain stable. The key to the growth of the market is for this technology to become a cost effective consumer choice for gas boiler replacements.

Risks (including unintended consequences)

As a fuel, electricity is less likely to be affected by import prices than fuels which are imported directly, particularly if a a significant amount of electricity is supplied by renewable resources within the country. However, unit costs and installation costs might not fall as expected, and good design, quality of installation and appropriate use are key to achieveing good coefficients of performance anywhere close to those derived in laboratory tests.

Watch points

Unit costs and installation costs, as well as the attractiveness of using electricity as a fuel for generating heat.

Gas Driven Heat Pumps

A gas-driven heat pump is a heat pump which derives almost all of its energy from the gas supply and uses very little electricity. Gas-driven heat pumps can be subdivided into engine-driven heat pumps and thermally-driven (gas sorption) heat pumps. Thermally-driven heat pumps ('sorption units') can be further subdivided into gas absorption heat pumps and gas adsorption heat pumps. Sorption units use a thermal compressor to heat the refrigerant, whereas gas engine driven heat pumps use a mechanical compressor. Gas engine driven heat pumps are similar to electric heat pumps except that the energy source is gas instead of electricity.

The gas driven heat pump market is at an earlier stage of development in the UK however the use of domestic scale gas driven heat pumps in Europe is growing. They present a wide range of potential applications. Some products can be operated at high temperatures and are therefore potentially suited to replace gas boilers in the retrofit market for use with existing high temperature distribution systems (e.g. existing radiators and hot water cylinders).

Strengths and weaknesses

Gas driven heat pumps are considerably more efficient than condensing boilers, but they incorporate additional technology for transferring heat. The capital and installation costs for gas driven heat pumps are several times higher than for gas condensing boilers. Gas-driven heat pumps typically have an efficiency of around 30% higher than gas condensing boilers (according to a report for DECC: "Domestic High Temperature, Hybrid and Gas Driven Heat Pumps").

Opportunities

Gas driven heat pumps have the potential to increase the uptake of low carbon heating solutions in the UK. For properties which are already on the gas grid, they may be installed with no or limited upgrades to existing gas heating systems. They can often operate with existing heat distribution systems and they provide domestic hot water.

Gas-driven heat pumps may help to overcome consumer inertia (as consumers are already familiar with gas fired heating, and might notice little difference), however these heat pumps are still very new in the domestic market and are expensive. Gas heat pumps are at an early stage of deployment for domestic applications, with sorption units only entering the UK market in 2016. Gas-driven heat pumps can reach higher temperatures than standard electric heat pumps - i.e. typically up to 65°C for gas absorption and gas engine heat pumps, and even 75°C in the case of gas adsorption heat pumps - whereas standard electric heat pumps only heat to 55°C. Innovation is under way for this technology to develop more domestic scale products, improve efficiencies and reduce unit size. Significant market uptake of space heating heat pumps has been predicted over the next 15-35 years. The potential market in the UK for gas driven heat pumps, as a replacement for gas boilers, is substantial because of the nature of the UK's housing infrastructure, where 85% of homes have a gas boiler. The key to the growth of this market is for this technology to become a cost effective consumer choice for gas boiler replacements. Significant cost reductions may be possible with higher deployment rates, but achieving wide uptake is also likely to require awareness raising and education of consumers to persuade them that gas driven heat pumps provide more efficient heat, and are a feasible alternative.

Manufacturers expressed the view that there are too many variables to make firm predictions of market potential, such as the future balance of incentive schemes and the relative prices of gas, oil and electricity which affect the competitiveness of heat pumps. They suggested, however, that if current incentives and energy prices remain the same then the market is likely to remain stable. The potential market could be 100,000 to 210,000 dwellings (on gas grid) for hybrid and gas driven heat pumps combined.

Risks (including unintended consequences)

The risks are small since reversion to gas condensing boilers should be relatively straightforward. The benefits of gas driven heat pumps will be linked to the future relative costs of gas and electricity. Good design, quality of installation and appropriate use are key to achieveing good coefficients of performance anywhere close to those derived in laboratory tests.

Watch points

Unit costs, installation costs, gas prices, electricity prices, coefficients of performance.

Hybrid Heat Pumps

A hybrid heat pump is a heat pump and boiler combination which consumes appreciable amounts of both gas/oil and electricity. Typically, they will use the electrically driven heat pump during mild weather when the coefficient of performance is likely to be high, and then the gas/oil boiler component during cold weather (for generating domestic hot water) when gas combustion is likely to be more economical than using the heat pump.

Hybrid heat pumps have a wide range of potential applications. When used in conjunction with existing high temperature radiators, the boiler can top up the space heating. They can be combined with an existing boiler and water tank, or with a combi boiler, reducing costs. BEIS highlight that hybrid heat pumps currently have up to 18% of heat pump market share (but this includes bivalent heat pumps fitted to oil boilers, for example).

Strengths and weaknesses

A hybrid heat pump is more complex than a standalone gas condensing boiler or an electric heat pump, and therefore capital costs and maintenance costs can be higher. They make optimal use of fuels however, using electricity when pumping heat is cheaper and using gas when gas combustion is cheaper. They actually stop using electricity during very cold weather, which is advantageous for the electricity grid, since the electricity grid is normally subject to more demand during cold weather. They also provide output temperatures suitable for domestic hot water and high temperature radiators.

Opportunities

Gas hybrid heat pumps could provide an attractive option for householders, as they can often operate with existing heat distribution systems and provide domestic hot water. They have potential to increase the uptake of low carbon heating solutions in the UK. Gas hybrids are suited to properties which are on the gas grid since they may be used with no or limited upgrades to existing heating systems.

Hybrid heat pumps could be a competitive low-carbon transition technology, delivering the carbon saving benefits of an electric heat pump with the performance of a gas boiler when required. Hybrid heat pumps can provide baseload low temperature heating at high efficiency. The boiler is then used to reach higher temperatures needed to provide hot water and meet peak heating loads. The intelligent controller can optimise running costs, energy efficiency or carbon emissions by switching between the two sources. It can also allow for remote operation, allowing electricity grid demand management.

Significant market uptake of space heating heat pumps has been predicted over the next 15-35 years. Hybrid heat pumps could provide an attractive option, as they can often operate with existing heat distribution systems and provide domestic hot water. The potential market could be 100,000 to 210,000 dwellings (on gas grid) for hybrid and gas driven heat pumps combined.

The potential market in the UK for hybrid heat pumps, as a replacement for gas boilers, is substantial because of the nature of the UK's housing infrastructure, where 85% of homes have a gas boiler. The key to the growth of this market is for these technologies to become a cost effective consumer choice for gas boiler replacements. The capital and installation costs for hybrid heat pumps are several times higher than for gas condensing boilers. Significant cost reductions may be possible with higher deployment rates, but achieving wide uptake is also likely to require awareness raising and education of consumers to persuade them of the benefits.

Risks

This type of heat pump is designed to operate in the most economical way, depending on temperature conditions and level of demand. Changes to relative prices of gas and electricity, and the carbon intensity of electricity could change its cost-effectiveness / carbon cost-effectiveness. Risks are low because reversion to a conventional gas/oil boiler would be straightforward, however as with most heat pumps good design, quality of installation and appropriate use are key to achieveing good coefficients of performance anywhere close to those derviced in laboratory tests.

Watch points

Gas and electricity prices, grid carbon intensity, unit efficiencies and unit costs.

Waste Water Heat Pump

A waste water heat pump extracts heat from sewage to provide space heating and water heating. Waste water heat pumps make use of the fact that waste water tends to be considerably warmer than cold supply water, and therefore it presents a good opportunity to provide heat for space and water heating.

Heat can be recovered before the waste water leaves the building, or it can be extracted from the sewer line. In some processes, solid matter is removed using conventional sewage technology, to make the liquid suitable for passing through a heat pump. Heat is extracted from the liquid component. The liquid sewage, once cooled, can then be recombined with the solid material and passed down the sewage line.

Strengths and weaknesses

Waste water heat pumps combine the established technologies of water source heat pumps and sewage technology with the considerable untapped resource of low-grade heat provided by sewage systems.

Opportunities

According to a leading manufacturer, 10 billion litres of sewage is created in the UK every day, and waste water is a constant energy source that contains sufficient heat to run the heating and cooling requirements of every industrial building in the UK.

The Linlithgow Energy Corridor "Heat from the Street" project aims to capture (using a heat pump) heat from waste water below Linlithgow's streets to heat public buildings. The report (dated 4 April 2016) concludes that "Heat from the Street is a viable project technically and funding wise."

In a demonstration project in Helsinki, Finland, which has been reported by BEIS, winter heat is recovered from sewage to assist a district heating network, where the heat recovered from the sewage is used to preheat the district return flow from 50°C to 62°C. The heat pumps were installed firstly because of their low cost of heat compared to gas boilers/CHP and secondly since a source of cooling was needed for the district cooling network. The installation was found to be economically attractive even without specific support for renewable heat generation. As a result, similar installations are being installed in other district heating/cooling systems in Finland. [Heat Pumps in District Heating, Case Studies, Element Energy and Carbon Alternatives, DECC, 2016]. The city of Vladivostok is also making extensive use of waste water heat recovery, showing that large-scale harvesting of heat from a city's sewage system is practicable.

Risks

The extraction of heat from waste water will lead to a reduction in the temperature of the sewage. This may present risk for downstream ecosystems, the extent of which may be dependent upon the scale of the system and the volumes of sewage in question.

Watch points

Availability of sewage and future prices of electricity may have an impact on the long-term potential for this technology.

Solar-Assisted heat pump

A solar-assisted heat pump (SAHP) is a technology that combines a heat pump and thermal solar panels to form an integrated system. A Solar Assisted Heat Pump transfers heat from collector panels to domestic heating and/or hot water. An external collector/absorber acts as an evaporator and utilises the heat in the atmosphere as well as direct solar radiation. Generally the absorber will be placed externally however in some cases it could be placed internally.

Strengths and weaknesses

The units are expensive but they can be reasonably economical to run and they require no maintenance. As per conventional heat pumps they will require a low temperature radiator circuit so are not ideal for retrofitting to existing radiators. They can also be recognised in SAP calculations. In Scotland, solar irradiance is relatively limited (although they can still operate without the help of sunlight) and this is likely to be a factor which limits their growth.

Opportunities

This technology could be attractive in properties where the installation of heat pumps would make sense, such as properties which are not on the gas network.

At present MCS mainly covers SAHPs which provide domestic hot water however it has one product which provides space heating.

Risks (including unintended consequences)

The main risk is that the incremental improvements in energy bills resulting from the use of the solar collectors will not be sufficient to justify their capital costs.

Watch points

Unit costs and research projects on the energy savings achievable with this type of technology.

BINE [http://www.bine.info/en/publications/themeninfos/publikation/elektrisch-angetriebene-waermepumpen/waermepumpen-plus-solar/] points out that whereas relevant guidelines exist for heat pumps and solar collectors, no corresponding standards are available for combined systems and that this could be a potential barrier to market.

Solar

PV-thermal (hybrid solar photovoltaic)

PV-T panels combine two well established renewable energy technologies, solar photovoltaics (PV) modules and solar thermal collectors, into one integrated component that removes generated heat from the solar PV thereby improving electrical efficiencies.

Domestic PV-T systems are normally installed for the following purposes;

- To provide a pre-heat for a hot water cylinder or thermal store to supply hot water
- To provide a pre-heat feed into a boiler for hot water and/or space heating
- To provide a pre-heat or direct feed for an air source heat pump
- To provide heat to charge a ground loop, borehole, earth bank or other inter-seasonal storage for a ground source heat pump (GSHP)
- To provide a pre-heat or direct feed for HVAC/ warm air heating systems

Strengths and weaknesses

On their own PV-T systems are not able to meet all hot water and space heating demands all year round in the UK. However, when incorporated as part of a hybrid heating system with an appropriately sized thermal store, it has the potential to meet half of electricity demand and over one third of hot water demand for a typical UK domestic property. One of the major benefits of PV-T technology, in comparison to PV only systems, is the potential to increase electrical generation efficiencies by extracting heat (for space heating or hot water) at an appropriate rate to maintain lower operational temperatures. This relationship between the two technologies does mean that flow temperatures in PV-T systems are typically 40 - 50°C which contrasts with the need for higher temperatures for hot water storage applications (typically 55 - 65°C). If a PV-T system is optimised for hot water temperatures then electrical generation efficiency can reduce to less than an equivalent solar PV module. The system needs a constant heat demand/sink to be most effective.

Opportunities

The possible growth markets for PV-T in the longer term are likely to include;

- Where there is limited roof space for installation (including zero carbon homes) or building where there is significantly high hot water demand (through the day and in the summer) - typically new build as retrofitting PV-T is more costly and complicated.

Risks

PV-T technology only makes technical and commercial sense where there is a suitable use for the low-temperature heat that the system can provide and therefore market growth will depend on how storage and heat demand change over time, and would require policy support.

Watch points

Potential barriers to the uptake of PV-T technology include;

- More complex system design and requirement for additional thermal storage capacity to ensure the system operates efficiently
- More technically demanding installation and installer availability
- Lack of awareness of the technology
- Longer financial payback than other solar technologies under current incentive rates

Solar Assisted, Positive Input Ventilation

Solar assisted, positive input ventilation uses solar collectors linked with (typically) a positive input ventilation system to provide pre-heated air to a property. Some systems offer additional functionality such as being able to divert the heat energy to a coil in domestic hot water cylinder or thermal store when the property is warm and no heat is needed by the ventilation system. PIV system typically doesn't interact with any other system, except where system have added functionality of being able to divert energy to a hot water store when there is no energy demand for the collected heat via the PIV system. In this case the system would need to be incorporated with a hot water cylinder with a solar coil or similar (which is likely to require existing cylinders to be replaced).

Systems generally installed in the loftspace so space is required. System is relatively straightforward to install. Once installed, the systems should operate quietly and should not disrupt occupants.

Strengths and weaknesses

PIV system are generally reliable systems and the solar collector uses air as opposed to being water filled. The main issues with the PIV system is likely to be maintenance/replacement of the air filters on a regular basis.

Can help support creating healthy environments. Relatively low impact on energy savings

Opportunities

PIV system offer advantage of the positive air pressure in the property driving out moisture and thus improving air quality and reducing risk of mould etc. Suited to retrofitting to existing dwellings as part of wider refurbishment. Not as suitable for new builds that typically have increased air tightness and most likely mechanical ventilation.

Risks

Unlikely to be significant potential to drive down costs via increased volume due to relatively low complexity of system.

Watch points

None.

Geothermal

Deep Geothermal

A deep geothermal system takes heat from depths exceeding 3 km below ground level and distributes it via a district heating system. Typically, flow and return pipes are installed in order to capture the ambient heat that exists deep below the ground.

Please also refer to the supplmenatry notes on "other geothermal" on the next page for additional considerations.

Strengths and weaknesses

A deep geothermal system can provide a steady supply of free heat for up to 50 years. The free heat is not subject to the prices of imported fuels and the system therefore offers significant potential for reducing energy costs and carbon. To work efficiently, the drill wells must be close to where the heat is needed – typically close to large population centres. Drilling can lead to small releases of noxious subterranean gases.

Opportunities

Advances in engineering mean that lower temperature resources in geologically stable regions are now usable.

In countries with an established industry, conventional geothermal plants are cost competitive already. Previous DECC research suggested that on a levelised cost basis, geothermal electricity from the lower temperature resources we have in the UK would be the same price as onshore wind electricity, and cheaper than solar or biomass. If the heat can be used, it is cheaper still, and the technology is still at a phase where substantial improvements are expected. Up-front costs associated with drilling down to 4 km appear to be the main obstacle to large scale roll-out. Another factor is the risk that a particular well might not work after the resources have gone into producing it.

The Eden deep geothermal project is described in more detail at http://www.edenproject.com/eden-story/behind-the-scenes/eden-deep-geothermal-energy-project#iLezXr5d6stRRmGU.97.

Risks (including unintended consequences)

The drilling of wells is expensive. In the initial drilling of a deep well, there is a high risk that the drills might be unsuccessful. There is a slight risk of earthquakes.

Watch points

Geological exploration, advances in drilling technology.

Other Geothermal

A geothermal system is usually considered to be 'deep' if the drill depth is around 3 km or more. For drills that are less than 3 km deep, useful heat can still be obtained from below the ground. For shallower drills, such as drills into aquifers, geothermal cooling is possible.

Strengths and weaknesses

Drilling involves high risk of failure, but successful drills will lead to a lasting heat resource.

Opportunities

Mine workings offer good opportunities in Scotland, and successful demonstration of geothermal resources has been demonstrated in Shettleston.

In a demonstration project at Wandsworth Riverside, reported by BEIS, heat pumps are used to extract heat from aquifers in winter, and in summer, unwanted heat is dumped into the same aquifers. In this way, waste heat in summer is effectively stored and used in the winter, providing seasonal heat storage - A key driver for the ground source heat pump system was the need to meet the renewable energy requirements of the London Plan and the accessible aquifer system also provided an efficient solution to the problem of where to reject heat from the use of chillers.

Risks (including unintended consequences)

Drill sites can still fail, but the risks are likely to be less than for deep geothermal

Watch points

Drilling technology, geological exploration, economic viability of geothermal when electricity and gas prices are considered

Hydrogen / Fuel Cells

Hydrocarbon Fuel Cells

A hydrocarbon gas fuel cell uses gas, normally from fossil fuels, and incorporates specialist electrodes to produce electricity and heat (cogeneration) through an electrolytic process.

Strengths and weaknesses

In general, a decentralised micro-CHP fuel cell system can be more efficient than the typical current combination of the grid plus a boiler, as there is less inefficiency associated with energy conversion and transmission losses. But a central issue in designing fuel cell CHP is that electricity and heat demand in homes are independently variable, both diurnally and annually, which makes sizing a small generator for a home very difficult. At one extreme, the generator can provide even the highest peak demand of the home, in which case it will be very expensive and not used at full capacity for the vast majority of the time. Sizing it to only provide the baseload power, so it will run permanently at high efficiency, means that the by-product heat it produces must also be used and something else must supply the remainder of the power for peak demand. It is essential to use (or store) all of the generated heat to ensure maximum efficiency of these systems.

Opportunities

Best suited to systems which can provide constant heat sink, so applications relatively restricted – although good design and thermal storage can mitigate. Large scale systems could be used in a CHP scheme or similar.

Viessmann has developed an integrated unit which incorporates a hydrocarbon fuel cell and this has been successfully deployed in Teterow to provide a combination of heat and power (http://www.viessmann.co.uk/en/residential-buildings/combined-heat-and-power-generation/micro-chp-unit-based-on-a-fuel-cell/vitovalor-300p.html).

Risks (including unintended consequences)

The technology is expensive and the electrodes are vulnerable to contamination. Incorrect sizing of the fuel cell could lead to heat being wasted, or not used which would in turn reduce the effectivenss of electrical generation.

Cost, maintenance issues and a long warm-up and cool-down time have been cited as barrier to increased market take up.

Watch points

Research is leading to improvements in their performance. Good design of the heating system is also essential. Research appears to be promising for the future improvement of this technology through increased efficiencies (Abstract of "Solid Oxide Fuel Cell Anode Materials for Direct Hydrocarbon Utilization" Authors Xiao-Ming Ge, Siew-Hwa Chan, Qing-Lin Liu, Qiang Sun. First published: 24 August 2012).

Hydrogen Fuel Cells

A hydrogen fuel cell uses hydrogen gas, and incorporates specialist electrodes to produce electricity and heat (cogeneration) through an electrolytic process. The two principal types are SOFCs and PEMFCs. SOFCs are usually preferred for stationary deployments such as domestic microCHP whereas PEMFCs are more likely for transport applications.

Strengths and weaknesses

Hydrogen is considered to be a low carbon fuel, and can, for example, be generated from surplus electricity. With the increased use of renewable energy generation, hydrogen fuel cells offer an opportunity to maximise the use of peaks in electricity generation from renewable sources.

Hydrogen is considered to be a good fuel for fuel cells because there are usually no risks of carbon deposition or poisoning of the catalyst e.g. by the odorant present in natural gas, although it is likely that hydrogen supplied through gas distribution networks will require such additives to facilitate leak detection and this may subsequently need removal. Stack lifetimes and capital costs are considered to be weaknesses.

In general, a decentralised micro-CHP fuel cell system can be more efficient than the typical current combination of the grid plus a boiler, as there is less inefficiency associated with energy conversion and transmission losses. But a central issue in designing fuel cell CHP is that electricity and heat demand in homes are independently variable, both diurnally and annually, which makes sizing a small generator for a home very difficult. At one extreme, the generator can provide even the highest peak demand of the home, in which case it will be very expensive and not used at full capacity for the vast majority of the time. Sizing it to only provide the baseload power, so it will run permanently at high efficiency, means that the by-product heat it produces must also be used and something else must supply the remainder of the power for peak demand. It is essential to use (or store) all of the generated heat to ensure maximum efficiency of these systems.

Opportunities

Hydrogen fuel cells have the advantage over natural gas fuel cells that they have lower material and component costs, largely because they do not need to incorporate a steam reformer.

A DECC report [no. 30686, July 2016] says that according to fuel cell manufacturers, the technology for using hydrogen in fuel cell appliances is already available with a supply chain generally present for the necessary product components. The majority of components are off-the-shelf and all components outside of the stack already exist at scale. It is estimated that approximately 1-2 years will be necessary for product design, safety architecture and compliance modifications. For scaling stack production, however, additional facilities will need to be built. Increasing stack lifetime should be an R&D priority going forward. However, a barrier to large-scale deployment is importantly cost which in turn relates to technology development, field trials, scale of production and data collection.

As for market development, sales of fuel cells in all applications Europe are low, including for stationary power. Nevertheless, for fuel cell mCHP Europe probably ranks second to Japan in terms of its near-term potential, with a number of current and past support schemes creating sufficient interest for large manufacturers to become engaged. However, these support schemes are much smaller than those in Japan and expected to remain so. In addition, Europe has more manufacturers and more different system designs so cost reduction through manufacturing volume and supply of similar parts is likely to be limited for some time. The different system designs are in part due to the different underlying technologies; in part to the different heating, electricity and hot water requirements in countries with both different climates and different buildings standards.

Hydrogen technology in general is most attractive in areas that are away from the existing gas network and/or link with renewable generation.

Risks (including unintended consequences)

The success of large-scale roll-out will depend very much upon fuel availability, future unit costs, installation costs and stack lifetimes.

Watch points

Future potential generation of hydrogen, and costs of generating/transporting it. Scrubbing technology for ensuring clean hydrogen. Consideration of whether hydrogen should be piped to homes or supplied in bottle form. Future research and development of fuel cells. Warning – hydrogen as a fuel is also likely to have to complete with application in energy storage and transport.

According to a DECC report [no. 30686, July 2016], hydrogen fuel cells (PEMFC and SOFC) are TRL 9 for some applications, but still require subsidies for many applications as they are not yet fully commercially mass-produced.

Development activities currently focus on cost reduction and stack lifetime improvement. Current lifetimes for stationary applications vary, with Japanese companies warrantying residential PEM CHP units up to 60-80,000 hours with the ENEFARM fuel cell warranting up to 10 years. Other types of fuel cell achieve around 30,000 hours with developers aiming to double this by system optimisation and development of more robust materials.

Hydrogen boilers & burners

A hydrogen boiler burns hydrogen gas to produce hot water to be used for space heating and/or domestic hot water. Options include flame burners and catalytic burners.

Strengths and weaknesses

A domestic gas boiler could be powered by a hydrogen pipe network or by bottled hydrogen gas.

Hydrogen boilers need different designs from those of other fuels because of the different wobbe indexes, flame speeds and appropriate emissivities (although the wobbe index for hydrogen is actually quite similar to that of natural gas). For this reason, hydrogen gas cannot simply be piped to an appliance which is configured for a different gas mixture. Small changes to the gas composition can typically be tolerated however, and in Germany some hydrogen is added to the natural gas (up to 3% by volume) thereby reducing the carbon content of the gas network slightly. The Scottish Government is supportive of Scotia Gas Network's interest in the practical demonstration of blending hydrogen with natural gas in the network, and the draft Climate Change Plan pathway for Scotland includes a moderate amount of hydrogen in the gas network from the mid-2020s.

A high percentage of wall mounted boilers are now sold with a back plate which both serves to fasten the boiler on the wall but also acts as a manifold for gas and water connections. This has valves which vastly simplifies the process of replacing the boiler. It is frequently the time taken to securely fasten this backplate to the wall and make the appropriate connections which takes the majority of the time for a new boiler installation. The idea of making new hydrogen boilers share a common back plate with existing natural gas is attractive to many manufacturers and this has the potential to reduce conversion times from (for example) a day to less than 2 hours. Such a design, whilst not technically 'dual fuel', considerably simplifies and speeds any conversion process.

Opportunities

Boilers / hydrogen boilers could potentially assist in reducing carbon emissions by utilising low carbon hydrogen gas.

According to previous DECC research, boiler manufacturers are confident that the cost and time uncertainties together with the other barriers associated with hydrogen technology can be overcome as the industry develops.

It should be possible to introduce areas of the gas network where hydrogen fuels 100% of the gas demand – as is proposed by the H21 Leeds City Gate project.

Risks (including unintended consequences)

The necessary standards and codes for hydrogen boilers are currently lacking and need to be developed. From the point of view of suppliers, hydrogen installation standards are considered to be more urgent than hydrogen product standards. It could take approximately 2 years to develop standards. New sales and distribution channels are unlikely to be needed as current boiler manufacturers could use existing channels. A hydrogen quality standard is important, although manufacturers may be able to pre-filter / treat the gas. Gas quality/purity is more critical for catalytic combustion than it is for flame combustion.

Watch points

In the development of hydrogen boilers, additional costs will be incurred in the R&D, product design and initial manufacturing phases above those normally incurred for natural gas appliances, and according to DECC research these might need to be supported within a stable regulatory and political framework. This would principally consist of a clear policy direction towards a market for hydrogen-using appliances, together with a staged plan showing the number of appliances that would be likely to be required at each stage. This could perhaps be supported by funding to create the necessary conditions for manufacturers to invest and engage in the roll-out, which could range from support for RD&D, through to support for a testing facility to allow multiple manufacturers to test appliances over long durations where a relatively large supply of hydrogen would be required.

While more analysis will be required, there is some evidence to suggest that hydrogen can offer significant cost savings for customers compared to alternative low carbon heat sources such as electricity, or district heating. A recent KPMG report also found it more practical and more acceptable to customers.

Hydrogen gas at scale will most likely require natural gas (methane) as the source feedstock and as such in order to be low carbon, carbon capture and storage facilities will be a necessary system requirement. Scotland is, however, well placed to support an emerging hydrogen economy, at least in the areas that are well away from the natural gas grid. In these areas hydrogen, perhaps generated from renewables, could potentially be used as a substitute for conventional bottled gas. In rural areas, hydrogen technology for heating might potentially be generated from surplus locally-generated electricity and/or from locally-generated biogas.

Proposals to use hydrogen, at national scale, have the potential to substantially support decarbonisation, but they will require further innovation in technology, high-volume hydrogen production at an acceptable cost, and a carefully managed hydrogen 'switch over' – as with the switch to natural gas in the 1970s.

That said, coordinated activity by the public and private sectors over the next five to ten years will be essential to achieve any large-scale roll out of hydrogen and fuel cell technologies from the mid-2020s.

Cogeneration

CHP

Combined Heat and Power (CHP) is the efficient cogeneration of power and useful heat energy by a single unit. During large scale electric generation (e.g. in power stations) waste heat is typically rejected to the atmosphere, whereas with CHP the heat is captured for use. CHP is therefore more thermally efficiency that electrical generation alone. CHP system can reclaim approximately 80% of the heat energy that would otherwise be wasted which results in greater overall efficiency, reduced carbon dioxide emissions and in many cases reduced costs of energy. Cogeneration and trigeneration can use a variety of fuels including fossil fuels (e.g. natural gas, oil), biogas or biomass.

CHP is a well-established way of producing energy with systems being utilised throughout Scotland on various scales. CHP can be an attractive option particularly for large scale operations where they can serve large buildings, or be used in district heating schemes, etc. Examples of this type of use in Scotland include at the University of Edinburgh where CHP is used to provide electricity and heat to campus buildings.

CHP also has the potential to reduce carbon dioxide emissions further by utilising low and zero carbon fuels such as biogas to produce heat and electricity (see biogas CHP section).

NB: when fueled by a fossil fuel, CHP cannot be considered a truly sustainable long term solution but rather it will help reduce emissions as a result of making more efficiency use of the fossil fuel. It is therefore useful where more sustainable options are not yet available or affordable.

Biogas CHP

Biogas is a gaseous mixture of methane (natural gas), carbon dioxide, and a few other trace compounds. It is produced when organic matter is broken down by bacteria in the absence of oxygen. It occurs naturally but it can be produced artificially in what are known as anaerobic digesters. The biogas mixture can be purified, or ‘scrubbed’, to remove most of the carbon dioxide and other trace compounds so that the resulting methane, or ‘biomethane’, can be injected directly into the mains gas network or used elsewhere as natural gas would be.

Strengths and weaknesses

Biogas is a 100% renewable resource since it is produced from organic material which can be produced in very short periods of time in comparison to the formation of fossil fuels such as coal, oil and gas. Biogas is not pure methane, however, and its calorific value differs from that of methane. Biogas will therefore not be immediately compatible with gas boilers which are configured to use natural gas. In the absence of a biogas grid, to be cost-effective, the source of biogas needs to be steady and ideally local to the CHP unit.

Opportunities

Scotland has an abundance of available organic waste streams which can be used as feedstocks for anaerobic digesters in order to produce biogas. For example in the food and drinks industries, agricultural industries and from domestic and commercial food waste. Focus needs to be placed on understanding the quantities of ‘free’ organic feedstocks which are available, the correct sizing of equipment, maintenance and operation requirements of associated equipment to make sure it is economically viable in respective situations.

Risks (including unintended consequences)

Biogas can contain corrosive gases which can affect equipment.

Watch points

Developments in biogas technology an fuel generation. Demonstration projects.

Micro CHP

Micro Combined Heat and Power (mCHP) refers to CHP units which are typically less than 45kW(thermal) in output capacity – and are therefore suited to a number of building energy applications including domestic and commercial applications.

Strengths and weaknesses

Making use of both the heat and electricity is highly efficient however system operate most effectively when running long hours (ideally 24/7) so there needs to be sufficient heat demand or storage capacity to facilitate this.

mCHP system are typically fueled by gas or oil. Gas systems can utilise existing mains gas connections should one exist. Systems can also be reasonably easily integrated with existing heating pipework for hot water and heating requirements. They can utilise mains electricity for start-up and shut-down operations as well as potentially for export options. However heat led micro CHP may have shortfall in electricity production so will require additional electricity 'top-up' from mains electricity.

Capital costs of mCHP are significantly higher when compared with a standard gas-fired condensing boiler.

Opportunities

Most suitable for domestic or small scale non-domestic operation where there is a near constant demand/sink for heat (e.g. commercial development, industry, health centres, care homes etc.). Micro CHP can be utilised in off grid situations where a main gas grid connection isn't available by using LPG or oil as the fuel source. Micro CHP units are generally most suited to buildings with higher and longer heat demand periods if cost savings and carbon reductions are to be made vs standard condensing boilers.

Risks (including unintended consequences)

Incorrect sizing of a system could lead to heat being wasted. Must be well maintained correctly to ensure reliability and efficiency.

Watch points

Micro CHP is a growing area of research with units becoming ever more economically and technically viable for small-scale situations such as in a domestic setting.

Electricity generated via Micro CHP which are less than 2kW in capacity can generate income via the Feed-In-Tariff which is currently the highest offering tariff at ~14p/kWh[6].

[6] Ofgem. FIT tariff 1 April 2017 to 30 June 2017.

Trigeneration

Combined Cooling Heat and Power (CCHP)

Combined cooling, heating and power (CCHP), or tri-generation, is the process of generating electricity whilst using the by-product from power generation to generate both useful heat and coolth (e.g. via an adiabatic chiller which can provide coolth via chilled water at ~10 degrees centrigrade minimum).

These systems typically consist of a gas engine, an electricity generator, a heat exchanger and an absorption chiller. The gas-fired generator produces heat as well as electricity. This exhaust heat is then passed to the absorption chiller which uses it to produce cooling energy. The resulting energy can be used for chilled water and/or hot water for air conditioning. The ratio of the electricity produced to the exhaust heat for the absorption chiller can be varied to meet specific requirements.

Strengths and weaknesses

The main strengths of CCHP are system efficiency and carbon saving potential. CCHP systems have a higher efficiency than conventional heat generation systems and typical CHP systems. However, it should be noted that the greatest efficiency is generally achieved only in applications that have a constant electrical, heating and cooling demand throughout the year.

Weaknesses include high capital costs and maintenance

Opportunities

Opportunities for deployment will require suitable site energy demands to match the outputs of the CCHP system. Opportunities may include commercial offices, university campuses, etc.

Risks

No significant risks to property or health identified. Given that CCHP provides heating, coolth and power there is increased risk that failure of the unit can impact significantly on the buildings operations, however systems are likely to provide base load heating/coolth, so auxiliary/top-up systems will still be available to provide some level of back-up.

Watch points

CCHP is most effective only in suitable climates / development types where there is a need for power, heating and cooling all year.

District Heating

4th Generation (Low Temperature) District Heating

The 4th Generation District Heating (4GDH) system is defined as a coherent technological and institutional concept, which by means of smart thermal grids assists the appropriate development of sustainable energy systems. 4GDH systems are designed to provide heat to low-energy buildings, with low grid losses in a way in which the use of low-temperature heat sources is integrated with the operation of the smart energy system.

(Please note that a separate scoresheet has also been prepared for 3rd generation district heating)

Strengths and Weaknesses

The concept is based on low flow temperatures meaning that it is generally unsuitable for retrofits and suited to supplying new build, low energy properties (where the carbon saving potential associated with fourth generation district heating is a considerable strength).

Due to the conceptual nature at present, it is not simple to predict the uptake of fourth generation district heating – currently 1st/2nd generation systems are being replaced by 3rd generation systems.

Opportunities

There is a realistic opportunity for fourth generation district heat to sit within a complete smart energy grid in Scotland however it is unclear how far in the future this is likely to happen.

Risks

Fourth generation district heating relies on low energy buildings as well as other smart / renewable technologies. There is a risk that, should there be no advance in all parts of the system, then the success/uptake of fourth generation would be at risk.

Watch points

See risks above.

Local Heaters

Infrared Heating

Infrared heaters work by heating building occupants (and the surface areas of a room) via infrared radiant energy as opposed to occupants attaining thermal comfort via a mixture of the air temperatures and room surfaces temperatures, as is the case with traditional wet (and other) forms of heating. The emitter of the heat energy is either composed of a steel tube (tube heater) or a ceramic surface (luminous heater) which is heated to a design temperature. Reflectors and positioning of the heaters ensure the radiant heat gets to where it needs to go.

Radiant heating is often one of the most suitable forms of heating in intermittently occupied, high thermal mass (e.g. churches) or draughty buildings (e.g. industrial buildings)

Strengths and weaknesses

Applications where the technology will save considerable energy/carbon is generally very limited.

Only likely to save significant energy/carbon in selected applications within buildings (e.g. buildings with high levels of ventilation and drafts and/or high thermal mass).

Opportunities

If electric infrared heaters are used in conjunction with a renewable supply then they can effectively be a low or zero carbon form of heating.

Risks (including unintended consequences)

Since it is based on electrical resistive heating, with an efficiency of only 100%, operating costs are likely to be high out with applications in intermittently occupied, high thermal mass or draughty buildings.

Watch points

None.

Electric Storage Heaters (high heat retention)

Electric storage heaters work by using electricity to generate heat which is then stored in a thermal storage material within the heater which can then be released into a room at a later time when required. Traditionally electric storage heaters were designed for customers to take advantage of cheaper electricity which was offered at off-peak times through tariffs such as Economy 7 or Economy 10. Modern units can be extremely well insulated and of high heat retention design often also offering better time and temperature controls. In addition, new energy storage materials are being developed which may more effectively retain large quantities of energy in order to improve the technology further.

Strengths and weaknesses

Carbon saving potential when (i) replacing old inefficient electric storage heaters, or (ii) when supplied with renewable electricity. Produce more carbon emissions than standard gas central heating if mains electricity is used.

Modern electric storage heaters offer better heat retention and improved user control. Electric storage heaters charge controls can take advantage of cheaper night time tariffs such as Economy 7 or 10 thereby assisting development of smart grids.

Since they are supplied by electricity this can often make them an expensive way of heating a building meaning low acceptance by consumers. Making use of off peak tariffs and the better system controls offered by modern systems help make them more acceptable.

Since it is based on electrical resistive heating, with an efficiency of <100%, life cycle costs are typically high - although system enable use of cheaper, off peak electricity.

Opportunities

Can be used in any building where an electricity supply is available, however only likely to save significant energy/carbon in building with older, inefficient storage heating.

One of the main advantages of electric storage heaters is their application within active network management system. E.g. if renewable generation is greater than demand then the low carbon electricity could be stored in the electric storage radiators to be used at a later time by consumers. This approach can provide wider benefit to the electrical system as Scotland / UK increases renewable generation.

Such an approach has been successfully trilled in the NINES project in Shetland.

Risks (including unintended consequences)

None. The technology is well-established.

Watch points

Decarbonisation of the grid. Off peak tariffs structures. Advances in active network management.

Heat Recovery

Waste Water Heat Recovery

The heat from waste water from a shower or bath can be recovered by transferring its heat to incoming cold water. In the case of showers, this is typically done using a contra-flow heat exchanger. In the case of a bath, heat from bathwater can be stored in a tank which transfers some of its heat to incoming cold water.

Strengths and weaknesses

Heat energy (that would otherwise be lost down the train) is captured by the system and pre-heats the incoming cold water supply to the shower thereby saving a relatively small amount of energy. This technology offers maximum potential in applications with lots of lengthy showers e.g. swimming pools, hotels and sports centres.

Compatible with mixer showers (may not be compatible with all electric showers - checks needs to be made). Systems can be under-shower tray type units or heat recovery coils around waste pipe type units. Suited to new build. More disruption / more costly to retrofit.

Waste water heat recovering is recognised in SAP and its use can improve SAP ratings.

Opportunities

The capital cost is most easily justified in sports facilities or other places where showers are heavily used.

Risks (including unintended consequences)

More suited to new build. More disruption / more costly to retrofit.

Watch points

None.

Passive Flue Gas Heat Recovery

Passive Flue Gas Heat Recovery (PFGHR) is a technology which gathers waste heat from flue gases which are produced during combustion. Typically, PFGHR is used in conjunction with gas/oil boilers in domestic settings where the waste heat expelled through the flue is recovered to preheat the input water to the boiler reducing overall heating requirements for domestic hot water or central heating. PFGHR typically cannot be used with condensing boilers as they already capture energy from the flue gasses by condensing the flue gas in an additional heat exchanger.

The term 'Passive' is used to indicate that the system requires no additional electricity input to operate whereas an Active Flue Gas Heat Recovery system does require additional electricity input.

Strengths and weaknesses

PFGHR is primarily used with combination boilers over system-type boilers because of the higher complexity of utilising a PFGHR in a system with a separate hot water cylinder which leads to higher overall costs. Since combination boilers dominate the consumer market over system type boilers focus is generally being placed by manufacturers on expanding the PFGHR market in this area. At present there are approximately 100,000 PFGHR devices installed in the UK. A major driver for PFGHR installations is to achieve a greater SAP rating particularly in the case of new build properties.

Opportunities

A PFGHR system varies typically between £250 and £650. Cost vary based on the design of the system such as the use of additional thermal storage being a major contributing factor. PFGHR devices without additional thermal storage will only provide energy savings when the boiler is only heating domestic hot water or 'summer' mode. Conversely those with additional thermal storage (typically 5 – 10 extra litres) provide energy savings in both domestic hot water and space heating modes.[7]

Risks (including unintended consequences)

Not suitable for all boilers. Not suitable for condensing boilers. More complex/costly for installing on system boilers versus combination boilers.

Watch points

Unit costs, installation costs.

[7] Evidence Gathering: Passive Flue Gas Heat Recovery Technologies (2016). BEIS

Active Flue Gas Heat Recovery

Active Flue Gas Heat Recovery (AFGHR) is a technology which gathers waste heat from flue gases which are produced during combustion. AFGHR can be used in conjunction with boilers where waste heat expelled through the flue is recovered using a heat pump, or other active means, to preheat the return/input water to the boiler, effectively increasing the efficiency of the boiler. [In some systems, the heat could be injected into the input air to the boiler, but in such systems, the burner often needs to be altered or changed in order to cope with the higher temperature of the input air.]

The term 'Active' is used to indicate that the system requires significant electricity input (or a sorption heat pump) to operate.

Strengths and weaknesses

For old, large boilers, of the order of 2000 kW, a payback period of 2-5 years could be achieved.

Opportunities

Recent research suggests that active flue gas heat recovery could be used even in conjunction with solid biomass burners, suggesting that it could be a way of improving the efficiency of district heating schemes.

According to Ion V. ION, Gheorghe CIOCEA, Florin POPESCU, "WASTE HEAT RECOVERY TECHNOLOGIES FROM HEATING BOILER FLUE GAS", the use of heat pumps for heat recovery from heating boilers represents a viable technology to improve the boiler efficiency, economic and environmental performance. The most efficient heat pump based heat recovery technology uses absorption heat pump and direct-contact heat exchangers. The techno-economic analysis of two heat recovery systems integrated with a 2000 kW heating boiler (electric heat pump and absorption heat pump) has shown that the electric heat pump system has a higher electricity cost and capital cost which leads to a higher total annual cost. The payback period of the electric heat pump system is over 2 times higher than that of the absorption heat pump system. The advantage of electric heat pump system consists in the lower greenhouse gas emission due to lower fuel consumption.

Risks (including unintended consequences)

Not suitable for all boilers. May not be cost effective in some applications. With some fuels, corrosion might be a factor to consider.

Watch points

Demonstration projects.

Appendix C – Typical Applications and Potential for Carbon Savings

Class	Intervention	Typical applications: Community / District Heating	Domestic	Public	Commercial	Industrial	on-gas grid	off-gas grid	Notes regarding potential applications for realising maximum carbon savings (NB: the applications noted below are not exhaustive and other applications are likely to exist)
Heat pump	high temperature heat pump	y	y	y	y	y		y	Replacing old, inefficient off-gas grid boilers (which serve high temperature distribution systems)
	gas driven heat pump	y	y	y	y	y	y		Replacement for on-grid gas boilers. Off-grid LPG options may also present opportunities but at higher cost.
	hybrid heat pumps		y	y	y	y	y	y	Applications as an add-on hybrid to retrofit to existing fossil-fueled boilers (on/off grid), or as an alternative to (old or inefficient) off-gas grid boilers
	waste water heat pump	y		y			y	y	Medium to large scale applications which present a substantial heat load within close proximity of a suitable sewage supply e.g. district heating or large public, industrial (including process heat load) or commerical buildings (or groups thereof)
	solar-assisted heat pump		y	y	y	y		y	Generally not as efficient as other forms of heat pumps and solar irradiance levels in Scotland imposes limitations. Likely to offer best carbon savings when replacing direct electric heating.
Solar	PV-thermal (PV-T) (hybrid solar photovoltaics)		y	y	y	y	y	y	More suited to new build applications. Only provides relatively small amount of useable heat so unlikley to serve entire building heating loads. PV-T can however provide some useful contribute where building have a demand for heat during times of PV generation e.g. sports centres, new build dwellings with thermal storage, etc.
	solar collector assisted, positive input ventilation		y	y	y	y	y	y	Relatively low savings potential. Domestic or small commercial applications where PIV can also help create healthier internal environments
Geothermal	deep geothermal	y					y	y	Large scale application due to cost. To be viable this technology will typically serve a district heating network. Suitable geological conditions are also required. Best opportunities are therefore likely to be district heating locations in or near cities.

Typical applications

Class	Intervention	Community / District Heating	Domestic	Public	Commercial	Industrial	on-gas grid	off-gas grid	Notes regarding potential applications for realising maximum carbon savings (NB: the applications noted below are not exhaustive and other applications are likely to exist)
Hydrogen / Fuel Cell	hydrocarbon fuel cell (cogeneration)	y	y	y	y	y	y		Best opportunities are in buildings where there is sufficient heat demand to ensure that all heat and electricity (co-generated by the unit) can be utilised e.g. dwellings with thermal storage (and good design), commercial buildings with high or constant heat demand (e.g. sports centres), etc. Regarding dwellings - less likley to be suitable for modern or new build dwellings due to their signfiicantly reduced heat requirement
	hydrogen fuel cells (cogeneration)	y	y	y	y	y		y	Lack of cheap hydrogen (and infrastructure) is currently restrictive. However, best opportunities will be as per hydrocarbon fuel cell above.
	hydrogen burners / boilers	y	y	y	y	y		y	Lack of cheap hydrogen (and infrastructure) is currently restrictive. First opportunities are likely to be with locally produced hydrogen supply serving off-grid applications, however longer-term opportunities will eventually be as replacement for on-grid boilers.
Cogeneration	biogas CHP (cogneration)	y		y	y	y		y	Currently unlikely to compete where a main gas connection is available. Best opportuntities are where a local biogas supply is available (or where large quantities of organic waste is available to produce biogas) and where there is a constant demand for heat (e.g. industrial processes, district heating, etc.)
	microCHP - heat led (cogeneration)		y	y	y	y	y		Most suitable for domestic or small scale non-domestic applications where there is a near-constant demand for heat e.g. commercial developments, industrial buildings, etc.) or where thermal storage can make effective use of the heat e.g. dwellings withrelatively high or constant heat loads. Micro CHP can be utilised in off grid situations where a main gas grid connection isn't available by using LPG or oil as the fuel source. Micro CHP units are generally most suited to buildings with higher and longer heat demand periods if cost savings and carbon reductions are to be made vs standard condensing boilers.
Trigeneration	Combined Cooling Heat and Power (CCHP) (trigeneration)	y		y	y	y	y	y	Applications are likely to be relatively restricted due to the technology needing to be matched (and well designed) to suitable applications where there is simultaneous demand for heat, electricity and chilled water cooling e.g. district heating, large public or commercial developments. Currently the economics and practicailities of CCHP (versus say a boiler/heat pump and seperate cooling system) do not always stack up.

Class	Intervention	Typical applications							Notes regarding potential applications for realising maximum carbon savings (NB: the applications noted below are not exhaustive and other applications are likely to exist)
		Community / District Heating	Domestic	Public	Commercial	Industrial	on-gas grid	off-gas grid	
District heating	3rd generation district htg	y					y	y	Opportunities in high heat density areas e.g. high rise flats, mixed use developments, etc.
	4th generation (low temperature) district htg	y					y	y	Low temperature distribution of 4th generation system are best suited to serving well insulated, low energy buildings (so suited to new build or major refurbishment)
Local heaters	infrared heaters		y	y	y	y	y	y	Can be used in any building where an electricity supply is available, however only likely to save energy/carbon in selected applications e.g. buildings with high levels of ventilation and drafts, intermittent occupancy and/or high thermal mass. Examples could include: churches, community halls, some historic buildings, etc.
	electric storage heaters (high heat retention)		y	y	y	y		y	Can be used in any building where an electricity supply is available, however only likely to offer energy/carbon savings as a replacement within buildings with older, more inefficient storage heating.
Heat recovery	waste water heat recovery	y	y	y	y	y	y	y	Best opportunities are in applications where there is significant shower use. Increasingly widely used in new build dwellings. Less suitable for retrofitting. Also suitable for other building types e.g. sports centres, hotels, secondary schools, etc.
	passive flue gas heat recovery	y	y	y	y	y	y	y	There are potentially many existing boilers suitable for being retrofitted with a PFGHR device, across the domestic and non-domestic sector in scotland (~ tens of thousands of boilers) - although arguably these could benefit further from replacement with a new boiler, heat pump, etc.
	active flue gas heat recovery	y		y	y	y	y	y	flue gas is relatively plentiful and hot such as in a large existing building (including mainly older less-efficient boiler/flue systems), district heating boilers, etc.

Appendix D – Current SAP Status

Class	Intervention	Domestic	in SAP 2012?	Notes
Heat pump	high temperature heat pump	y	y - see notes	The SAP heat pump calculation method (*) allows for high temperature heat pumps. SAP 2012 cannot accept higher temperatures than 55°C, however SAP 2016 (when released) will allow for design flow temperatures up to 65°C. Temperatures above 65°C currently cannot be supported in SAP 2016.
	gas driven heat pump	y	n	The "Application for recognition of a new technology category route (Appendix Q)" applies **
	hybrid heat pumps	y	n	Current guidance exists as to how assessors should model specific hybrid units, although in general the "Application for recognition of a new technology category route (Appendix Q)" applies (**).
	solar-assisted heat pump	y	y	
Solar	PV-thermal (PV-T) (hybrid solar photovoltaics)	y	n	The "Application for recognition of a new technology category route (Appendix Q)" applies (**)
	solar collector assisted, positive input ventilation	y	y	
Hydrogen / Fuel Cell	hydrocarbon fuel cell (cogeneration)	y	n	The "Application for recognition of a new technology category route (Appendix Q)" applies (**)
	hydrogen fuel cells (cogeneration)	y	n	The "Application for recognition of a new technology category route (Appendix Q)" applies (**)
	hydrogen burners / boilers	y	n	The "Application for recognition of a new technology category route (Appendix Q)" applies (**)
Cogeneration	microCHP - heat led (cogeneration)	y	y	
Local heaters	infrared heaters	y	y - see notes	Electric (direct acting) room heaters (all types) (i.e. including radiant heaters) are currently included in SAP. Please refer to the "treatment of electrical panel heaters in SAP - all types" principle paper (***) for more information.
	electric storage heaters (high heat retention)	y	y	
Heat recovery	waste water heat recovery	y	y	
	passive flue gas heat recovery	y	y	

Notes:

Product data is held in either the Product Characteristics Database (PCDB) or the SAP Appendix Q database in support of the National Calculation Methodologies (NCM) for Energy Rating Dwellings. NB: SAP does not 'approve' products.

* see http://www.ncm-pcdb.org.uk/sap/filelibrary/pdf/Calculation_Methodology/SAP_2012/CALCM-01---SAP-REVISED-HEAT-PUMP-PERFORMANCE-METHOD---V1.1.pdf

** more information on the "applying for recognition of a new technology" is available here: http://www.ncm-pcdb.org.uk/sap/page.jsp?id=20

*** see here for the "principle paper" on the treatment of electrical panel heaters in the NCM: http://www.ncm-pcdb.org.uk/sap/page.jsp?id=37

For more information please refer to: http://www.ncm-pcdb.org.uk

Appendix E – Useful references and supporting information

Heat pumps

[1] Evidence gathering – Low Carbon Heating Technologies, Domestic High Temperature Heat Pumps, BEIS, November 2016.

According to this report, COPs from 2.2 to 3.1 have been quoted at A7/W65 (i.e. ambient air source at 7°C and water output at 65°C) for the air source products studied. High temperature heat pumps are well covered by existing heat pump standards and regulations for performance and design. The price of high temperature heat pumps ranges from 20% to 35% more than standard heat pumps, but the price premium based on fully installed costs is closer to 10-20%. The product price for high temperature heat pumps ranges from £3,000 - £7,000 (air source), with the fully installed price ranging from £6,000 to £14,000.This compares with a typical gas fired boiler replacement cost of £2,500. Small cost savings are possible relative to a gas fired boiler, but these would be unlikely to give an economic payback period at current energy prices in the absence of incentives. It would appear reasonable to say that compatibility with existing systems is very good for high temperature heat pumps because they can service heating systems which conventional heat pumps could not service without immersion top-up. It is noted that some high temperature heat pumps can provide heat at temperatures up to 80°C either by using carbon dioxide, propane and ammonia or by using a double cascade or a sorption cycle.

[2] Star Renewable Energy http://www.neatpumps.com/about-us.aspx

Star reports that output temperatures of 90°C can be achieved using high temperature heat pump with an ammonia cycle, and they have demonstrated this in a 14MW scheme in Drammen, Norway.

[3] Evidence Gathering – Low Carbon Heating Technologies, November 2016, Domestic High Temperature, Hybrid and Gas Driven Heat Pumps: Summary Report, BEIS, 2016.

[4] Heat4U project, Gas Absorption Heat Pumps Solution for Existing Residential Buildings, FP7/2007-2013, Grant Agreement 285158. http://www.heat4u.eu/en/

Results of field trials suggested that this type of heat pump could achieve 35% better than a conventional gas condensing boiler.

[5] Gas heat pumps : product overview: Engine driven heat pumps & Thermally driven heat pumps. Juliette PROMELLE, GDF SUEZ, Research division, 2011.

This paper suggests that gas engine heat pumps can achieve COP values of up to 2 if they incorporate flue gas heat recovery, but without flue gas heat recovery their COP tends to be in the range of 1.2 to 1.6. Thermally-driven heat pumps (gas absorption and gas adsorption) tend to have a 30% higher efficiency than gas condensing boilers (thermally driven gas sorption heat pumps use thermal compression instead of mechanical compression). According to this paper, gas engine heat pumps tend to be used for offices, hospitals and housing whereas thermally driven heat pumps are more likely to be used for housing.

[6] BINE information service, Energy research for application, Solar-assisted heat pumps, 2013. [http://www.bine.info/en/publications/themeninfos/publikation/elektrisch-angetriebene-waermepumpen/waermepumpen-plus-solar/]

BINE points out that whereas relevant guidelines exist for heat pumps and solar collectors, no corresponding standards are available for combined systems (i.e. solar assisted heat pumps), warning that this could be a potential barrier to market.

Solar

[7] Evidence Gathering – Low Carbon Heating Technologies - Hybrid Solar Photovoltaic Thermal Panels, DBEIS, 2016

This report examines various types of systems, looking at the current state of the art, a market and product review, performance and costs.

Geothermal

[8] The Eden deep geothermal project is described in more detail at http://www.edenproject.com/eden-story/behind-the-scenes/eden-deep-geothermal-energy-project#iLezXr5d6stRRmGU.97.

This website describes the project, which involves generation of electricity from heat extracted from approximately 4 km below the ground in a deep geothermal scheme.

[9] Study into the Potential for Deep Geothermal Energy in Scotland, Scottish Government Project Number: AEC/001/11, Aecom Energy, 2013.

This report notes that the best "hot dry rock" prospects in Scotland are likely to exist in geological settings where heat produced by radioactive decay of elements like uranium (radiogenic heat) in the crust augments the background heat flow, producing localised high-temperature anomalies. There are numerous exposed granite intrusions in Scotland, and a small proportion of these produce significant quantities of radiogenic heat.

[10] Electricity Generation Costs, DECC, October 2012, URN 12D/383.

This report indicates, in Table 7, that on a levelised cost basis deep geothermal electricity generation is cheaper than onshore wind.

[11] Heat Pumps in District Heating, for DECC by Element Energy and Carbon Alternatives, URN 15D/537, 2016.

This report describes the Wandsworth project where heat is obtained from aquifers which provide both heating and cooling to housing.

[12] Deep Geothermal Energy in the Shetland Isles, Cluff Geothermal Ltd, September 2013.

Hydrogen / fuel cells

[13] Viessmann has developed an integrated unit which incorporates a hydrocarbon fuel cell and this has been successfully deployed in Teterow, Germany, to provide a combination of heat and power (http://www.viessmann.co.uk/en/residential-buildings/combined-heat-and-power-generation/micro-chp-unit-based-on-a-fuel-cell/vitovalor-300p.html).

[14] Cost, mainentance issues and a long warm-up and cool-down time have been cited by an Australian business magazine as a barrier to increased market share of hydrocarbon-based fuel cells (http://www.theaustralian.com.au/business/business-spectator/ceramic-fuel-cells--a-dead-end-technology/news-story/0c6c965dc1c584cc3a92c7a88407768f).

[15] "Solid Oxide Fuel Cell Anode Materials for Direct Hydrocarbon Utilization" Xiao-Ming Ge, Siew-Hwa Chan, Qing-Lin Liu, Qiang Sun. First published: 24 August 2012.

This paper describes advances in the development of electrodes which can be used in hydrocarbon fuel cells.

[16] Kiwa DECC report no. 30686, July 2016.

According to fuel cell manufacturers, the technology for using hydrogen fuel cell appliances is already available with a supply chain generally present for the necessary product components. In the development of hydrogen boilers, additional costs will be incurred in the R&D, product design and initial manufacturing phases above those normally incurred for natural gas appliances, and according to the Kiwa/E4tech/DECC report these might need to be supported within a stable regulatory and political framework.

[17] H21 Leeds City Gate project.

This project is relevant to the development of hydrogen boilers and burners as an emerging green technology. It shows that it should be possible to introduce areas of the gas network where hydrogen fuels 100% of the gas demand.

Cogeneration

[18] GPG 388 – Good Practice Guide for combined heat and power for buildings – Selecting, installing and operating CHP in buildings – a guide for building services engineers. Action Energy, April 2004.

[19] Introducing combined heat and power, a new generation of energy and carbon savings, CTV044, Carbon Trust, September 2010.

[20] Ofgem. FIT tarriff 1 April 2017 to 30 June 2017.

[21] Micro-CHP Accelerator, final report, Carbon Trust, March 2011.

This report addresses the economics of micro-CHP.

Trigeneration

[22] District Heating and Cooling – Programme of Research, Development and Demonstration on District Heating and Cooling – District Heating and Cooling Connection Handbook, IEA.

[23] Heat Pumps in District Heating, for DECC by Element Energy and Carbon Alternatives, URN 15D/538, 2016.

This report describes a project in Helsinki where district heating and district cooling are both provided.

District heating

[24] A technical guide to district heating, FB72, IHS BRE press, 2014.

[25] District Heating and Cooling – Programme of Research, Development and Demonstration on District Heating and Cooling – District Heating and Cooling Connection Handbook, IEA.

[26] Heat Policy Statement - Towards Decarbonising Heat: Maximising the Opportunities for Scotland - The Scottish Government, June 2015. This publication discusses targets for district heating, current and future trends, heat demand, storage and heat generation.

[27] Fourth Generation District Heating – Integrating smart thermal grids into future sustainable energy systems – Lund et al. Energy 68 (2014), Elsevier, 2014.

This paper discusses smart grids and thermal networks for providing district heating and cooling.

Local heating

[28] Intentionally blank

Heat recovery

[29] Linlithgow Natural Grid 'Heat From the Street' - Local Energy Challenge Fund Phase 1, Final Project Report, 4th April 2016, http://www.localenergyscotland.org/media/89091/GCF135-Linlithgow-Final-Report.pdf.

The project concludes that the urban development of new waste water heat projects requires local community support for the necessary infrastructure and that Linlithgow's Heat from the Street project will provide the template for that model, by convening the required partners, integrating efficiently with the local electricity grid, and maximising local consumption of locally produced renewable heat and electricity.

[30] Heat pumps in District Heating: Case Studies, prepared for DECC by Element Energy and Carbon Alternatives, 2016, URN 15D/538.

In winter heat is recovered from sewage from the city of Helsinki and used to preheat the district return flow from 50°C to 62°C. This is lower than the network temperature, but in this way the heat pump can run more efficiently. All cooling is provided directly from sea water (free cooling), so the heat pumps are not used to meet this demand.

[31] Sharc technology, http://www.sharcenergy.com/ supplies waste water heat pumps and provides some helpful information on their website.

[32] Evidence Gathering: Passive Flue Gas Heat Recovery Technologies, BEIS, 2016.

[33] Ion V. ION, Gheorghe CIOCEA, Florin POPESCU, "WASTE HEAT RECOVERY TECHNOLOGIES FROM HEATING BOILER FLUE GAS",

According to the authors, the use of heat pumps for heat recovery from heating boilers represents a viable technology to improve the boiler efficiency, economic and environmental performance.

[34] Combination of wastewater treatment plants and heat pumps, Pacific Science Review, Volume 16, Issue 1, June 2014, pages 36-39. Leonid N. Alekseiko, Viacheslav V. Slesarenko, Alexander A. Yudakov.

This paper discusses waste water heat pumps used in tandem with a district heating network in Vladivostok, Russia.

General

[35] Draft Scottish Energy Strategy: The future of energy in Scotland, Scottish Government, January 2017.

Appendix F – Glossary

Active network management – The real time management of electricity generation and loads within an electricity network using control systems

Active operation – Requires electricity to operate

Air tightness – The resistance to inward or outward air leakage through unintentional leakage points or areas in the building envelope

Anaerobic digester – A vessel in which organic material is broken down by microorganisms in the absence of oxygen to produce biogas

Aquifer – A body of permeable rock which can contain or transmit groundwater

Baseload energy – The baseload energy is the minimum amount of energy demand required over a period of time

Biogas – Biogas is the gas produced from the anaerobic digestion process in which organic material is broken down by microorganisms in the absence of oxygen. Biogas is a mixture of methane (natural gas), carbon dioxide and small amounts of other gases. Biogas has to undergo a process called 'scrubbing' before it is chemically similar to natural gas

Biomass – Organic matter used as a fuel, especially in a power station for the generation of electricity

Biomethane – Biogas which has had all of its gas components, other than the methane component, removed. It is chemically identical to natural gas and differs only in its origin

Calorific value – The energy contained within a fuel

Carbon capture – Carbon capture is the process of capturing carbon dioxide from sources so that it does not contribute to atmospheric carbon dioxide levels

Catalytic combustion – A combustion process which uses a catalyst to speed desired oxidation reactions of a fuel thereby reducing the formation of undesired products, especially pollutant nitrogen oxide gases (NOx) far below what can be achieved without catalysts

Circular economy – An alternative to a traditional linear economy (make, use, dispose) in which resources are kept in use for as long as possible, the maximum value is extracted from them whilst in use, then the products and materials are recovered and regenerated at the end of each service life.

Coefficient of performance (COP) – Ratio of useful heating to input energy required. A heat pump with a higher COP is more efficient and more desirable.

Cogeneration – The generation of electricity and useful heat jointly

Combined Heat and Power (CHP) – The use of a heat engine or power station to generate electricity and useful heat at the same time

Competent Persons Scheme – A scheme introduced by the UK Government to allow individuals and enterprises to self-certify that their work complies with the Building Regulations

Convection heater – A heater which uses convective heat transfer as the main mechanism with which to heat a room.

Decarbonising – reducing the amount of carbon dioxide released as a result of a process

Decentralised energy – Energy which is generated close to the point of use rather than at, for example, a large power plant which uses the national grid to transmit and distribute energy.

Distribution temperature – The temperature of the working fluid which is passed around a heating system. In a conventional central heating network this would be the temperature the water is raised to before distributing it around the radiator network.

District heating – The supply of heat or hot water from one source to a district or a group of buildings.

District heating (third generation) – Third generation district heating system makes use of high efficiency fossil fuel or renewable technologies which offers the potential for carbon savings and low customer bills versus conventional standalone systems.

District heating (fourth generation) – Fourth generation district heating system makes use of renewable energy technologies to produce the heat required. The system also utilises energy storage.

Electrical immersion heating – An electric water heater where electricity is used to heat a metal heating element which in turn heats the surrounding fluid, most commonly water

Electricity led CHP – CHP which is sized based on the electricity demand profile of the site/building rather than based on the heat demand profile

Electrode (hydrogen production) – An electrode, in the context of hydrogen production, is a metallic rod with an induced electrostatic potential. In hydrogen production there are two electrodes – one with a positive potential and one with a negative potential. See 'Electrolysis' definition for further context.

Electrolysis – The process in which water is separated into oxygen and hydrogen using an electric current.

Energy efficiency – Improving energy efficiency means producing more useful output energy for the same amount of input energy

Energy load – The amount of energy required by the building.

Environmentally impact of materials – The associated environmental impact of a material which accounts for things such as the associated environmental impact from extraction, transportation and manufacturing processes.

Feed-In-Tariff (FIT) – A policy mechanism designed to accelerate investment in renewable energy technologies. Monetary payments are made per kWh of electricity generated, the amount of which depends on the current rate for that technology set by the UK Government.

Flame combustion – The use of flame to ignite a chemical substance to produce heat

Flow temperature – The temperature of the water in the supply (flow) pipe in a heating system or separate part of a heating system.

Fuel Cell – An electrochemical cell that converts the chemical energy from a fuel into electricity.

Fuel cell stack – The assembly of cells within a fuel cell.

Heat exchanger – A device designed to efficiently transfer or "exchange" heat from one matter to another.

Heat led CHP – CHP which is sized based on the heat demand profile of the site/building rather than based on the electricity demand profile.

Heat recovery – The process of recovering waste heat that would normally be exhausted. This improves the overall efficiency of the system or system.

Heat sink – A device or substance for absorbing excessive or unwanted heat.

High temperature distribution system – A heat distribution system in which the working fluid is at a high temperature.

Hydrocarbon – An organic compounding consisting entirely of hydrogen and carbon. Common hydrocarbons include methane (natural gas) and propane.

Hydrogen (as a fuel source) – Hydrogen fuel is a zero-emission fuel when burned with oxygen, if water is considered not to be an emission.

Hydrogen fuel cell – A fuel cell which uses hydrocarbon gases and oxygen to generate electricity, water, waste gases and heat.

Life cycle cost – Sum of all recurring and one-time (non-recurring) costs over the full life span or a specified period of a good, service, structure, or system. It includes purchase price, installation cost, operating costs, maintenance and upgrade costs, and remaining (residual or salvage) value at the end of ownership or its useful life.

Low energy building - A low-energy building is any type of building that from design, technologies and building products uses less energy, from any source, than a traditional or average contemporary building.

Mechanical ventilation – Any system that uses mechanical means, such as a fan, to provide ventilation for a building. As opposed to passive ventilation, mechanical ventilation requires an electricity supply to operate.

Microgeneration Certification Scheme (MCS) – An industry-led and nationally recognized quality assurance scheme, supported by the Department for Business, Energy & Industrial Strategy (BEIS). MCS certifies microgeneration products used to produce electricity and heat from renewable sources. MCS also certifies installation companies to ensure the microgeneration products have been installed and commissioned to the highest standard for the consumer.

National Calculation Method (NCM) – The methodology developed for the Department for Communities and Local Government to satisfy the Energy Performance of Building Directive (EPBD). The calculation method is used to determine a building’s energy performance and assess compliance with the energy component of the building regulations.

Negative air pressure – The pressure within a building is lower than its surroundings. This causes air movement from outside to inside via gaps in the building fabric until an equilibrium is released.

Off gas grid – A building which is not connected to the national gas network.

Operational cost – The expenses related to the operation of the heat technology in question.

Passive operation – Does not require electricity to operate**.**

Passive ventilation – A natural ventilation system that makes use of natural forces, such as wind and thermal buoyancy, to circulate air to and from an indoor space. Unlike mechanical ventilation passive ventilation systems have no moving parts and do not require electricity to operate.

Payback period – The length of time required for an investment to recover its initial outlay in terms of profits or savings.

PEMFC - Proton Exchange Membrane Fuel Cell - a type of fuel cell being developed for transport applications as well as for stationary and/or portable fuel cell applications.

Photovoltaics (PV) – A device which converts solar radiation into electricity.

Positive air pressure – The pressure within a building is greater than its surroundings. This causes air movement from inside to outside via gaps in the building fabric until an equilibrium is released.

Primary heating fuel – The main fuel used to heat majority of a buildings heating requirements.

Operational temperature – The temperature at which an electrical or mechanical device operates.

Refrigerant – A substance or mixture, usually a fluid, used in a heat pump and refrigeration cycle.

Renewable Energy Consumer Code (RECC) – In order to become MCS certified, installation companies must be members of the Renewable Energy Consumer Code (RECC).

Renewable Heat Incentive (RHI) – A UK Government scheme set up to encourage uptake of renewable heat technologies amongst householders, communities and businesses through financial incentives.

Retrofit – The addition of new parts and furnishing to an existing building. For example a building could be retrofitted with improved building services and fabric upgrades.

SAP (Standard Assessment Procedure) – The UK Government’s method system for assessing the carbon compliance of new build dwellings and/or assessing the energy rating of dwellings.

SBEM (Simplified Building Energy Model) – The UK Government's method system for assessing the carbon compliance of new build non-domestic buildings and/or assessing the energy rating of non-domestic buildings.

Scrubbing (gas) – Removing a gaseous mixture of undesirable compound. In the case of biogas this usually involves the removal of carbon dioxide and corrosive compounds to make it more chemically similar to natural gas.

Smart energy technologies – Smart energy refers to the next generation of energy technologies whereby the communication between technologies is improved with the overall aim of optimising performance and efficiency.

SOFC - Solid Oxide Fuel Cell - An electrochemical conversion device that produces electricity directly from oxidising a fuel.

Steam reforming – A method for producing hydrogen, carbon monoxide, or other useful products from hydrocarbon fuels such as natural gas.

Storage heaters – Heaters which have the ability to store energy which can be released at a later time when required.

Technology Readiness Level (TRL) – A type of measurement system used to assess the maturity level of a particular technology. Each technology project is evaluated against the parameters for each technology level and is then assigned a TRL rating based on the projects progress. There are nine technology readiness levels. TRL 1 is the lowest and TRL 9 is the highest.

Thermal mass – Thermal mass is the ability of a material to absorb and store heat energy. A lot of heat energy is required to change the temperature of high density materials like concrete, bricks and tiles. They are therefore said to have high thermal mass. Lightweight materials such as timber have low thermal mass.

Thermal solar panel – Solar thermal technology uses the sun's energy, rather than fossil fuels, to generate low-cost, environmentally friendly thermal energy. This energy is used to heat water or other fluids, and can also power solar cooling systems.

Thermal store – A thermal store is a way of storing and managing renewable heat until it is needed. In a domestic setting, heated water is usually stored in a large well-insulated cylinder often called a buffer or accumulator tank.

Trigeneration – Sometimes referred to as combined cooling, heat and power (CCHP). The process by which some of the heat produced by a cogeneration plant is used to generate chilled water for air conditioning or refrigeration.

Waste heat – Waste heat is by necessity produced both by machines that do work and in other processes that use energy, for example in a refrigerator warming the room air or a combustion engine releasing heat into the environment.

Wobbe Index (WI) – an indicator of the interchangeability of fuel gases which is used to compare the combustion energy output of different composition fuel gases in an appliance (fire, cooker etc.). If two fuels have identical Wobbe Indices then for given pressure and valve settings the energy output will also be identical. The Wobbe Index is a critical factor to minimise the impact of substitute natural gas changeovers.

Zero energy building – Also known as a zero net energy building (ZNE). A building with zero net energy consumption, meaning the total amount of energy used by the building on an annual basis is roughly equal to the amount of renewable energy created on the site.