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

August 2017

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 of the technologies for their potential suitability inclusion within Scotland's Energy Efficiency Programme (SEEP).

Heat Technologies

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

High temperature heat pump

Electric heat pumps which deliver heated water above 55 degrees C (e.g. 55-80+ degrees C) without the need for electric immersion top-up

Technical	Scoring	Score	Comments
Technology readiness	TRL score 1-9	**9**	Commercially available. They are well suited to applications where a higher distribution temperature is required or advantageous e.g. existing buildings with a traditionally sized wet distribution systems (i.e. retrofits where existing radiators are to be retained, particularly off gas grid).
Efficiency (product / technology efficiency)	1 (low) to 5 (high) score	4	If the heat pump regularly operates with a high output temperature then this will lower its overall efficiency (coefficient of performance, COP). The maximum efficiency of a high temperature heat pump is less than that of a conventional (lower temperature) heat pump. This generally makes the technology uncompetitive versus mains gas boilers (currently) but potentially competitive against oil or LPG. The COP for a high temperature heat pump might, for example, be ~2.5 (for producing water at 55/60C).
Reliability	1 (low) to 5 (high) score	3	Similar reliability to conventional heat pumps. They use a different refrigerant (e.g. R134A which is better for these high temperature units) and some will incorporate a double cascade, in order to deliver the heat to the desired temperature, so the technology is little more complicated (and as a result more expensive) but similar in many other aspects.
(level of) Compatibility with existing systems	1 (low/poor) to 5 (high/good) score	4	In terms of heating system retrofitting, they offer better compatibility than traditional heat pumps. This is because their higher output temperature meant that they tend to be suitable with traditionally sized radiator/distribution systems.
Complexity of systems/ their integration	1 (complex) to 5 (simple) score	3	Similar to that of electric heat pumps.
Risk/severity of unintended consequences	1 (high) to 5 (low) score	3	Likely to be less risky than traditional heat pumps as they can be retrofitted to traditionally sized radiator/distribution system as opposed to requiring a low temperature distribution system. No other significant risks to property or health identified.
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Environmental	Scoring	Score	Comments
(In-use) carbon saving potential	1 (low) to 5 (high) score	3	Uses electricity. If retrofitting and making use of an existing, traditionally sized radiator system, then high temperature heat pumps are likely to offer a lower electricity consumption versus a conventional heat pump that typically required an electric immersion to raise its output temperature to the temperature required for the distribution system. However, in new build or retrofits where the radiation/distribution system is being replaced then a traditional heat pump will typically be better assuming a low temperature distribution system can be accommodated.
Whole life environmental impact	1 (high) to 5 (low) score	3	Typically constructed using conventional, well known, and relatively low impact materials.
		6	

Policy / Regulation	Scoring	Score	Comments
Compatibility with Scottish policy	1 (low) to 5 (high) score	3	Can support current policy on conservation of energy and carbon (particular in combination with a decarbonised grid - as driven by (currently high carbon) electricity).
Compatibility with current regulation	1 (low) to 5 (high) score	5	Heat pumps fits well within current regulations.
Compatibility with current assessment methodologies	1 (low) to 5 (high) score	5	No significant issues. SAP/SBEM already have established methodologies.
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Monetary	Scoring	Score	Comments
Capital costs	1 (high) to 5 (low) score	1	Typical costs are around £500 to £1100 / kW. When installation costs are included, the capital cost can be ~10 to 20% higher than that of traditional heat pumps. The capital cost of products typically range from £3,000 -£7,000 (air source) with the installed price (capital + installation) ranging from £6,000 to £14,000. This compares with a typical gas fired boiler replacement cost of ~£2,500, so purchasing and installing a high temperature heat pump can be ~ 3 or 4 times as expensive as a condensing gas boiler (Ref: Table 9 of Evidence Gathering – Low Carbon Heating Technologies - Domestic High Temperature, Hybrid and Gas Driven Heat Pumps: Summary Report, BEIS, November 2016).
Life cycle costs	1 (high) to 5 (low) score	3	With good design this technology can still return a good COP, so running / life cycle costs are likely to be reasonable in areas off the mains gas network. Although capital costs are 10 to 20% higher than conventional electric heat pumps, they can work with conventional heat distribution systems thereby avoiding the cost of re-designing / re-plumbing the radiators/distribution system.
Carbon cost effectiveness (£ per tCO2 saved)	1 (low) to 5 (high) score	2	The carbon cost effectiveness depends very much upon the decarbonisation of the electricity supply, so this will improve with a decarbonised grid.
(Potential for) economy of scale (to drive down costs)	1 (low) to 5 (high) score	3	According to a relatively recent DECC report, manufacturers expressed the view that there are too many variables to make firm predictions of market potential, therefore future economy of scale is currently difficult to predict.
		9	

Capacity/ Supply Chain	Scoring	Score	Comments
Applicability	1 (low) to 5 (high) score	4	Widely applicable. High temperature heat pumps are particularly suited to heating installations where a higher temperature distribution/radiator circuit is required (e.g. retrofits where the heating distribution system is not being replaced) or where there is a large or relatively constant domestic hot water requirement in addition to space heating demand. They are likely to be particularly well suited to off gas grid applications.
Existing Scottish capacity/skills	1 (low) to 5 (high) score	5	Similar to conventional heat pumps, Scottish installers are well-placed to install this technology.
Scottish content	1 (low) to 5 (high) score	1	Currently limited / relatively low.
Potential for cross-sector involvement/benefit	1 (low) to 5 (high) score	3	Large scale deployment will increase electrical demand, but can also offer potential for smart control or demand response particularly where incorporating thermal storage.
Scottish economic impact potential	1 (low) to 5 (high) score	3	Likely to return relatively low cost savings although this technology could reduce Scotland's dependence upon LPG and oil in rural areas in buildings where conventional heat pumps would not work efficiently without major re-design/refurbishment of the heating distribution systems (i.e. where the heat distribution system requires water of a temperature above 55 degrees C). The technology is however currently unlikely to penetrate the markets as well in areas where mains gas is available.
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Consumer	Scoring	Score	Comments
User friendliness / practicality	1 (low) to 5 (high) score	5	Similar to other heat pumps / wet heating systems and their controls and therefore practical to users.
Disruption	1 (high) to 5 (low) score	3	The level of disruption will be similar to that of a conventional heat pump.
Customer acceptance	1 (low) to 5 (high) score	4	High temperature electric heat pumps will be attractive to a wide market of customers since they can provide effective space heating with standard high temperature radiator systems and domestic hot water. Cost is the main problem since they have a lower potential COP than conventional heat pumps and they are unlikely to compete with the overall costs of mains gas boilers, and therefore they are only likely to be competitive in areas which are not on the mains gas grid.
Savings on bills	1 (low) to 5 (high) score	3	High temperature electric heat pumps will be attractive to a wide market of customers since they can provide effective space heating with standard high temperature radiator systems and domestic hot water. Cost is the main problem since they have a lower potential COP than conventional heat pumps and they are unlikely to compete with the overall costs of mains gas boilers, and therefore they are only likely to be competitive in areas which are not on the mains gas grid.
Maintenance requirements	1 (high) to 5 (low) score	3	Generally low (as per other heat pumps).
Health/wellbeing/comfort	1 (high negative impact) to 5 (high positive impact) score	3	High temperature heat pumps are generally more suitable than conventional heat pump for providing heat to radiators on cold/extremely cold winter days.
Existing consumer protection? (Adequacy?)	1 (low) to 5 (high) score	4	Similar to that of other electric heat pumps.
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Opportunities / risks	Scoring	Score	Comments
Critical success factors/watch points	List/Describe		High temperature heat pumps are likely to remain relatively niche in the short term since they are currently well suited to older, generally inefficient (i.e. with high heat loss) buildings, often off the gas grid and/or buildings with high domestic hot water demand. A 2016 DECC evidence gathering report suggests that there could be significant market uptake of heat pumps for space heating has been predicted in the short-medium terms (15-35 years) and that the potential market could be 29,000-60,000 dwellings per year. High temperature heat pumps could provide an attractive option, as they can often operate with existing heat distribution systems and provide domestic hot water, however there are considerable inertia barriers to overcome, and they will be in competition with other technology solutions including hybrid and gas driven heat pumps.
Other relevant considerations/risks/opportunities	List/Describe		Manufacturers have previously 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.
Adaptability / future proofing	List / Describe		No issues identified. As a fuel, electricity is less likely to be affected by import prices than fuels which are imported directly, particularly if a lot of electricity comes from sources within the UK.
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Gas driven heat pump

Heat pumps which use methane gas as their fuel (and not electricity)(and can provide output water temperatures to circa 65C)

Technical	Scoring	Score	Comments
Technology readiness	TRL score 1-9	**8**	Gas heat pumps are at an early stage of deployment for domestic applications, with [thermally-driven (i.e. absorption or adsorption)] units only entering the UK market in 2016. For larger buildings, mechanically-driven (i.e. gas engine) heat pumps are often used instead of thermally-driven gas heat pumps, but in other respects the issues are similar.
Efficiency (product / technology efficiency)	1 (low) to 5 (high) score	4	In EU field trials, adsorption heat pumps achieved 35% reductions in energy costs compared to gas condensing boilers. Some manufacturers quote peak efficiencies of over 160%.
Reliability	1 (low) to 5 (high) score	3	Similar reliability to conventional heat pumps. Gas driven heat pumps have been found to be reliable in field trials. Watch for further trials (at larger scale) to provide more learning.
(Level of) Compatibility with existing systems	1 (low/poor) to 5 (high/good) score	4	When retrofitting to replace a gas boiler, a gas driven heat pump can use the same gas supply and the existing radiators/heating distribution system as the output temperature can be circa 65C which is acceptable for existing central heating systems. This makes it more compatible with than fitting a conventional electric heat pump (with typical output temperature in the order of 45/50C) as it will typically require a radiator re-design to suit the lower distribution temperature.
Complexity of systems/ their integration	1 (complex) to 5 (simple) score	3	They offer good potential to replace gas boilers and can connect to the existing gas supply and heating pipework, although unlike a gas boiler they require an externally located "heat collector" to be installed (e.g. like the external unit of an air source heat pump, or ground collector of a GSHP) and so this makes them slightly more complicated (but similar in complexity to traditional heat pumps).
Risk/severity of unintended consequences	1 (high) to 5 (low) score	3	No significant risks to property or health identified.
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Environmental	Scoring	Score	Comments
In-use) carbon saving potential	1 (low) to 5 (high) score	4	Uses a fossil fuel however they are typically more efficient than a gas condensing boiler. EU trials suggest that adsorption heat pumps can be 35% more efficient than gas condensing boilers. Gas absorption and gas engine heat pumps appear to have similar efficiencies.
Whole life environmental impact	1 (high) to 5 (low) score	3	Typically constructed using conventional, well known, and relatively low impact materials.
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Policy / Regulation	Scoring	Score	Comments
Compatibility with Scottish policy	1 (low) to 5 (high) score	5	Can support current policy on conservation of energy and carbon (particularly until a significantly decarbonised grid - as uses (relatively) low carbon gas).
Compatibility with current regulation	1 (low) to 5 (high) score	5	Heat pumps fits well within current regulations.
Compatibility with current assessment methodologies	1 (low) to 5 (high) score	5	No significant issues. SAP/SBEM already have established methodologies.
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Monetary	Scoring	Score	Comments
Capital costs	1 (high) to 5 (low) score	1	The capital costs are currently several times higher than for gas condensing boilers, and currently also higher than conventional heat pump systems. For gas absorption heat pumps, typical heat production costs are £500 to £650 / kW. When installation costs are included, the cost of a gas absorption heat pump is £9000-£12000, which is about twice that of conventional heat pumps, but capital cost is likely to fall if mass produced. A typical capital costs of a gas absorption heat pumps is £7000 and a typical installation cost is £2000-£5000 (Ref: Table 9 of Evidence Gathering – Low Carbon Heating Technologies - Domestic High Temperature, Hybrid and Gas Driven Heat Pumps: Summary Report, BEIS, November 2016). For comparison, £3500 is regarded as a typical price of a conventional heat pump Ref: DECC Desk study on the development of a hydrogen-fired appliance supply chain, DECC, July 2016.
Life cycle costs	1 (high) to 5 (low) score	3	Offers good potential for savings but owing to the high capital and installation costs, gas driven heat pumps are currently not cost effective without incentives. In Heat4U trials for gas absorption heat pumps, the efficiency for space heating was found to be 132% and the efficiency for water heating was found to be 128% and the system was found to be very reliable. These percentages compare favourably with percentages of the order of 90% for gas condensing boilers. Ref: Evidence Gathering – Low Carbon Heating Technologies - Domestic High Temperature, Hybrid and Gas Driven Heat Pumps: Summary Report, BEIS, November 2016.
Carbon cost effectiveness (£ per tCO2 saved)	1 (low) to 5 (high) score	4	Gas driven heat pumps offer excellent efficiency when compared to condensing gas boilers, but the current high capital costs are a barrier to large-scale uptake.
(Potential for) economy of scale (to drive down costs)	1 (low) to 5 (high) score	4	Gas pumps are at an early stage of deployment in the UK, only entering the market in 2016. Since they can replace existing gas boilers their potential for large-scale use is very high if their high capital costs can be driven down by economy of scale.
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Capacity/ Supply Chain	Scoring	Score	Comments
Applicability	1 (low) to 5 (high) score	4	Widely applicable - although requires a gas connection (e.g. grid or LPG). Gas driven heat pumps can provide hot water at 65 degrees C, so (similar to the temperature provided by high temperature heat pumps) they can cope with most existing radiator distribution systems and they can also heat domestic hot water.
Existing Scottish capacity/skills	1 (low) to 5 (high) score	5	Minor upskilling of current boiler/heat pump installers needed to enable them to install gas driven heat pumps.
Scottish content	1 (low) to 5 (high) score	1	Currently limited / relatively low.
Potential for cross-sector involvement/benefit	1 (low) to 5 (high) score	3	The skillset of the heat pump and gas boiler industries could help with upskilling installers.
Scottish economic impact potential	1 (low) to 5 (high) score	4	Many homes in Scotland use gas boilers so the potential for replacing boilers with gas heat pumps is very high. Substantial reductions in consumption of gas (methane/biomethane), and savings to customers, due to the high efficiency of the units.
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Consumer	Scoring	Score	Comments
user friendliness / practicality	1 (low) to 5 (high) score	5	Good, because they can replace an existing condensing gas boiler. Apart from initial costs, this technology is likely to be attractive to consumers.
disruption	1 (high) to 5 (low) score	3	Some internal units of gas heat pumps are as compact as a gas boiler (so they offer potential to just replace the boiler and can connect to the existing gas supply and heating pipework) although unlike a gas boiler they require an externally located "heat collector" to be installed (e.g. like the external unit of an air source heat pump, or ground collector of a GSHP).
customer acceptance	1 (low) to 5 (high) score	4	Gas heat pumps may help overcome consumer reluctance to install heat pumps. They may be used with existing heat distribution systems, thereby reducing cost, and offers familiar controls and higher output system temperatures than conventional heat pumps. However, gas heat pumps are currently high capital cost.
savings on bills	1 (low) to 5 (high) score	5	More efficient than gas condensing boilers, so gas bills will be lower.
maintenance requirements	1 (high) to 5 (low) score	4	For the domestic-sized thermally-driven heat pumps the annual maintenance check is similar to a gas boiler. A more involved (major) service is typically needed every 2-3 years (currently estimated to cost circa £350, including parts).
health/wellbeing/comfort	1 (high negative impact) to 5 (high positive impact) score	3	Provides central heating (and is controlled) similar to a gas boiler and is likely to be compatible with existing heat distribution systems (radiators etc.)
Existing consumer protection? (Adequacy?)	1 (low) to 5 (high) score	4	Established gas safe standards and accreditation. In addition, heat pumps are an established technology, so consumer protection likely to be high.
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Opportunities / risks	Scoring	Score	Comments
Critical success factors/watch points	List/Describe		Unit costs will be a major factor, but the potential market for gas-driven and hybrid heat pumps taken together was estimated by Kiwa Ltd (2016) to be 100,000 to 210,000 dwellings annually in the UK.
other relevant considerations/risks/opportunities	List/Describe		This technology could work in tandem with the development of scrubbed biomethane thereby conferring an efficient technology with a low-carbon fuel.
adaptability / future proofing	List / Describe		Firm predictions of future market potential will depend very much upon potential future incentive schemes and on future prices of gas (and of competing fuels like electricity). However, the market and environmental potential is very high because so many homes already use gas boilers.
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Hybrid heat pump

A heat pump which is a hybrid/combination of a conventional electric heat pump and a gas boiler. The system will typically use the (electrically driven) heat pump electricity during mild weather (when the coefficient of performance is high) and the gas boiler component during cold weather (or for domestic hot water production) when combustion of gas is likely to be more economical than using the heat pump.

Technical	Scoring	Score	Comments
Technology readiness	TRL score 1-9	**9**	Already being marketed to householders. Aimed predominantly at off-gas grid customers. Currently only a small number of suppliers.
Efficiency (product / technology efficiency)	1 (low) to 5 (high) score	4	Overall, it is considered to be more efficient than a standalone condensing gas boiler (although capital costs are higher). The typical coefficient of performance of 2.7 for the electric portion of the heating (Ref: Scottish Enterprise - Low Carbon Heat - Fore sighting Paper).
Reliability	1 (low) to 5 (high) score	3	Similar reliability to conventional heat pumps. No significant long term trials although no major concerns as the technology is a hybrid of two existing and well established technologies.
(level of) Compatibility with existing systems	1 (low/poor) to 5 (high/good) score	4	Existing gas supply and radiator pipework can be retained when switching from conventional boiler to a hybrid heat pump.
complexity of systems/ their integration	1 (complex) to 5 (simple) score	3	They offer good potential to replace gas boilers (of off gas grid boiler) and can connect to the existing gas/LPG supply and heating pipework, although unlike a gas boiler the heat pump requires an externally located "heat collector" to be installed (i.e. the external unit of an air source heat pump, or ground collector of a GSHP).
risk/severity of unintended consequences	1 (high) to 5 (low) score	3	No significant risks to property or health identified.
		26	

Environmental	Scoring	Score	Comments
(in-use) carbon saving potential	1 (low) to 5 (high) score	3	Overall, more efficient than gas condensing boilers, but the heat pump uses electricity which is currently significantly higher in carbon that grid electricity, so the system currently offers best potential replacing off-gas grid LPG or oil boilers. Greater potential as the grid decarbonises.
whole life environmental impact	1 (high) to 5 (low) score	3	Slightly lower than average as essentially 2 x systems - but both typically constructed using conventional, well known, and relatively low impact materials.
		6	

Policy / Regulation	Scoring	Score	Comments
compatibility with Scottish policy	1 (low) to 5 (high) score	4	Can support current policy on conservation of energy and carbon (particular in combination with a decarbonised electricity and gas grid - as the hybrid works with both gas and electricity).
compatibility with current regulation	1 (low) to 5 (high) score	5	Heat pumps fits well within current regulations.
compatibility with current assessment methodologies	1 (low) to 5 (high) score	5	No significant issues. SAP/SBEM already have established methodologies.
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Monetary	Scoring	Score	Comments
capital costs	1 (high) to 5 (low) score	1	Capital cost high. The up-front cost currently make market growth difficult. Typical heat production costs are £350 to £1800 / kW. When installation costs are included, the marginal cost of a hybrid heat pump is about £4000 - £10000 compared to the cost of installing a gas boiler. Ref: Evidence Gathering – Low Carbon Heating Technologies - Domestic Hybrid Heat Pumps, BEIS, November 2016.
life cycle costs	1 (high) to 5 (low) score	2	Less vulnerability to future prices of imported gas when compared to a conventional boiler. It can select the most cost-efficient operation (between heat pump and gas burning). Expected lifetime of hybrid heat pump is 15 to 20 years. Compared to a standard electric heat pump the savings are 0 to 15% / year. Compared to a standard condensing gas boiler the savings are -19% to 0% / year. Ref: Table 11 of Evidence Gathering – Low Carbon Heating Technologies - Domestic Hybrid Heat Pumps, BEIS, November 2016.
carbon cost effectiveness (£ per tCO2 saved)	1 (low) to 5 (high) score	3	Medium, due to the high capital cost of heat pump technology.
(potential for) economy of scale (to drive down costs)	1 (low) to 5 (high) score	3	Scale of impact will be closely linked to the development of other competing heat pump products, with this technology most likely being a transitional product in the meantime.
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Capacity/ Supply Chain	Scoring	Score	Comments
applicability	1 (low) to 5 (high) score	4	Widely applicable although requires a gas connection (e.g. grid or LPG).
existing Scottish capacity/skills	1 (low) to 5 (high) score	5	Current boiler/heat pump installers could install with only minor upskilling.
Scottish content	1 (low) to 5 (high) score	1	Currently limited / relatively low.
potential for cross-sector involvement/benefit	1 (low) to 5 (high) score	4	Combines gas boiler technology with electric heating technology, so in the future this offers potential for smart control/switching between operating modes to help reduce peak electricity network demands or maximise saving by managing the system to capitalise on low rate tariffs etc.
Scottish economic impact potential	1 (low) to 5 (high) score	3	Likely to return relatively low cost savings. Scale of impact will be closely linked to the development of other competing heat pump products, with this technology most likely being a transitional product.
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Consumer	Scoring	Score	Comments
user friendliness / practicality	1 (low) to 5 (high) score	4	Good. Can be installed relatively quickly and use existing gas supply (if present) radiators and pipes. Similar to installing a heat pump and gas boiler.
disruption	1 (high) to 5 (low) score	3	Typically no need to alter gas pipe, radiators or pipework for those properties that already has a gas boiler. Additional space will be required for the external "heat collector".
customer acceptance	1 (low) to 5 (high) score	2	Perceived complexity of a hybrid containing 2 x systems likely to put some customers off.
savings on bills	1 (low) to 5 (high) score	3	This depends largely on what heating system / fuel the system would replace. Medium-good potential for savings versus oil. Medium potential versus LPG, gas or electric.
maintenance requirements	1 (high) to 5 (low) score	2	Since it combines two technologies, there is a slightly increased maintenance requirement (although both technologies are well established).
health/wellbeing/comfort	1 (high negative impact) to 5 (high positive impact) score	3	Comfort is likely to match that of other systems that use radiators and thermostats.
Existing consumer protection? (Adequacy?)	1 (low) to 5 (high) score	4	Established gas safe standards and accreditation. In addition, heat pumps are an established technology, so consumer protection likely to be high.
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Opportunities / risks		Scoring		Score		Comments
Critical success factors/watch points		List/Describe				Capital costs. Unit costs will be a major factor, but the potential market for gas-driven and hybrid heat pumps taken together was estimated by Kiwa Ltd (2016) to be 100000 to 210000 dwellings annually.
other relevant considerations/risks/opportunities		List/Describe				This technology could work in tandem with the development of scrubbed biomethane thereby conferring an efficient technology with a fuel which is considered low-carbon.
adaptability / future proofing		List / Describe				Using an optimal combination of two fuels is likely to make it adaptable in the face of changing fuel prices.
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Waste water heat pump

A heat pump which extracts (and upgrades) heat from waste or sewage water (generally at a temperature that is well above ambient temperature) and uses it for space heating

Technical	Scoring	Score	Comments
Technology readiness	TRL score 1-9	**9**	This technology has been demonstrated in Scotland on a small scale. It is also used on a large scale in the cities of Helsinki and Vladivostok where it has been demonstrated to work well.
Efficiency (product / technology efficiency)	1 (low) to 5 (high) score	4	The technology can offer a very good COP (coefficient of performance) / efficiency as the temperature source (water) could typically be 20 degrees C (which is significantly higher than ambient air used for air source heat pumps, and which is also higher than other typically water source heat pump sources e.g. rivers and lochs).
Reliability	1 (low) to 5 (high) score	3	Electric heat pumps technology is well established and reliable, although limited trials in waste water applications.
(level of) Compatibility with existing systems	1 (low/poor) to 5 (high/good) score	3	Similar to a conventional electric heat pump. The system will be most efficiency when outputting relatively low temperatures, so this will need a low temperature distribution system within the target building e.g. underfloor heating - otherwise likely to require a refurbished/red-designed heating distribution system and radiators.
complexity of systems/ their integration	1 (complex) to 5 (simple) score	2	Requires installation of heat collector is sewage lines (and resulting permissions etc.) - typically out with the buildings the system serves.
risk/severity of unintended consequences	1 (high) to 5 (low) score	2	Extracting heat from the sewage shall reduce its temperature and this may have a knock-on effect on river ecosystems. There are no significant risks to buildings or users of buildings which are heated using this technology.
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Environmental	Scoring	Score	Comments
(in-use) carbon saving potential	1 (low) to 5 (high) score	5	Upgrades waste sewage heat using electricity. Sewage is an abundant, and as yet relatively untapped resource, which can provide a good heat source and therefore potential for significant carbon savings.
whole life environmental impact	1 (high) to 5 (low) score	3	Typically constructed using conventional, well known, and relatively low impact materials.
		8	

Policy / Regulation	Scoring	Score	Comments
compatibility with Scottish policy	1 (low) to 5 (high) score	5	This technology has good potential to assist in reducing carbon emissions. It upgrades waste heat, is very efficient, and uses electricity - a fuel which has potential to be decarbonised.
compatibility with current regulation	1 (low) to 5 (high) score	2	Heat pumps fits well within current regulations. Waste water regulations will need further investigation / may need development to enable uptake.
compatibility with current assessment methodologies	1 (low) to 5 (high) score	4	There are recognised procedures for assessing the efficiency of heat pumps, so assessment should be relatively straightforward, and current assessment methodologies can then suitably incorporate.
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Monetary	Scoring	Score	Comments
capital costs	1 (high) to 5 (low) score	1	High capital costs despite water source heat pump technology and sewage technology being well-established. There will also be additional costs associated with integrating the technology with district heating networks or large buildings and this depends on proximity to the heat source. According to the Heat Pumps in District Heating report for DECC, the Duindorp project indicated an incremental cost of 5,500 euros per dwelling (i.e. around £5000 per dwelling). This is a little higher than the cost of a typical conventional air source heat pump, when installation costs are excluded, but it is about 40% less than the cost of a conventional air source heat pump if installation costs for an individual dwelling were included.
life cycle costs	1 (high) to 5 (low) score	4	Experience from city-wide installations suggests that the overall cost is competitive with traditional sources of heating. The lifetime of a heat pump incorporated into a waste water scheme is likely to be similar to that of a conventional heat pump.
carbon cost effectiveness (£ per tCO2 saved)	1 (low) to 5 (high) score	4	The COP is very high when sewage is used because of the relatively high temperature of the heat source.
(potential for) economy of scale (to drive down costs)	1 (low) to 5 (high) score	3	Large city scale projects currently appear to be economical. Economies of scale may however be restricted by the relatively low number of sites offering significant opportunity.
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Capacity/ Supply Chain	Scoring	Score	Comments
applicability	1 (low) to 5 (high) score	2	Reasonably widely applicable although requires suitable waste water source. Offers potential for large sites, large energy users, cities and district heating scheme. Engagement with, and buy-in from, the water authority will be essential to understanding the scale of opportunity.
existing Scottish capacity/skills	1 (low) to 5 (high) score	3	Heat pump expertise and sewage expertise are both established in Scotland.
Scottish content	1 (low) to 5 (high) score	1	Currently low regarding heat pump technology.
potential for cross-sector involvement/benefit	1 (low) to 5 (high) score	2	Heat pump expertise and sewage expertise are both established in Scotland. Involvement of water authority is essential. May impact on river ecology or the current sewage operations and this needs to be explored and investigated.
Scottish economic impact potential	1 (low) to 5 (high) score	2	Schemes offer potential to have a relatively high impact, although they may be relatively small in number / customers served.
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Consumer	Scoring	Score	Comments
user friendliness / practicality	1 (low) to 5 (high) score	4	Similar to that of conventional heat pumps.
disruption	1 (high) to 5 (low) score	3	Likely to require works to integrate with the sewer lines in streets and to establish heating distribution network(s).
customer acceptance	1 (low) to 5 (high) score	4	Not an individual dwellings scale technology. However it can be used as a standalone heat pump for large scale buildings, estates, etc. or integrated with district heating scheme.
savings on bills	1 (low) to 5 (high) score	4	Experience from city wide projects in other countries indicate that it is financially viable.
maintenance requirements	1 (high) to 5 (low) score	3	Heat pumps generally have low maintenance requirements. It is currently unknown whether the use of such system would result in increased maintenance (or other related issues) for the Scottish water / sewage system operators.
health/wellbeing/comfort	1 (high negative impact) to 5 (high positive impact) score	3	The heat pump can provide heat to a central heating system for distribution of heat. No known health issues for occupiers benefiting from space heating.
Existing consumer protection? (Adequacy?)	1 (low) to 5 (high) score	4	Consumer protection is medium-high given that it combines two established technologies - sewage and heat pump. The design, installation, operation and maintenance of heat pump systems is a reasonably well established industry.
		25	

Opportunities / risks		Scoring		Score		Comments
Critical success factors/watch points		List/Describe				Observed efficiencies and any problems in demonstration projects such as the Linlithgow Heat From The Street project.
other relevant considerations/risks/opportunities		List/Describe				Need to investigate whether use of such system is permitted by the water authority and whether they would result in increased maintenance (or other related issues) for the Scottish water / sewage system operators. However, sewage represents a massive amount of fluid at a temperature that is considerably higher than outdoor temperature, and city-wide projects in other countries are showing that the potential is very large.
adaptability / future proofing		List / Describe				The sewage resource is likely to remain large for the foreseeable future.
				89		

Solar-assisted heat pump

A solar-assisted heat pump (SAHP) is a technology that combines a heat pump and thermal solar collector to form an integrated system. A Solar Assisted Heat Pump uses an external collector as it evaporator to capture energy from the ambient air as well as direct solar radiation.

Technical	Scoring	Score	Comments
Technology readiness	TRL score 1-9	**9**	Thermodynamic panels are commercially available in the UK. Some products are Microgeneration Certification Scheme (MCS) accredited meaning they are eligible for RHI.
Efficiency (product / technology efficiency)	1 (low) to 5 (high) score	2	COPs typically lower than air source heat pumps. Electric top up required for heating domestic hot water (as per conventional heat pump)
Reliability	1 (low) to 5 (high) score	3	Similar reliability to conventional heat pumps so considered suitably reliable.
(level of) Compatibility with existing systems	1 (low/poor) to 5 (high/good) score	3	Similar to a conventional electric heat pump (i.e. typical output temperature in the order of 45/50C) so well suited to underfloor heating - otherwise will most likely require a radiator re-design to suit the lower distribution temperature.
Complexity of systems/ their integration	1 (complex) to 5 (simple) score	3	Similar to that of electric heat pumps.
Risk/severity of unintended consequences	1 (high) to 5 (low) score	3	No adverse consequences identified. No significant health risks or risks to building identified (provided roof/wall is structurally sound to accept collectors).
		23	

Environmental	Scoring	Score	Comments
(in-use) carbon saving potential	1 (low) to 5 (high) score	2	The panels provide a reasonably efficient heat source for heat pumps by drawing heat from both external air and sunlight - although are generally poorer performing than conventional, well-designed, heat pump systems.
Whole life environmental impact	1 (high) to 5 (low) score	3	Typically constructed using conventional, well known, and relatively low impact materials.
		5	

Policy / Regulation	Scoring	Score	Comments
Compatibility with Scottish policy	1 (low) to 5 (high) score	2	Not as efficient as other forms of heat pumps and solar irradiance levels in Scotland imposes limitations.
Compatibility with current regulation	1 (low) to 5 (high) score	5	Heat pumps fits well within current regulations.
Compatibility with current assessment methodologies	1 (low) to 5 (high) score	5	No significant issues. Currently recognised by the Microgeneration Certification Scheme.
		12	

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Monetary	Scoring	Score	Comments
Capital costs	1 (high) to 5 (low) score	1	Relatively high capital costs. A typical domestic thermodynamic panel based heat pump installation can be ~£7000 to £10000. For comparison, DECC have reported £3500 as a typical price of a conventional heat pump.
Life cycle costs	1 (high) to 5 (low) score	2	Relatively high capital costs, and generally low efficiency likely to result in only limited running cost savings. Similar maintenance costs to other heat pumps. Typical system lifespan is 25 years which is similar to alternatives.
Carbon cost effectiveness (£ per tCO2 saved)	1 (low) to 5 (high) score	2	Not as effective as other forms of heat pumps with higher efficiencies.
(Potential for) economy of scale (to drive down costs)	1 (low) to 5 (high) score	2	Technology deployment is currently small, but suggest only limited scope for cost savings from scaling due to its lower efficiency versus other forms of heat pump
		8	

Capacity/ Supply Chain	Scoring	Score	Comments
Applicability	1 (low) to 5 (high) score	2	Widely applicable although roof or external wall (ideally south facing) needed to locate solar collector.
Existing Scottish capacity/skills	1 (low) to 5 (high) score	4	Scotland generally well placed owing to experience with solar and heat pump technology.
Scottish content	1 (low) to 5 (high) score	1	Currently limited / relatively low. Products manufactured out with the UK.
Potential for cross-sector involvement/benefit	1 (low) to 5 (high) score	1	Limited.
Scottish economic impact potential	1 (low) to 5 (high) score	1	Relatively low. Relatively poor solar irradiance levels (and the resulting detriment on system efficiency) is likely to restrict significant uptake in Scotland.
		9	

Consumer	Scoring	Score	Comments
User friendliness / practicality	1 (low) to 5 (high) score	3	Similar to conventional heat pumps.
Disruption	1 (high) to 5 (low) score	3	Similar to conventional heat pumps although with added requirement for a on roof or on wall collector to be installed.
Customer acceptance	1 (low) to 5 (high) score	3	Similar to other heat pumps, although generally poorer efficiency may limit acceptance.
Savings on bills	1 (low) to 5 (high) score	4	Likely to be less than with other conventional heat pump systems.
Maintenance requirements	1 (high) to 5 (low) score	3	Generally low, similar to air source heat pumps.
Health/wellbeing/comfort	1 (high negative impact) to 5 (high positive impact) score	3	No significant impacts or benefits.
Existing consumer protection? (Adequacy?)	1 (low) to 5 (high) score	4	MCS accredited system offer protection via Renewable Energy Consumer Code.
		23	

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Opportunities / risks		**Scoring**		**Score**		**Comments**
Critical success factors/watch points		List/Describe				
Other relevant considerations/risks/opportunities		List/Describe				Generally poor solar irradiance levels (and the resulting detriment on system efficiency) is likely to restrict significant uptake in Scotland.
Adaptability / future proofing		List / Describe				
				80		

PV-thermal (PV-T) (hybrid solar photovoltaics)

Hybrid solar photovoltaic thermal systems combine solar photovoltaics (PV) modules and solar thermal collectors, into one integrated product that removes, captures and makes use of, heat generated by the solar PV thereby improving electrical efficiency.

Technical	Scoring	Score	Comments
Technology readiness	TRL score 1-9	**8**	
Efficiency (product / technology efficiency)	1 (low) to 5 (high) score	2	PV-T as a standalone technology will provide electricity and low grade heat with an overall theoretical efficiency of 60-80%. Without a constant heat requirement during times of PV electrical generation, the PV-T panels can stagnate and present a negative impact on electrical efficiency. Well-designed systems present an improved electrical efficiency of 4-12% when compared to a PV only scenario. PV-T provide small relatively small amounts of useable heat during PV generation.
Reliability	1 (low) to 5 (high) score	3	Early systems have had reliability issues due to immature products and lack of experience and skills in design/ installation/ maintenance. Reliability continues to improve.
(Level of) Compatibility with existing systems	1 (low/poor) to 5 (high/good) score	2	PV-T works at its best when designed in conjunction with a system that can accept a constant heat transfer.
Complexity of systems/ their integration	1 (complex) to 5 (simple) score	3	Systems are no more complex that standard PV and solar thermal systems.
Risk/severity of unintended consequences	1 (high) to 5 (low) score	3	No significant risks to property or health identified. The main risk is with achievability of optimum system efficiencies - so need a heat source to make use of heat captured from the PV-T panel.
		21	

Environmental	Scoring	Score	Comments
In-use) carbon saving potential	1 (low) to 5 (high) score	2	Low carbon saving potential from "heat" alone, but can save more carbon that PV alone. Reports suggest that a typical domestic PV-T system can meet ~51% electricity demand & ~36% hot water demand. This can be increased where there are applications with large requirements for low grade heat. Similar carbon savings to standard PV & STh systems.
Whole life environmental impact	1 (high) to 5 (low) score	2	Similar to standard PV, however recent studies suggest show that environmental impact could potentially be reduced for PV by factor of 6 by implementing high-value recycling processes.
		4	

Policy / Regulation	Scoring	Score	Comments
Compatibility with Scottish policy	1 (low) to 5 (high) score	2	Can help support current policy on conservation of energy and carbon in a limited way.
Compatibility with current regulation	1 (low) to 5 (high) score	4	The Microgeneration Certification Scheme (MCS) currently recognises PV-T as a variation of PV and therefore is FIT eligible.
compatibility with current assessment methodologies	1 (low) to 5 (high) score	3	Currently needs to be assessed as separate technologies (PV & STH) and therefore does not accurately reflect in use performance.
		9	

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Monetary	Scoring	Score	Comments
capital costs	1 (high) to 5 (low) score	2	Excluding the costs of thermal storage, PV-T systems cost 1.5-2 times of an equivalently sized PV system and up to 1.5 times of an equivalent solar thermal system.
life cycle costs	1 (high) to 5 (low) score	3	Life cycle costs are similar to separate PV and solar thermal.
carbon cost effectiveness (£ per tCO2 saved)	1 (low) to 5 (high) score	3	Similar to standard PV.
(potential for) economy of scale (to drive down costs)	1 (low) to 5 (high) score	2	Economies of scale with new build applications - less likely to be realised with retrofit projects.
		10	

Capacity/ Supply Chain	Scoring	Score	Comments
applicability	1 (low) to 5 (high) score	2	Widely applicable. As per PV / solar thermal, but best efficiencies when there is a constant heat demand during PV generation hours.
existing Scottish capacity/skills	1 (low) to 5 (high) score	2	Not aware of any designers/installers in Scotland, but capacity to upskill existing PV/ STH workforce. Could easily be integrated into product offering of local renewable energy companies.
Scottish content	1 (low) to 5 (high) score	1	Low / limited regarding UK based product. However, suitable electrical and heating installation skills exists in Scotland.
potential for cross-sector involvement/benefit	1 (low) to 5 (high) score	1	No / low potential for cross sector benefit.
Scottish economic impact potential	1 (low) to 5 (high) score	1	Likely to be limited.
		7	

Consumer	Scoring	Score	Comments
user friendliness / practicality	1 (low) to 5 (high) score	3	Relatively simple technology that should be self-managing if designed and installed correctly.
disruption	1 (high) to 5 (low) score	2	Similar to PV and STh installations. Harder to integrate in retrofit applications.
customer acceptance	1 (low) to 5 (high) score	3	Similar to PV & STh which is considered widely acceptable.
savings on bills	1 (low) to 5 (high) score	3	Only realised with well-designed systems and requirements for low grade heat/constant heat sink during generation.
maintenance requirements	1 (high) to 5 (low) score	3	Similar to PV & STH system.
health/wellbeing/comfort	1 (high negative impact) to 5 (high positive impact) score	3	No significant advantages or disadvantages.
Existing consumer protection? (Adequacy?)	1 (low) to 5 (high) score	4	Covered under MCS and therefore Renewable Energy Code of Conduct (RECC).
		21	

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Opportunities / risks		Scoring		Score		Comments
Critical success factors/watch points		List/Describe				The property must have a (constant) requirement for low grade heat or be matched with a system that can accept lots of low grade heat. Highest system efficiencies have been seen when working in conjunction with GSHP.
other relevant considerations/risks/opportunities		List/Describe				Cost and complexity of retrofit integration can be prohibitive.
adaptability / future proofing		List / Describe				Technology can work with third party control systems and therefore can be adapted as required but inexperience of designers/ installers/ maintainers is a current issue until technology becomes more mainstream. Limitations with retrofit solutions. Best suited to new build applications.
				72		

Solar collector assisted, positive input ventilation (PIV)

Uses solar collectors integrated with a (typically) positive input ventilation (PIV) 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.

Technical	Scoring	Score	Comments
Technology readiness	TRL score 1-9	9	Commercially available
Efficiency (product / technology efficiency)	1 (low) to 5 (high) score	2	Provides a solar-assisted pre-heat of air for the PIV system.
Reliability	1 (low) to 5 (high) score	3	Reliable. 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.
(level of) Compatibility with existing systems	1 (low/poor) to 5 (high/good) score	3	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).
complexity of systems/ their integration	1 (complex) to 5 (simple) score	3	Relatively straightforward. Similar to standard PIV with added roof work for installation of collector. Requires considerable loft space for the equipment and ducting.
risk/severity of unintended consequences	1 (high) to 5 (low) score	4	No significant risks to property or health identified. 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.
		24	

Environmental	Scoring	Score	Comments
(in-use) carbon saving potential	1 (low) to 5 (high) score	2	Relatively low savings potential. Energy provided by the system will however offset energy that would otherwise have to be provided by the property's heating system.
whole life environmental impact	1 (high) to 5 (low) score	3	Product are generally relatively simple, straightforward and present no significant sustainability issues.
		5	

Policy / Regulation	Scoring	Score	Comments
compatibility with Scottish policy	1 (low) to 5 (high) score	2	Can help support creating healthy environments. Relatively low impact on energy savings.
compatibility with current regulation	1 (low) to 5 (high) score	3	Compatible. Similar to traditional PIV.
compatibility with current assessment methodologies	1 (low) to 5 (high) score	4	SAP 2012 already has a methodology for assessing solar assisted PIV.
		9	

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Monetary	Scoring	Score	Comments
capital costs	1 (high) to 5 (low) score	2	More expensive than standalone PIV due to solar collector element.
life cycle costs	1 (high) to 5 (low) score	3	Relatively low, as low maintenance product. Main item requiring replacement is the air filter (every 1-3 years).
carbon cost effectiveness (£ per tCO2 saved)	1 (low) to 5 (high) score		Unable to assess with accuracy due to lack of reliable data or independent reports.
(potential for) economy of scale (to drive down costs)	1 (low) to 5 (high) score	2	Unlikely to be significant potential to drive down costs via increased volume due to relatively low complexity of system.
		9	

Capacity/ Supply Chain	Scoring	Score	Comments
applicability	1 (low) to 5 (high) score	4	Suited to retrofitting to existing dwellings (as new builds typically have increased air tightness (and potentially mechanical ventilation) e.g. as part of wider refurbishment.
existing Scottish capacity/skills	1 (low) to 5 (high) score	3	Existing skilled installers of solar collectors, PIV systems (and hot water cylinders). Limited upskilling required.
Scottish content	1 (low) to 5 (high) score	2	Currently no / limited content regarding manufacture. Low-medium content in general installation / maintenance.
potential for cross-sector involvement/benefit	1 (low) to 5 (high) score	1	No / low potential for cross sector benefit.
Scottish economic impact potential	1 (low) to 5 (high) score	2	Likely to be limited due to relatively small market.
		12	

Consumer	Scoring	Score	Comments
user friendliness / practicality	1 (low) to 5 (high) score	4	Relatively simple system. Manufacturers produce easy-to-use control interface.
disruption	1 (high) to 5 (low) score	2	Systems generally installed in the loft space so space is required. System is relatively straightforward to install. Once installed, the systems should operate quietly and should not disrupt occupants.
customer acceptance	1 (low) to 5 (high) score	4	Typically acceptable to occupants due to low disruption and resulting increased levels of thermal comfort i.e. warmer, well ventilated rooms.
savings on bills	1 (low) to 5 (high) score	3	Some savings in bills due to reduction in heating bills. Other indirect benefits including better ventilation.
maintenance requirements	1 (high) to 5 (low) score	5	Low maintenance. Requirements to replace air filters (e.g. every 2 - 5 years).
health/wellbeing/comfort	1 (high negative impact) to 5 (high positive impact) score	4	The system can assist in providing a healthy and comfortable environment for building occupants. The system can ensure spaces are both well ventilated and provides some pre-heat.
Existing consumer protection? (Adequacy?)	1 (low) to 5 (high) score	4	Consumer protection is currently in place and adequate e.g. installers likely to be members of electrical contracting competency schemes, and/or ventilation competency schemes.
		26	

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Opportunities / risks		Scoring		Score		Comments
Critical success factors/watch points		List/Describe				
other relevant considerations/risks/opportunities		List/Describe				
adaptability / future proofing		List / Describe				
				85		

Deep geothermal

Geothermal heat extracted from hot rocks/aquifers, typically at depths of around 3 km or more, and distributed via district heating

Technical	Scoring	Score	Comments
Technology readiness	TRL score 1-9	**8**	Some demonstration projects are proving the concept. Deep geothermal energy projects in the UK are currently dependent upon a dedicated Renewable Heat Incentive Tariff to make them viable.
Efficiency (product / technology efficiency)	1 (low) to 5 (high) score	4	Efficiency will depend upon the conditions of the particular drill well - but can offer significant potential.
Reliability	1 (low) to 5 (high) score	3	Some wells don't actually work, so there is a risk element when drilling that it might all be a waste of time. Exploratory drilling is expensive, and therefore deep geothermal schemes have a very high up-front cost, but once the boreholes have been drilled, geothermal schemes appear to be very reliable.
(level of) Compatibility with existing systems	1 (low/poor) to 5 (high/good) score	3	Heat will typically be supplied to a district heating scheme.
complexity of systems/ their integration	1 (complex) to 5 (simple) score	2	Relatively complex installation. District heating is well established, and becoming more prevalent in Scotland.
risk/severity of unintended consequences	1 (high) to 5 (low) score	3	No significant risks to property or health identified however drilling can lead to small releases of noxious subterranean gases. NB: slight risk of earthquakes (as per Basel drillings).
		23	

Environmental	Scoring	Score	Comments
(in-use) carbon saving potential	1 (low) to 5 (high) score	5	Deep geothermal wells typically provide useful heat for around 50 years.
whole life environmental impact	1 (high) to 5 (low) score	5	Low impact as conventional / well known materials and products are used and large amounts of renewable heat can be extracted.
		10	

Policy / Regulation	Scoring	Score	Comments
compatibility with Scottish policy	1 (low) to 5 (high) score	4	This technology provides a lasting low-carbon source of heating, helping to achieve the Scottish target of near-zero-carbon housing by 2050. Planning / environmental policies / permissions might need to be adapted to accommodate drill wells?
compatibility with current regulation	1 (low) to 5 (high) score	4	This technology supports the decarbonisation of heating. Planning consent issues often need to be addressed (but the visual intrusiveness is low after the scheme and heating network have been laid).
compatibility with current assessment methodologies	1 (low) to 5 (high) score	4	Deep geothermal is well suited to district heating applications. Measurement of heat delivered via district heating is an established methodology.
		12	

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Monetary	Scoring	Score	Comments
capital costs	1 (high) to 5 (low) score	1	Very high cost of initial drilling, with the risk that the well might not work. Deep geothermal is still reliant on subsidy. Aecom estimates capital costs of 0.05 to 0.08 £/kWh, at 2012 prices (Table 7.5 of AEC/001/11)
life cycle costs	1 (high) to 5 (low) score	3	Deep geothermal wells typically last around 50 years. Although initial costs are high, the ongoing costs can be low once the geothermal facility has been established.
carbon cost effectiveness (£ per tCO2 saved)	1 (low) to 5 (high) score	4	High up-front costs, but large amounts of heat can be obtained over a long period of time.
(potential for) economy of scale (to drive down costs)	1 (low) to 5 (high) score	4	Needs to be investigated further but cost will likely reduce as system become more common and techniques developed. In countries with an established industry, conventional geothermal plants are already cost competitive. Previous DECC analysis suggests that on a level 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, and geothermal heating is cheaper than geothermal electricity production.
		12	

Capacity/ Supply Chain	Scoring	Score	Comments
applicability	1 (low) to 5 (high) score	3	To be viable, the technology requires a district heating network (e.g. locations in or near cities are likely to be suitable).
existing Scottish capacity/skills	1 (low) to 5 (high) score	3	Geological surveys and drilling for oil already established in Scotland, therefore Scotland potentially well placed for drilling for hot rocks.
Scottish content	1 (low) to 5 (high) score	4	Currently limited / relatively low. Products manufactured out with the UK, however geological, drilling and heat pump expertise exists in Scotland.
potential for cross-sector involvement/benefit	1 (low) to 5 (high) score	4	Existing installers of district heating could easily be involved in future schemes. Scotland has considerable experience in exploratory drilling.
Scottish economic impact potential	1 (low) to 5 (high) score	4	Economic impact could be very large, subject to geological exploration to locate local hot spots such as granite intrusions. High up-front investment would be the main barrier.
		18	

Consumer	Scoring	Score	Comments
user friendliness / practicality	1 (low) to 5 (high) score	3	District heating is an established technology.
disruption	1 (high) to 5 (low) score	3	Schemes would need to explored and established. District heating networks would also need to be installed to capitalise.
customer acceptance	1 (low) to 5 (high) score	3	Acceptance will be similar to that for other district heating schemes. Possible political issues if earthquakes occur, as occurred in Basel.
savings on bills	1 (low) to 5 (high) score	4	Largely affected by initial capital costs for drilling, but ongoing costs are very low once it is up and running.
maintenance requirements	1 (high) to 5 (low) score	4	Low maintenance requirements in almost all schemes.
health/wellbeing/comfort	1 (high negative impact) to 5 (high positive impact) score	4	No significant customer impacts or benefits (excluding potential for low cost renewable heat).
Existing consumer protection? (Adequacy?)	1 (low) to 5 (high) score	4	Consumers will be protected in the same way that they are for other types of district heating.
		25	

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Opportunities / risks		Scoring		Score		Comments
Critical success factors/watch points		List/Describe				Geological data for Scotland. Improvements in identifying suitable locations for drilling, and cost reduction in drilling and extraction techniques.
other relevant considerations/risks/opportunities		List/Describe				High risk of boreholes being unsuccessful, requiring redrilling and possible abandonment of drillings. However, significant benefits for successful schemes i.e. reliable long term supply of heat and costs not subject to the fluctuations in prices of imported fuels.
adaptability / future proofing		List / Describe				
				100		

Hydrocarbon fuel cell (cogeneration)

A fuel cell which uses hydrocarbon gases and oxygen to generate electricity, water and heat (whilst also producing waste gases)

Technical	Scoring	Score	Comments
Technology readiness	TRL score 1-9	9	Domestic sized systems commercially available. Devices incorporating fuel cells are marketed by well established companies (e.g. Viessmann (Germany)).
Efficiency (product / technology efficiency)	1 (low) to 5 (high) score	4	In north European climates, the combination of electricity and heat can be utilised successfully/efficiently within a combined heat and power setting, at least at times of the year when heat can be utilised. Most viable/economically advantageous if it is running at maximum capacity (so will require a constant heat demand/sink).
Reliability	1 (low) to 5 (high) score	3	Susceptible to contamination unless gas is very clean (so gas grid standards will ensure suitability).
(level of) Compatibility with existing systems	1 (low/poor) to 5 (high/good) score	3	Links with traditional systems to provide heating and electricity, but units tend to be rather bulky.
complexity of systems/ their integration	1 (complex) to 5 (simple) score	3	Links with traditional systems to provide heating and electricity, but units tend to be rather bulky.
risk/severity of unintended consequences	1 (high) to 5 (low) score	3	No significant risks to property or health identified.
		25	

Environmental	Scoring	Score	Comments
(in-use) carbon saving potential	1 (low) to 5 (high) score	4	If there is sufficient heat demand to ensure that all heat and electricity can be utilised, then the potential energy saving are good.
whole life environmental impact	1 (high) to 5 (low) score	3	The electrodes incorporate some rare metals. Otherwise environmental impact is relatively good.
		7	

Policy / Regulation	Scoring	Score	Comments
compatibility with Scottish policy	1 (low) to 5 (high) score	4	Can support current policy on conservation of energy and carbon (particular in combination with a decarbonised gas grid).
compatibility with current regulation	1 (low) to 5 (high) score	4	Cogeneration fits well within current regulations.
compatibility with current assessment methodologies	1 (low) to 5 (high) score	2	Efficiencies of fuel cells are relatively difficult to define - robust assessment likely to need some development.
		10	

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Monetary	Scoring	Score	Comments
capital costs	1 (high) to 5 (low) score	1	Very high. Capital costs are currently many times that of gas boilers, and currently also greater than micro-CHP.
life cycle costs	1 (high) to 5 (low) score	4	Good potential if system can run 24/7 (i.e. constant heat and power requirements).
carbon cost effectiveness (£ per tCO2 saved)	1 (low) to 5 (high) score	3	Needs to be more fully investigated / determined as the market and technology develops. Capital costs are high, but efficiencies are also high and fuel costs (gas) relatively low.
(potential for) economy of scale (to drive down costs)	1 (low) to 5 (high) score	4	Capital costs are currently high and uptake low as a result, so economies of scale are likely to help drive down unit costs.
		12	

Capacity/ Supply Chain	Scoring	Score	Comments
applicability	1 (low) to 5 (high) score	3	Best suited to systems which can provide constant heat sink, so applications relatively restricted. Large scale systems could be used in a CHP scheme or similar.
existing Scottish capacity/skills	1 (low) to 5 (high) score	2	Low / limited regarding UK based product. However, fuel cell skills and expertise exists in Scotland and there are growing numbers of fuel cell demonstrators (including transport applications).
Scottish content	1 (low) to 5 (high) score	1	Low / limited regarding UK based product. However, fuel cell skills and expertise exists in Scotland and there are growing numbers of fuel cell demonstrators (including transport applications).
potential for cross-sector involvement/benefit	1 (low) to 5 (high) score	3	There are complementary skills in Scotland's emerging hydrogen sector.
Scottish economic impact potential	1 (low) to 5 (high) score	3	Offers potential. Watch for key development and innovations. High capital cost, but high efficiencies.
		12	

Consumer	Scoring	Score	Comments
user friendliness / practicality	1 (low) to 5 (high) score	2	Maintenance and regular replacement of electrodes necessary. Fuel cells are likely to be more suited to combined heat and power than to individual dwellings.
disruption	1 (high) to 5 (low) score	2	Domestic units are large but can be easily integrated with existing (/traditionally designed) heating distribution pipework and electricity supplies - although for maximum efficiency it is likely that a thermal store will be required.
customer acceptance	1 (low) to 5 (high) score	3	Mixed reviews to date - potentially due to immaturity of market.
savings on bills	1 (low) to 5 (high) score	4	Efficiency is very high, provided the heat and electricity can both be utilised.
maintenance requirements	1 (high) to 5 (low) score	2	The stack of electrodes requires regular maintenance / renewal and gas supply must be clean.
health/wellbeing/comfort	1 (high negative impact) to 5 (high positive impact) score	3	No significant property or health risks identified.
Existing consumer protection? (Adequacy?)	1 (low) to 5 (high) score	3	Gas and renewable competent person schemes already exist.
		19	

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Opportunities / risks		**Scoring**		**Score**		**Comments**
Critical success factors/watch points		List/Describe				Research on development of electrodes. Gas scrubbing methods. Relative cost of alternative technologies. Fuel cell expertise in Scotland.
other relevant considerations/risks/opportunities		List/Describe				Fuel cells could complement biogas generation, enabling electricity and heat to be generated very efficiently from biogas.
adaptability / future proofing		List / Describe				
				85		

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Hydrogen fuel cells (cogeneration)

A fuel cell which uses hydrogen gas and oxygen to generate electricity, water and heat

Technical	Scoring	Score	Comments
Technology readiness	TRL score 1-9	9	A (small) number of units are commercially available via several manufacturers who have required capacity and production facilities to produce hydrogen fuel cells at small volume (i.e. <1000 units). A 2016 DECC report (by Kiwa) highlights that hydrogen appliances still require subsidies as they are not yet fully commercially mass-produced. The technology components are however generally available, and early supply chain present, for hydrogen fuel cell appliance components, with the majority of components outside of the fuel cell stack being commercially available. It is estimated that approximately 1-2 years will be necessary for product design, safety architecture and compliance modifications and for scaling stack production from say 1000-10,000 units (and beyond), however, industry will need to build additional manufacturing facilities and so R&D and strong policy signals will be required.
Efficiency (product / technology efficiency)	1 (low) to 5 (high) score	4	The US Department of Energy "Hydrogen Program" suggests that a 60% efficiency for electricity production and an overall efficiency of 85% for CHP could reasonably be achieved.
Reliability	1 (low) to 5 (high) score	3	Fuel cells are very susceptible to contamination unless the gas is very clean.
(level of) Compatibility with existing systems	1 (low/poor) to 5 (high/good) score	3	Links with traditional systems to provide heating and electricity.
complexity of systems/ their integration	1 (complex) to 5 (simple) score	3	Links with traditional systems to provide heating and electricity.
risk/severity of unintended consequences	1 (high) to 5 (low) score	3	No significant risks to property or health identified.
		25	

Environmental	Scoring	Score	Comments
(in-use) carbon saving potential	1 (low) to 5 (high) score	4	Very high, as this is linked to the carbon content of hydrogen production.
whole life environmental impact	1 (high) to 5 (low) score	3	The manufacture of platinum electrodes lead to significant environmental impact.
		7	

Policy / Regulation	Scoring	Score	Comments
compatibility with Scottish policy	1 (low) to 5 (high) score	5	Can support current policy on conservation of energy and carbon (particularly if hydrogen can be produced cost effectively).
compatibility with current regulation	1 (low) to 5 (high) score	2	Development of hydrogen regulations will be needed e.g. product, design, installation and maintenance standards etc.
compatibility with current assessment methodologies	1 (low) to 5 (high) score	2	Efficiencies of fuel cells are relatively difficult to define - robust assessment likely to need some development.
		9	

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Monetary	Scoring	Score	Comments
capital costs	1 (high) to 5 (low) score	1	Cost is currently a barrier to large-scale deployment. The first 1000th units are expected to cost around £ 11,000/unit. This compares with a cost of only about £450 – £750 capital cost for a gas boiler.
life cycle costs	1 (high) to 5 (low) score	1	Currently dependent upon costs of hydrogen fuel. If relatively low then they can offer good potential if system can run 24/7 (i.e. constant heat and power requirements). Maintenance costs of hydrogen fuel cells will very much depend upon the cleanliness of the hydrogen.
carbon cost effectiveness (£ per tCO2 saved)	1 (low) to 5 (high) score	2	The high capital cost and high fuel cost are the main issues currently.
(potential for) economy of scale (to drive down costs)	1 (low) to 5 (high) score	5	For scaling up of fuel cell stack production, additional manufacturing facilities will likely need to be built. A 2016 DECC report suggests that manufacturers already have capacity to produce 1,000 stacks but 10,000 stacks would require further investment in capacity of £3-4 million and roughly 2-year lead time. Going above 10,000 will require strong market signals for manufacturers to take the risk of scaling up. The first 1000th units are expected to cost around £ 11,000/unit.
		9	

Capacity/ Supply Chain	Scoring	Score	Comments
applicability	1 (low) to 5 (high) score	1	Lack of cheap hydrogen (and infrastructure) is currently restrictive. From a technical perspective, the technology is best suited to systems which can provide constant heat sink, so applications relatively restricted. Large scale systems could be used in a CHP scheme or similar.
existing Scottish capacity/skills	1 (low) to 5 (high) score	2	Low / limited regarding UK based product. However, fuel cell skills and expertise exists in Scotland and there are growing numbers of fuel cell demonstrators (including transport applications).
Scottish content	1 (low) to 5 (high) score	2	Low / limited regarding UK based product. However, fuel cell skills and expertise exists in Scotland and there are growing numbers of fuel cell demonstrators (including transport applications).
potential for cross-sector involvement/benefit	1 (low) to 5 (high) score	4	Hydrogen could be generated from various sources in Scotland, including electrolysis of surplus renewable electricity (e.g. onshore/offshore wind).
Scottish economic impact potential	1 (low) to 5 (high) score	4	Offers significant potential. Watch for key development and innovations. High capital cost, but high efficiencies and opportunities to link to renewables sector.
		13	

Consumer	Scoring	Score	Comments
user friendliness / practicality	1 (low) to 5 (high) score	2	Maintenance and regular replacement of electrodes necessary. Fuel cells are likely to be more suited to combined heat and power than to individual dwellings.
disruption	1 (high) to 5 (low) score	2	Domestic units are large but can be easily integrated with existing (/traditionally designed) heating distribution pipework and electricity supplies - although for maximum efficiency it is likely that a thermal store will be required.
customer acceptance	1 (low) to 5 (high) score	2	Currently low due to lack of consumer knowledge regarding (i) hydrogen, and (ii) fuel cells.
savings on bills	1 (low) to 5 (high) score	3	Efficiency of fuel cells is high, so good savings are theoretically possible, although in reality these will be closely linked to the cost of generating hydrogen.
maintenance requirements	1 (high) to 5 (low) score	2	Contamination of the "stack" is a problem. Most gas odorants (used for safety) would contaminate fuel cells.
health/wellbeing/comfort	1 (high negative impact) to 5 (high positive impact) score	3	No significant property or health risks identified.
Existing consumer protection? (Adequacy?)	1 (low) to 5 (high) score	1	Standards and codes of practice relating to hydrogen need to be developed.
		15	

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Opportunities / risks		Scoring		Score		Comments
Critical success factors/watch points		List/Describe				An important factor in the development of the hydrogen appliance market is a plan for the local deployment of bulk pipeline hydrogen through the existing natural gas network.
other relevant considerations/risks/opportunities		List/Describe				Research to extend stack lifetimes. Research to find suitable odorants which do not contaminate stacks. Upskilling. Economical sources of hydrogen.
adaptability / future proofing		List / Describe				
				78		

Hydrogen boilers

Boilers configured to run using hydrogen to provide hot water to radiators and domestic hot water

Technical	Scoring	Score	Comments
Technology readiness	TRL score 1-9	7	There are few specific issues which are intrinsic to hydrogen. Standards (installation, quality etc.) would need to be developed. Giacomini markets hydrogen boilers. Technology appears to be TRL 9 but gas distribution might be at an earlier level.
Efficiency (product / technology efficiency)	1 (low) to 5 (high) score	4	According to the Pure Energy Centre, an efficiency of 90% can easily be achieved for hydrogen boilers.
Reliability	1 (low) to 5 (high) score	3	The technology for flame-based hydrogen boilers is not any more complex than that of natural gas boilers and reliability is likely to be similar. For catalytic burners, reliability will depend on how clean the gas is.
(level of) Compatibility with existing systems	1 (low/poor) to 5 (high/good) score	3	Converting network from natural gas to hydrogen is feasible, but requires training/upskilling as well as appliance modifications. New sales and distribution channels are unlikely to be needed as current boiler manufacturers could use existing channels. Hydrogen quality standards and standards for installing appliances are needed (although filtering and treating the gas might be an option). The quality of the gas is more critical for catalytic burners than for flame burners.
complexity of systems/ their integration	1 (complex) to 5 (simple) score	3	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 would 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 R&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.
risk/severity of unintended consequences	1 (high) to 5 (low) score	3	No significant risks to property or health identified. There are few major issues in switching to hydrogen apart from the problem of mass-producing it affordably. The old town gas contained an appreciable amount of hydrogen in the mix.
		23	

Environmental	Scoring	Score	Comments
(in-use) carbon saving potential	1 (low) to 5 (high) score	4	The carbon emissions at the site of burning are negligible. Hydrogen can be generated from surplus electricity, potentially of low carbon content. Mass-producing hydrogen might be harder, and some reports suggest that hydrogen gas at scale will most likely require natural gas (methane) as the source feedstock and to be low carbon would require carbon capture technology.
whole life environmental impact	1 (high) to 5 (low) score	4	Similar to gas boilers. Typically constructed using conventional, well known, and relatively low impact materials.
		8	

Policy / Regulation	Scoring	Score	Comments
compatibility with Scottish policy	1 (low) to 5 (high) score	5	Can support current policy on conservation of energy and carbon (particularly if hydrogen can be produced cost effectively).
compatibility with current regulation	1 (low) to 5 (high) score	2	Development of hydrogen regulations will be needed e.g. product, design, installation and maintenance standards etc.
compatibility with current assessment methodologies	1 (low) to 5 (high) score	4	Efficiency of a hydrogen boiler can be assessed in a similar way to efficiency of other gas boilers.
		11	

Monetary	Scoring	Score	Comments
capital costs	1 (high) to 5 (low) score	1	Technology is similar to that of conventional gas boilers (but pre-mass production which drove down gas boiler cost). Capital cost of hydrogen burners/boilers currently ~4 x cost of gas boiler. For mass production, estimated capital costs are £700 to £1100 per unit. It has been estimated that with mass production hydrogen boilers could cost about 1.5 times as much as conventional gas boilers. By comparison, conventional gas boilers cost around £450 to £750. Installation costs are typically similar so the installed cost of a (mass produced) hydrogen boiler is likely to be ~ 10 – 20% higher than that of a conventional gas condensing boiler.
life cycle costs	1 (high) to 5 (low) score	1	Currently dependent upon the cost of hydrogen fuel. There appear to be no indications to suggest that hydrogen boilers will have a lifetime differing significantly from the typical lifetime of 12 years for natural gas boilers (Kiwa, 2016).
carbon cost effectiveness (£ per tCO2 saved)	1 (low) to 5 (high) score	2	The relatively high capital cost and high fuel cost are the main issues currently.
(potential for) economy of scale (to drive down costs)	1 (low) to 5 (high) score	5	The timeline for developing hydrogen-fired boilers is dependent on the number of units manufactured. A 2016 DECC report highlights that incorporating a product line of 100,000 units is estimated to take up to 4 to 7 years with the first 1,000 units ready within 2 to 4 years from project start. Product designs would be complete in the lead up to the production of the first batches i.e. comprising the first 2-3 years of the project. Capital costs for the first 1000 units were estimated at four times the cost of equivalent natural gas fired appliances. This could fall to 1.5 times natural gas appliances when production was increased to 100,000 units. Units are highly likely to be manufacturers by those currently manufacturers natural gas fired boilers.
		10	

Capacity/ Supply Chain	Scoring	Score	Comments
applicability	1 (low) to 5 (high) score	1	Lack of cheap hydrogen (and infrastructure) is currently restrictive.
existing Scottish capacity/skills	1 (low) to 5 (high) score	2	Low / limited regarding UK based product. However, fuel cell skills and expertise exists in Scotland and there are growing numbers of fuel cell demonstrators e.g. Methil, Fife, and transport demonstrators.
Scottish content	1 (low) to 5 (high) score	2	Low / limited regarding UK based product. However, fuel cell skills and expertise exists in Scotland and there are growing numbers of fuel cell demonstrators e.g. Methil, Fife, and transport demonstrators.
potential for cross-sector involvement/benefit	1 (low) to 5 (high) score	4	Hydrogen could be generated from various sources in Scotland, including electrolysis of surplus renewable electricity (e.g. onshore/offshore wind).
Scottish economic impact potential	1 (low) to 5 (high) score	4	Offers significant potential. Watch for key development and innovations. High capital cost, but high efficiencies and opportunities to link to renewables sector.
		13	

Consumer	Scoring	Score	Comments
user friendliness / practicality	1 (low) to 5 (high) score	4	Flame is more difficult to see compared to natural gas, leading to a burn risk. The use of an odorant, for safety purposes, presents some difficulties for catalytic burners. Otherwise, hydrogen presents few difficulties which are not already there with natural gas.
disruption	1 (high) to 5 (low) score	3	From 1967-77, town gas appliances were converted to take natural gas. Converting to hydrogen is feasible too, but requires training/upskilling as well as appliance modifications to allow for the different Wobbe index etc.
customer acceptance	1 (low) to 5 (high) score	3	We can draw upon the experience of switching from town gas (1967-77) to natural gas in understanding how customers view/accept new fuels.
savings on bills	1 (low) to 5 (high) score	2	Costs are largely influenced by costs of producing hydrogen.
maintenance requirements	1 (high) to 5 (low) score	4	Maintenance of hydrogen boilers are unlikely to present difficulties which are not currently present in other types of boiler.
health/wellbeing/comfort	1 (high negative impact) to 5 (high positive impact) score	4	The low radiance of hydrogen flames presents a problem for flame detection. Catalytic combustion of hydrogen might be preferred but the catalyst will be vulnerable to any contaminants. If a boiler is faulty, harmful oxides of nitrogen could be produced, however the production of carbon monoxide is not possible. Odorants are normally added to gas as a safety precaution, but most odorants could contaminate catalytic burners - Standards will need to be developed to prevent any issues. With this in mind there should be no significant property or health risks.
Existing consumer protection? (Adequacy?)	1 (low) to 5 (high) score	1	Standards and codes of practice relating to hydrogen need to be developed.
		21	

Opportunities / risks	Scoring	Score	Comments
Critical success factors/watch points	List/Describe		Cost of generating hydrogen, quality/purity of hydrogen and development of standards for installing hydrogen boilers. Hydrogen might be more suited to transport than to space heating (e.g. hydrogen can be used in buses in Aberdeen).
other relevant considerations/risks/opportunities	List/Describe		In areas off the gas grid, bottled hydrogen could potentially be used instead of other types of bottled gas, however the volumetric calorific value of hydrogen is less than that of other gases. Further demonstrations of hydrogen technology could assist development of this technology.
adaptability / future proofing	List / Describe		Hydrogen is likely to be less affected by future import prices than natural gas is.
		86	

Biogas CHP (cogeneration)

Combined heat and power generation using biogas/biomethane (e.g. produced locally from anaerobic digestion)

Technical	Scoring	Score	Comments
Technology readiness	TRL score 1-9	9	CHP technology is well established and biogas technology is developing.
Efficiency (product / technology efficiency)	1 (low) to 5 (high) score	5	High efficiency, established, cogeneration technology. Most viable/economically advantageous if it is running at maximum capacity (so will require a constant heat demand/sink).
Reliability	1 (low) to 5 (high) score	3	CHP operation very similar to traditional fuel CHP. System reliability depends largely on the quality of biogas fuel - which is dependent on local biogas generation technologies and scrubbing of fuel (or a supply of biogas in the grid network)
(level of) Compatibility with existing systems	1 (low/poor) to 5 (high/good) score	2	Inputs: Needs a source of biogas (ideally local). Outputs: provides cogeneration of low temperature hot water (which can be integrated with existing heating/hot water systems) and electricity for local use or export.
complexity of systems/ their integration	1 (complex) to 5 (simple) score	2	Identical to traditional CHP when it comes to making use of the biogas CHP outputs (i.e. hot water and electricity). It is therefore compatible with the majority of systems e.g. district heating, thermal stores, large heating distribution systems, etc. To be most efficiency the CHP engine will need to run 24/7 and therefore needs a constant heat demand.
risk/severity of unintended consequences	1 (high) to 5 (low) score	3	No significant risks to property or health identified. Biogas can be corrosive if not treated properly which can degrade equipment. Risk involved with biogas production / distribution / handling given its flammability - although strict codes of practice /standards are in place - particularly for biogas injection to the gas grid (ref: national grid standards).
		24	

Environmental	Scoring	Score	Comments
(in-use) carbon saving potential	1 (low) to 5 (high) score	5	Cogeneration from CHP plant, powered from a renewable biogas fuel supply can provide high carbon savings.
whole life environmental impact	1 (high) to 5 (low) score	5	Biogas can be produced from organic waste streams from different industries e.g. agricultural and food & drink.
		10	

Policy / Regulation	Scoring	Score	Comments
compatibility with Scottish policy	1 (low) to 5 (high) score	5	Good potential for biogas CHP to assist with policy delivery of waste and carbon emissions reductions (either served with locally produced biogas or via a biogas gas grid).
compatibility with current regulation	1 (low) to 5 (high) score	4	CHP fits well within current regulations, some work may be needed regarding biogas.
compatibility with current assessment methodologies	1 (low) to 5 (high) score	5	Compatible. Biogas currently included in SBEM and therefore enables calculation for building regulations compliance / asset performance ratings. Assessment of CHP engines, and quality of CHP schemes, well established e.g. BEIS' CHP Quality Assurance Programme.
		14	

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Monetary	Scoring	Score	Comments
capital costs	1 (high) to 5 (low) score	1	Biogas CHP unit costs will be slightly higher than gas-fired CHP (~10%). Adding an anaerobic digester/ biogas treatment will increase capital costs significantly if biogas needs to be generated on site e.g. if a local biogas supply cannot be sourced. Cost of AD/CHP plants vary significantly as a result of varying technology, inputs, outputs, location, etc. £2,500 to £7,000 per kW has previously been reported [source: http://research.ncl.ac.uk/pro-tem/components/pdfs/TEM_in_food_and_drink/TEM_in_food_drink_industry_AD.pdf].
life cycle costs	1 (high) to 5 (low) score	3	Systems are durable with regular (annual) maintenance. Maintenance costs may be higher than conventional gas fired CHP due to the corrosive nature of un-scrubbed biogas (more of a potential issue for local biogas supplies). Life cycle costs are largely dependent on biogas fuel supply costs, so biogas supply is critical.
carbon cost effectiveness (£ per tCO2 saved)	1 (low) to 5 (high) score	4	High carbon savings if biogas is made from 100% renewable source.
(potential for) economy of scale (to drive down costs)	1 (low) to 5 (high) score	3	Currently, most cost effective at larger scale. Economy of scale opportunities may be presented by significant increases in biogas production (local and/or biogas grid) - although this may be limited by the organic waste material.
		12	

Capacity/ Supply Chain	Scoring	Score	Comments
applicability	1 (low) to 5 (high) score	3	Applicable where 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 (or a heat sink). Unlikely to currently compete where a main gas connection is available.
existing Scottish capacity/skills	1 (low) to 5 (high) score	2	Low / limited regarding UK based product. However, existing gas/CHP skills exists but further education/awareness is needed to promote understanding of sector.
Scottish content	1 (low) to 5 (high) score	2	Low / limited regarding UK based product. However, existing gas/CHP skills exists but further education/awareness is needed to promote understanding of sector.
potential for cross-sector involvement/benefit	1 (low) to 5 (high) score	4	Good opportunity for wider sectors to benefit from wider biogas industry e.g. food and drink industries, skills cross-over from traditional oil and gas, etc.
Scottish economic impact potential	1 (low) to 5 (high) score	4	Offers significant potential. Watch for key development and innovations. Opportunities for partnering/making use of local feedstocks/waste material. Waste reduction / circular economy potential.
		15	

Consumer	Scoring	Score	Comments
user friendliness / practicality	1 (low) to 5 (high) score	3	Large systems in particular will require expertise to design, installation, maintain and operate.
disruption	1 (high) to 5 (low) score	3	Biogas CHP can be integrated with existing (/traditionally designed) heating distribution pipework and electricity supplies. Most disruption / difficulty will be from design, integration and operation of biogas production or sourcing biogas.
customer acceptance	1 (low) to 5 (high) score	3	Systems can integrate with traditional heating and hot water system so that property occupants will be unaffected by the use of system. The acceptance of property owners will largely depend on security of biogas supply, reliability of equipment, maintenance, and installation and running costs - all of which could vary significantly from site to site.
savings on bills	1 (low) to 5 (high) score	4	Good potential for savings versus oil/LPG, if there is suitable biogas supply (or potential for local production).
maintenance requirements	1 (high) to 5 (low) score	2	Relatively high and most likely concerning issues associated with the quality of biogas fuel as market and technology develops. Maintenance of CHP engine is also key to efficient operation (but skills exist). Maintenance requirements likely to reduce over time as fuel quality / consistency and awareness improves.
health/wellbeing/comfort	1 (high negative impact) to 5 (high positive impact) score	3	No significant property or health risks identified. Biogas CHP systems will output heat and power to traditional property energy systems so users will be unaware of fuel source.
Existing consumer protection? (Adequacy?)	1 (low) to 5 (high) score	3	Assessment of CHP engines, and quality of CHP schemes, well established e.g. BEIS' CHP Quality Assurance Programme. The design, installation, operation and maintenance of heat and power systems are all well established and understood industries with relevant competent persons schemes and similar. In addition, there are increasing standards and codes of practice for biogas fuel production.
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Opportunities / risks		Scoring		Score		Comments
Critical success factors/watch points		List/Describe				- The developing biogas sector
other relevant considerations/risks/opportunities		List/Describe				- Good opportunities for industries that produce large amounts of organic waste e.g. food & drink and the agricultural industries, to add value to their existing organic waste streams by generating/selling biogas. - Good potential to reduce organic waste stream treatment costs and help the move towards a circular economy. - The technology market for biogas CHP is still relatively immature.
adaptability / future proofing		List / Describe				
				96		

Micro CHP (heat led) (cogeneration)

Micro (<45Kw thermal) scale combined heat and power systems which typically uses fossil fuel to generate heat and electricity. Being heat-led the system is design to provide thermal heat output to suit the buildings heat demands (and generates electricity whilst supplying this heat).

Technical	Scoring	Score	Comments
Technology readiness	TRL score 1-9	9	Micro CHP has been available to consumers for many years now however far less manufacturers of micro CHP than conventional CHP. Technology is continuously improving with particular regard to improving reliable operation and overall efficiency and carbon performance.
Efficiency (product / technology efficiency)	1 (low) to 5 (high) score	4	Cogeneration technology makes use of waste heat during production of electricity thereby improving overall efficiency. Maximising efficiency is made possible from good specification of micro CHP to a particular site i.e. one that is suitable for the site's energy patterns.
Reliability	1 (low) to 5 (high) score	3	Reliability similar to standard CHP with regards to operational and maintenance requirements. Field data available demonstrating micro CHP as a competent and reliable source of providing heat and electricity to a building.
(level of) Compatibility with existing systems	1 (low/poor) to 5 (high/good) score	3	Can utilise existing mains gas connections. Can be integrated with existing hot water pipework for hot water and heating requirements. 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.
complexity of systems/ their integration	1 (complex) to 5 (simple) score	3	Heat led micro CHP must be sized appropriately based on the heat demand profile of the building. Site energy requirements and usage patterns must be carefully understood before commissioning a particular CHP unit to make sure energy demands will be adequately met. They can connect to traditional heating distribution and storage systems.
risk/severity of unintended consequences	1 (high) to 5 (low) score	3	No significant risks to property or health identified. If systems are not specified appropriately to the sites energy demand patterns this could result in reduced overall efficiency. May require additional heating sources to meet heating requirements if CHP isn't sized correctly.
		25	

Environmental	Scoring	Score	Comments
(in-use) carbon saving potential	1 (low) to 5 (high) score	3	A study by the Carbon Trust stated that field trial results of micro CHP used in commercial settings showed significant variations in carbon savings.
whole life environmental impact	1 (high) to 5 (low) score	3	Can reduce carbon emissions compared with conventional heating systems e.g. combination boilers. May be preferable to utilise more guaranteed options to reduce carbon emissions e.g. biomass boiler etc. gas fired micro CHP could be fed with biomethane to reduce carbon dioxide emissions greatly.
		6	

Policy / Regulation	Scoring	Score	Comments
compatibility with Scottish policy	1 (low) to 5 (high) score	4	Good potential for mCHP to assist with policy of energy and carbon emissions reductions. Renewable or low carbon fuelled micro CHP has improved potential.
compatibility with current regulation	1 (low) to 5 (high) score	5	CHP fits well within current regulations
compatibility with current assessment methodologies	1 (low) to 5 (high) score	5	No significant issues. There are recognised procedures for assessing the efficiency and performance.
		14	

Monetary	Scoring	Score	Comments
capital costs	1 (high) to 5 (low) score	1	Significantly higher when compared with a standard gas-fired condensing boiler which capital costs being many multiples of the capital cost of condensing boiler of an equivalent capacity however mCHP also contributed useful electrical generation.
life cycle costs	1 (high) to 5 (low) score	2	Life cycle costs vary (depending upon system design) but generally better than a standalone gas boilers due to the additional electrical generation component. Operational costs can be improved by installing the system in application where there is a constant heat demand/sink thereby increasing the utilisation factor of the unit via long operating cycles which reduces system losses.
carbon cost effectiveness (£ per tCO2 saved)	1 (low) to 5 (high) score	3	Good potential to reduce carbon emissions if the application of the technology is well suited to the site and the system is designed, installed and commissioned appropriately.
(potential for) economy of scale (to drive down costs)	1 (low) to 5 (high) score	2	Micro CHP market is much smaller than larger CHP - largely owing to the fact that smaller properties have smaller (non-constant) energy loads and this significantly reduces the number of potential applications for efficiency mCHP. This limits opportunity for economies of scale as a result.
		10	

Capacity/ Supply Chain	Scoring	Score	Comments
applicability	1 (low) to 5 (high) score	3	Most suitable for small scale non-domestic operation where there is a near constant demand 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 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.
existing Scottish capacity/skills	1 (low) to 5 (high) score	2	Low / limited regarding UK based product. However, existing skills (e.g. building service engineers, gas engineers and electrical engineers) exist.
Scottish content	1 (low) to 5 (high) score	2	Low / limited regarding UK based product. However, existing skills (e.g. building service engineers, gas engineers and electrical engineers) exist. A potential area of interest may be low carbon based micro CHP such as from biogas, biomass or fuel cell.
potential for cross-sector involvement/benefit	1 (low) to 5 (high) score	2	Sectors can be involved in manufacture, design, installation, and operation/maintenance.
Scottish economic impact potential	1 (low) to 5 (high) score	2	Low-medium potential - mainly related to businesses making savings through use of systems.
		11	

Consumer	Scoring	Score	Comments
user friendliness / practicality	1 (low) to 5 (high) score	3	Control of CHP is largely automated and if designed, installed and commissioned correctly should require little input from site staff. If units begin to operate outside of designed parameters usually an alarm will sound to alert attention. Relevant staff members e.g. facilities manager should ideally be trained or made aware of the purpose of the CHP unit as well the importance of condition and monitoring.
disruption	1 (high) to 5 (low) score	3	Disruption during install. Minor disruption during maintenance and servicing periods.
customer acceptance	1 (low) to 5 (high) score	4	Systems can integrate with traditional heating and hot water system so that property occupants will be unaffected by the use of system. Operators will accept system as long as user operation and monitoring requirements are low and the system provides energy savings over conventional heating systems.
savings on bills	1 (low) to 5 (high) score	4	Potential to reduce energy costs versus standalone boiler assuming site energy demands suit mCHP and if the system is design, installed and commissioned appropriately so that efficiency is maximised i.e. maximising use of electricity and heat produced by the mCHP unit.
maintenance requirements	1 (high) to 5 (low) score	3	Must be well maintained correctly to ensure reliability and efficiency. Units should be serviced appropriately as by manufacturers and installers guidelines.
health/wellbeing/comfort	1 (high negative impact) to 5 (high positive impact) score	4	No significant property or health risks identified. mCHP systems will output heat and power to traditional property energy systems so users will be unaware of fuel source.
Existing consumer protection? (Adequacy?)	1 (low) to 5 (high) score	4	Micro CHP units included in Department BEIS' Microgeneration Certification Scheme (MCS) provide quality assurance to consumers that the product has been manufactured and installations designed and installed to MCS standards. Certified installers of micro CHP systems are covered in the scheme. MCS accredited system offer protection via Renewable Energy Consumer Code.
		25	

Opportunities / risks		Scoring		Score		Comments
Critical success factors/watch points		List/Describe				Careful attention needs to be placed on the application of micro CHP to sites that have suitable energy demand patterns suitable for a particular micro CHP unit. Micro CHP may in fact be less environmentally beneficial and cost-effective than a standard gas condensing boiler and mains electricity in some situations.
other relevant considerations/risks/opportunities		List/Describe				**Risks:** - Potentially very long payback periods if micro CHP unit is unsuitable for sites energy demand patterns **Opportunities:** - Potential to significantly reduce energy costs and carbon emissions if designed and installed appropriately.
adaptability / future proofing		List / Describe				May be less relevant in the future for helping to reduce carbon dioxide emissions as grid electricity becomes ever more decarbonised making other forms of heating e.g. heat pumps more attractive. However this can be bypassed if micro CHP are fuelled by renewable heat sources e.g. biomass or biogas.
				91		

Combined Cooling Heat and Power (CCHP) (trigeneration)

Combined Cooling Heat and Power (CCHP) (also known as "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 centigrade minimum).

Technical	**Scoring**	**Score**	**Comments**
Technology readiness	TRL score 1-9	**9**	Commercially available. There are numerous successful applications in the UK (e.g. Olympic Park, Natural History Museum and Edinburgh University Vetinary Campus). The installations are mainly large commercial developments / campuses /hospitals / large buildings etc. as these building types present a suitable heating and coolth demand profile suited to CCHP. The technology is not suitable for residential developments - other than potentially being part of a district heating and cooling network. Currently most CCHP installations are fuelled by mains gas.
Efficiency (product / technology efficiency)	1 (low) to 5 (high) score	4	4 if using a fossil fuel. 5 if using a renewable fuel. Highly efficient use of fossil or renewable fuel. Needs a constant demand of heating and cooth for maximum efficiency and cost effective operation.
Reliability	1 (low) to 5 (high) score	3	The technology is well established. This is particularly true for fossil fuelled systems. Some renewable fuelled systems are in their relative infancy. Main reliability issues are as a result of fuel quality/consistency (for renewable fuels) and/or improper design and integration with heating/cooling distribution systems (fossil or renewable fuelled). The CCHP system will typically provide base loads so systems will typically be supplemented by back-up (or top up) boilers meaning there will be some traditional heating / cooling systems should the system fail.
(level of) Compatibility with existing systems	1 (low/poor) to 5 (high/good) score	2	Only suited to specific applications where there is a relatively constant demand for heating and coolth simultaneously (e.g. universities, hospitals, industrial buildings, large commercial estates). When the demand profile are suitable then integration with existing systems should be possible, although systems are likely to operate best when designed as part of a new build or major refurbishment / services replacement.
complexity of systems/ their integration	1 (complex) to 5 (simple) score	3	CCHP systems are inherently more complex units than standalone systems as they perform combined functions from a single unit. Their integration will require good design and installation, commissioning and maintenance is key to ensuring effective and efficient operation.
risk/severity of unintended consequences	1 (high) to 5 (low) score	3	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. On the plus side, as power is generated locally then the system could be used to ensure that essential services remain operational during power cuts assuming suitable change-over switching is incorporated and suitably managed.
		24	

Environmental	**Scoring**	**Score**	**Comments**
(in-use) carbon saving potential	1 (low) to 5 (high) score	4	4 if using a fossil fuel. 5 if using a renewable fuel. As these systems are high efficiency they provide increased carbon saving potential versus standalone systems. Significant carbon savings are available where systems are fuelled by renewable sources.
whole life environmental impact	1 (high) to 5 (low) score	4	4 if using a fossil fuel. 5 if using a renewable fuel. As these systems are high efficiency they provide increased carbon saving potential versus standalone systems. Significant carbon savings are available where systems are fuelled by renewable sources. Fossil fuelled systems may potentially be suitable for conversion to renewable fuel at a later date.
		8	

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Policy / Regulation	Scoring	Score	Comments
compatibility with Scottish policy	1 (low) to 5 (high) score	4	CCHP systems can assist with policy delivery of carbon emissions reductions. Potential is significantly increased if fuelled by renewable resources. Combined Heat and Power systems (and CCHP) are described as offering the most significant single opportunity to reduce energy costs. [DEFRA Policy Paper, 2016]
compatibility with current regulation	1 (low) to 5 (high) score	4	No major issues identified. Currently most CCHP installations are fuelled by mains gas.
compatibility with current assessment methodologies	1 (low) to 5 (high) score	4	Included within current methodologies for assessing energy performance on non-domestic buildings.
		12	

Monetary	Scoring	Score	Comments
capital costs	1 (high) to 5 (low) score	2	More expensive than traditional CHP systems however offer the systems also usefully contribute chilled water for cooling.
life cycle costs	1 (high) to 5 (low) score	3	Good potential if there is constant demand for the power, heat and coolth (although applications may be limited as result) and a high percentage of the system outputs can be used on site.
carbon cost effectiveness (£ per tCO2 saved)	1 (low) to 5 (high) score	4	Good potential if there is constant demand for the power, heat and coolth (although applications may be limited as result) and a high percentage of the system outputs can be used on site.
(potential for) economy of scale (to drive down costs)	1 (low) to 5 (high) score	3	Medium potential. Applications are likely to be relatively restricted although district heating provides an opportunity. A current key barrier restricting uptake is the issue that the technology needs to be matched (and well designed) to suitable applications. Currently the economics and practicalities of utilising CCHP (versus say a boiler/heat pump and separate cooling system) do not always stack up.
		12	

Capacity/ Supply Chain	Scoring	Score	Comments
applicability	1 (low) to 5 (high) score	2	Applications are likely to be relatively restricted although district heating provides an opportunity. A current key barrier restricting uptake is the issue that the technology needs to be matched (and well designed) to suitable applications. Currently the economics and practicalities of utilising CCHP (versus say a boiler/heat pump and separate cooling system) do not always stack up.
existing Scottish capacity/skills	1 (low) to 5 (high) score	3	Design skills exist, but offer potential for improvement. Mechanical and electrical contractors have existing skillsets to install. Manufacturing capability is very limited / none.
Scottish content	1 (low) to 5 (high) score	1	Limited / very low regarding products
potential for cross-sector involvement/benefit	1 (low) to 5 (high) score	3	Provides local generation of power which will reduce reliance on the electrical network.
Scottish economic impact potential	1 (low) to 5 (high) score	2	Low-medium. Potential for design/manufacture (?)/install/operation and maintenance businesses in Scotland.
		11	

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Consumer	Scoring	Score	Comments
user friendliness / practicality	1 (low) to 5 (high) score	3	As they are typically large scale systems, building users generally won't interact with the system. Operation/control interaction likely to rest with facility managers or similar.
disruption	1 (high) to 5 (low) score	3	Unlikely to cause disruption to building owners / user given that they are large scale system that will form part of the buildings energy systems and will likely to be managed by facility management team or similar. Potential for increase disruption if fuelled by biomass (i.e. increase breakdowns due to quality of fuel, disruption due to deliveries, etc.).
customer acceptance	1 (low) to 5 (high) score	4	Providing systems are well designed and operated, systems may present building owners with acceptable operational benefits i.e. effective running costs with no detrimental impact on comfort etc.
savings on bills	1 (low) to 5 (high) score	3	Depends on the application and energy demand profiles. Needs careful assessment of saving potential versus traditional alternatives. Good design and operation/maintenance also critical to ongoing operation.
maintenance requirements	1 (high) to 5 (low) score	2	Due to the nature of the trigeneration system (and its relative complexity given it provides power, heat and coolth from one unit) they require regular (annual) maintenance to ensure they remain operational at maximum efficiency.
health/wellbeing/comfort	1 (high negative impact) to 5 (high positive impact) score	3	No significant benefits / issues. Occupant health, wellbeing and comfort should not be affected versus traditional alternatives.
Existing consumer protection? (Adequacy?)	1 (low) to 5 (high) score	3	Assessment of CHP engines, and quality of CHP schemes, well established e.g. BEIS' CHP Quality Assurance Programme. In addition, the design, installation, operation and maintenance of power, heat and coolth system are all well established and understood industries with relevant competent persons schemes and similar.
		21	

Opportunities / risks	Scoring	Score	Comments
Critical success factors/watch points	List/Describe		Requires a near constant heat, power and electricity demand so applications likely to be restricted. Opportunities presented by district heating.
other relevant considerations/risks/opportunities	List/Describe		Opportunities to link with policy on district heating development
adaptability / future proofing	List / Describe		
		88	

3rd generation district heating design

This technology, sometimes referred to as 'Scandinavian district heating technology' since many of the component manufacturers are Scandinavian. Pressurised water is the heat carrier but the supply temperatures are generally below 100 degC (lower compared to 1st / 2nd generation systems). Typical components are prefabricated, pre-insulated pipes directly buried into the ground, compact substations using plate stainless steel heat exchangers, and material lean components. These third generation systems are what 1st / 2nd generation systems are currently being replaced with in Central and Eastern Europe and all extensions / new systems in China, Korea, Europe, USA and Canada are all third generation systems.

Technical	**Scoring**	**Score**	**Comments**
Technology readiness	TRL score 1-9	**9**	
Efficiency (product / technology efficiency)	1 (low) to 5 (high) score	3	Lower system temperatures (circa 60-80 degrees C) and integration with lower energy systems compared to 1st / 2nd generation district heating systems. Pre-fabricated elements such as the pre-insulated pipes ensure better quality products leading to reduced losses.
Reliability	1 (low) to 5 (high) score	3	Standardised, pre-fabricated elements which help lead to a better quality of product less susceptible to faults.
(level of) Compatibility with existing systems	1 (low/poor) to 5 (high/good) score	3	Suitably compatible with existing heating systems in buildings owing to distribution temperatures and techniques used.
complexity of systems/ their integration	1 (complex) to 5 (simple) score	1	Currently relatively complex and costly to retrofit district heating and connect building to the DH network.
risk/severity of unintended consequences	1 (high) to 5 (low) score	3	No significant risks to property or health identified.
		22	

Environmental	**Scoring**	**Score**	**Comments**
(in-use) carbon saving potential	1 (low) to 5 (high) score	3	A 3GDH system may make use of high efficiency fossil fuel or renewable technologies which will offer potential for carbon savings and low customer bills versus conventional standalone systems
whole life environmental impact	1 (high) to 5 (low) score	3	A 3GDH system may make use of high efficiency fossil fuel or renewable technologies which will offer potential for carbon savings and low customer bills versus conventional standalone systems
		6	

Policy / Regulation	**Scoring**	**Score**	**Comments**
compatibility with Scottish policy	1 (low) to 5 (high) score	5	Good potential to reduce energy and carbon in line with policy targets
compatibility with current regulation	1 (low) to 5 (high) score	4	No significant issues foreseen, beyond conventional district heating
compatibility with current assessment methodologies	1 (low) to 5 (high) score	4	District heating well established within existing assessment methods
		13	

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Monetary	Scoring	Score	Comments
capital costs	1 (high) to 5 (low) score	1	Very high DH infrastructure costs
life cycle costs	1 (high) to 5 (low) score	4	Opportunity for low life cycle costs due to economies of scale of heat generating plant via DH system.
carbon cost effectiveness (£ per tCO2 saved)	1 (low) to 5 (high) score	4	Offer good potential versus standalone heating systems
(potential for) economy of scale (to drive down costs)	1 (low) to 5 (high) score	1	Infrastructure costs are most significant barrier as opposed to economies of scale. However, with most current systems in Europe being replaced by 3GDH systems and all extensions / new systems being 3GDH (worldwide), it is likely that the cost of some 3GDH components will come down in the near future.
		10	

Capacity/ Supply Chain	Scoring	Score	Comments
applicability	1 (low) to 5 (high) score	2	Suited to high heat density areas
existing Scottish capacity/skills	1 (low) to 5 (high) score	2	Currently relatively low, however there are growing skills within Scotland in terms of district heating development/design/installation/operation/maintenance.
Scottish content	1 (low) to 5 (high) score	2	Limited / little manufacturing content. Scottish content in skills outlined above. Opportunity for Scottish biomass fuel industry.
potential for cross-sector involvement/benefit	1 (low) to 5 (high) score	4	There is increased potential for cooperation with renewable energy companies (e.g. Biomass / CHP Biomass) who's systems could be integrated within a 3GDH system.
Scottish economic impact potential	1 (low) to 5 (high) score	3	Would require sizeable/costly infrastructure projects
		13	

Consumer	Scoring	Score	Comments
user friendliness / practicality	1 (low) to 5 (high) score	3	system controls and operation are typically similar to conventional wet central heating system
disruption	1 (high) to 5 (low) score	3	disruption to consumers is largely similar to having a gas boiler replacement / central heating installation
customer acceptance	1 (low) to 5 (high) score	4	Good assuming low running costs. Also, system controls and operation are typically similar to conventional wet central heating system. On the negative side occupants may not accept that they may be tied in to one energy supplier so careful thought needed here when developing a DH scheme
savings on bills	1 (low) to 5 (high) score	4	offers good potential due to economies of scale
maintenance requirements	1 (high) to 5 (low) score	4	relatively low for consumers
health/wellbeing/comfort	1 (high negative impact) to 5 (high positive impact) score	4	Opportunity for increased comfort due to lower running costs. Otherwise, no significant benefits / issues.
Existing consumer protection? (Adequacy?)	1 (low) to 5 (high) score	3	as per conventional DH schemes
		25	

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Opportunities / risks		Scoring		Score		Comments
Critical success factors/watch points		List/Describe				Watch for European based demonstrators and learning.
other relevant considerations/risks/opportunities		List/Describe				
adaptability / future proofing		List / Describe				3GDH, as per conventional DH schemes, should be fully adaptable / facilitate integration with any new or emerging heat generating technologies.'
				89		

4th generation (low temperature) district heating design

4th Generation District Heating (4GDH) systems is an emerging design approach / concept based upon providing heat supply to low energy buildings whilst lowering DH distribution system losses. A key component of this is the use of lower distribution temperatures and the use of low-temperature heat sources.

Technical	Scoring	Score	Comments
Technology readiness	TRL score 1-9	**3**	Conceptual / research stage. Most existing UK based DH systems are "2nd generation". 3rd generation systems are what is currently replacing old systems.
Efficiency (product / technology efficiency)	1 (low) to 5 (high) score	4	Lower temperatures and integration within a "smart energy grid" including renewable technologies and storage facilities ensure 4GDH have a much higher potential efficiency than 2nd/3rd generation systems.
Reliability	1 (low) to 5 (high) score	3	Due to the lack of information available, it is difficult to determine whether this will be any less/more reliable than 2nd/3rd generation systems. One concern is that the dependence upon efficient buildings (<25 kWh/m2 space heat load) may mean that the low temperature DH system will not be able to maintain thermally comfortable buildings unless the building are inherently low energy (i.e. refurbished to a very high standard or new build)
(level of) Compatibility with existing systems	1 (low/poor) to 5 (high/good) score	2	Less compatible with existing systems than 2nd/3rd generation DH - supplies low energy buildings only.
complexity of systems/ their integration	1 (complex) to 5 (simple) score	1	Currently relatively complex and costly to retrofit district heating and connect building to the DH network. Increased complexity with 4GDH due to lower operating temperature and further integration with smart energy systems.
risk/severity of unintended consequences	1 (high) to 5 (low) score	3	No significant risks to property or health identified. 4GDH systems should be fully adaptable / future proofed to enable integration with any new technologies.
		16	

Environmental	Scoring	Score	Comments
(in-use) carbon saving potential	1 (low) to 5 (high) score	4	A 4GDH system should make use of renewable technologies as well as energy storage which will lead to an increase in carbon savings compared to 2nd/3rd generation systems
whole life environmental impact	1 (high) to 5 (low) score	4	A 4GDH system should make use of renewable technologies as well as energy storage which will lead to an increase in carbon savings compared to 2nd/3rd generation systems
		8	

Policy / Regulation	Scoring	Score	Comments
compatibility with Scottish policy	1 (low) to 5 (high) score	2	Likely to be suitable (in the future) for delivering Scottish policy on energy, carbon and district heating - mainly linked to new build or deep retrofitted buildings
compatibility with current regulation	1 (low) to 5 (high) score	3	No significant issues foreseen, beyond conventional district heating
compatibility with current assessment methodologies	1 (low) to 5 (high) score	3	District heating well established within existing assessment methods
		8	

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Monetary	Scoring	Score	Comments
capital costs	1 (high) to 5 (low) score	1	Very high DH infrastructure costs
life cycle costs	1 (high) to 5 (low) score	4	Opportunity for low life cycle costs due to economies of scale of heat generating plant via DH system.
carbon cost effectiveness (£ per tCO2 saved)	1 (low) to 5 (high) score	4	Offers good potential versus standalone heating systems, Also offer greater potential versus current 3GDH schemes as the lower temperature distribution should results in less system losses - however building need to be very low energy.
(potential for) economy of scale (to drive down costs)	1 (low) to 5 (high) score	2	Infrastructure costs are most significant barrier as opposed to economies of scale. At this stage, with no plan to introduce 4GDH and most current systems only being replaced by 3rd gen systems, it is unlikely that the cost of 4GDH will come down in the near future.
		11	

Capacity/ Supply Chain	Scoring	Score	Comments
applicability	1 (low) to 5 (high) score	2	4GDH generally only applicable for low energy buildings. The vast majority of Scotland’s current building stock is not suitably low energy.
existing Scottish capacity/skills	1 (low) to 5 (high) score	2	Currently relatively low, there are growing skills within Scotland in terms of district heating development/design/installation/operation/maintenance.
Scottish content	1 (low) to 5 (high) score	2	Limited / no manufacturing content. Scottish content in skills outlined above. Opportunity for Scottish biomass fuel industry.
potential for cross-sector involvement/benefit	1 (low) to 5 (high) score	4	There is increased potential for cooperation with renewable energy companies whose technologies are likely to be included within a future smart thermal grid.
Scottish economic impact potential	1 (low) to 5 (high) score	3	Would require sizeable/costly infrastructure projects
		13	

Consumer	Scoring	Score	Comments
user friendliness / practicality	1 (low) to 5 (high) score	3	system controls and operation are typically similar to conventional wet central heating system
disruption	1 (high) to 5 (low) score	3	disruption to consumers is largely similar to having a gas boiler replacement / central heating installation
customer acceptance	1 (low) to 5 (high) score	4	Good assuming low running costs. Also, system controls and operation are typically similar to conventional wet central heating system. On the negative side occupants may not accept that they may be tied in to one energy supplier so careful thought needed here when developing a DH scheme
savings on bills	1 (low) to 5 (high) score	4	offers good potential due to economies of scale
maintenance requirements	1 (high) to 5 (low) score	4	relatively low for consumers
health/wellbeing/comfort	1 (high negative impact) to 5 (high positive impact) score	4	Opportunity for increased comfort due to lower running costs. Otherwise, no significant benefits / issues.
Existing consumer protection? (Adequacy?)	1 (low) to 5 (high) score	3	as per conventional DH schemes
		25	

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Opportunities / risks	Scoring	Score	Comments
Critical success factors/watch points	List/Describe		Watch for European based demonstrators and learning
other relevant considerations/risks/opportunities	List/Describe		works in conjunction with low energy buildings - so offers most potential with significantly large new build developments
adaptability / future proofing	List / Describe		4GDH, as per conventional DH schemes, should be fully adaptable / facilitate integration with any new emerging heat generating technologies.
		81	

Infrared heating

Infrared heaters work by heating the surface area of a room and building occupants via infrared radiant energy.

Technical	Scoring	Score	Comments
Technology readiness	TRL score 1-9	9	Technology is available for purchase on the market and is widely used.
Efficiency (product / technology efficiency)	1 (low) to 5 (high) score	2	100% conversion of electricity into heat, as per other direct acting electric heaters i.e. less efficient than electric heat pumps
Reliability	1 (low) to 5 (high) score	4	Highly durable and low maintenance requirements. However may not reliably heat building as desired.
(level of) Compatibility with existing systems	1 (low/poor) to 5 (high/good) score	4	Standalone system so limited/no need for integration. Require only an electricity connection and a suitable place of positioning e.g. wall mounting. Currently most suitable for places with high levels of natural ventilation and drafts. Preferable to high levels of thermal mass within building to improve occupant thermal comfort.
complexity of systems/ their integration	1 (complex) to 5 (simple) score	3	Easy to install however care needs to be taken around positioning within a building (and proximity to obstructions etc.) to ensure they are effective.
risk/severity of unintended consequences	1 (high) to 5 (low) score	2	No significant risks to property or health identified. Usually require multiple small heaters and careful positioning to ensure radiant heat is distributed effectively e.g. use of a single large infrared heater (as opposed to multiple smaller, and well positioned heaters) can lead to cold spots within a building.
		24	

Environmental	Scoring	Score	Comments
(in-use) carbon saving potential	1 (low) to 5 (high) score	1	Carbon saving potential only when supplied with renewable electricity. Produce more carbon emissions than standard gas central heating if mains electricity is used.
whole life environmental impact	1 (high) to 5 (low) score	3	Relatively simple product typically constructed using conventional, well known, and relatively low impact materials
		4	

Policy / Regulation	Scoring	Score	Comments
compatibility with Scottish policy	1 (low) to 5 (high) score	2	High associated emissions if mains electricity is used. Compatible only if low carbon electricity is supplied.
compatibility with current regulation	1 (low) to 5 (high) score	5	Suitably acceptable within current regulations
compatibility with current assessment methodologies	1 (low) to 5 (high) score	5	No significant issues. SAP/SBEM have established methodologies for acknowledging performance on new heating products.
		12	

Monetary	Scoring	Score	Comments
capital costs	1 (high) to 5 (low) score	4	Capital costs can be ~ £100-200/kW. Capital costs plus installation is likely to be significantly cheaper than installation and gas boiler and wet central heating system, and similar in cost to installing alternative direct electric heating systems.
life cycle costs	1 (high) to 5 (low) score	1	Since it is based on electrical resistive heating, with an efficiency of ~100%, life cycle costs are high. There is currently a lack of reliable data on operational cost comparisons (or other benefits) of infrared vs other electric heating systems.
carbon cost effectiveness (£ per tCO2 saved)	1 (low) to 5 (high) score	1	Generally very poor if mains electricity is used.
(potential for) economy of scale (to drive down costs)	1 (low) to 5 (high) score	2	Applications where the technology will save considerable energy/carbon is generally very limited so limited scope for driving down costs.
		8	

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Capacity/ Supply Chain	Scoring	Score	Comments
applicability	1 (low) to 5 (high) score	2	Can be used in any building where an electricity supply is available, however only likely to save energy/carbon in selected applications within buildings (e.g. buildings with high levels of ventilation and drafts and/or high thermal mass).
existing Scottish capacity/skills	1 (low) to 5 (high) score	3	Many installers of infrared heaters are available however the theory is often not understood meaning there is risk that their application is not communicated accurately to customers.
Scottish content	1 (low) to 5 (high) score	1	Low / limited regarding UK based product. However, electrical installation skills exists in Scotland
potential for cross-sector involvement/benefit	1 (low) to 5 (high) score	1	No / low potential for cross sector benefit
scottish economic impact potential	1 (low) to 5 (high) score	1	Likely to be limited due to relatively small market where significant energy/carbon savings can be achieved.
		8	

Consumer	Scoring	Score	Comments
user friendliness / practicality	1 (low) to 5 (high) score	4	Simple and easy to operate.
disruption	1 (high) to 5 (low) score	5	Low levels of disruption during install. Heaters can be positioned in many locations therefore reducing the disruption. Other objects within building may need to be moved in order to ensure radiant heat reaches desired location.
customer acceptance	1 (low) to 5 (high) score	2	Systems must be sized and positioned properly in order to provide a comfortable internal environment. Since infrared heaters are supplied by electricity this can often make them an expensive way of heating a building meaning low acceptance by consumers
savings on bills	1 (low) to 5 (high) score	1	Only likely to save significant energy/carbon in limited applications within buildings (e.g. buildings with high levels of ventilation and drafts and/or high thermal mass). Generally uncompetitive against other common forms of heating i.e. gas boiler.
maintenance requirements	1 (high) to 5 (low) score	5	No / very low maintenance requirements.
health/wellbeing/comfort	1 (high negative impact) to 5 (high positive impact) score	3	Can provide warmth in building where convection heaters are not suitable. However in other circumstances infrared heaters may not suitably heat building if not sized and installed properly - hot and cold spots may occur.
Existing consumer protection? (Adequacy?)	1 (low) to 5 (high) score	3	Electrical installation competent person schemes already exist.
		23	

Opportunities / risks	Scoring	Score	Comments
Critical success factors/watch points	List/Describe		
other relevant considerations/risks/opportunities	List/Describe		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)
adaptability / future proofing	List / Describe		
		79	

Electric storage heater (high heat retention)

Modern electric storage heaters offering 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.

Technical	Scoring	Score	Comments
Technology readiness	TRL score 1-9	9	Technology is currently in use and is well established, though technology is constantly evolving and improving with particular regards to storage medium.
Efficiency (product / technology efficiency)	1 (low) to 5 (high) score	2	Heat store cores are very well insulated, although less than 100% efficient due to storage losses. Storage heaters are much less efficient than electric heat pumps.
Reliability	1 (low) to 5 (high) score	5	Durable and reliable.
(level of) Compatibility with existing systems	1 (low/poor) to 5 (high/good) score	4	Standalone system so limited/no need for integration. Storage heaters require only an electricity supply although will require two-tariff meter if cheaper night-time tariffs are to be used.
complexity of systems/ their integration	1 (complex) to 5 (simple) score	4	System only requires an electricity connection. Heaters are wall-mounted.
risk/severity of unintended consequences	1 (high) to 5 (low) score	3	No significant risks to property or health identified.
		27	

Environmental	Scoring	Score	Comments
(in-use) carbon saving potential	1 (low) to 5 (high) score	1	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.
whole life environmental impact	1 (high) to 5 (low) score	3	Relatively simple product typically constructed using conventional, well known, and relatively low impact materials
		4	

Policy / Regulation	Scoring	Score	Comments
compatibility with Scottish policy	1 (low) to 5 (high) score	3	High associated emissions if mains electricity is used. Compatible only if low carbon electricity is supplied. Can however play an important part in providing storage when renewable generation is greater than traditional demand.
compatibility with current regulation	1 (low) to 5 (high) score	5	Suitably acceptable within current regulations
compatibility with current assessment methodologies	1 (low) to 5 (high) score	5	No significant issues. SAP/SBEM have established methodologies for acknowledging performance on new heating products.
		13	

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Monetary	Scoring	Score	Comments
capital costs	1 (high) to 5 (low) score	4	Capital and installation costs tend to be lower than gas boiler plus wet system. Higher costs than direct acting electric heaters due to the storage element. Capital costs can vary ~£300 - £500/kW compared to direct acting electric heaters which are typically ~ £50 - £200/kW.
life cycle costs	1 (high) to 5 (low) score	1	Since it is based on electrical resistive heating, with an efficiency of <100%, life cycle costs are typically high - although storage systems enable use of cheaper, off peak electricity, which can help generate running costs savings versus direct acting electric heaters. Higher running costs than gas boilers due to use of electricity.
carbon cost effectiveness (£ per tCO2 saved)	1 (low) to 5 (high) score	1	Currently low as mains electricity is used with an efficiency <100%
(potential for) economy of scale (to drive down costs)	1 (low) to 5 (high) score	3	Should offer some potential for cost savings at increased scale.
		9	

Capacity/ Supply Chain	Scoring	Score	Comments
applicability	1 (low) to 5 (high) score	3	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
existing Scottish capacity/skills	1 (low) to 5 (high) score	3	Existing electrical installation capacity and skills
Scottish content	1 (low) to 5 (high) score	1	Low / limited regarding UK based products. However, electrical installation skills exists in Scotland
potential for cross-sector involvement/benefit	1 (low) to 5 (high) score	4	Good potential to link with low carbon / renewable generation, e.g. excess generation from Scottish wind, i.e. storage heaters can be supplied by low carbon wind power through the night when electrical demand is otherwise low, or other times when generation exceeds demand. This also means that daytime demand for heating is reduced as the storage heaters draw on the stored energy.
Scottish economic impact potential	1 (low) to 5 (high) score	3	Most potential in areas where either localised or large scale roll out can help increase penetration of intermittent renewable energy sources such as wind and solar energy.
		14	

Consumer	Scoring	Score	Comments
user friendliness / practicality	1 (low) to 5 (high) score	4	Relatively simple, easy to operate and typically include temperature and time scheduling control
disruption	1 (high) to 5 (low) score	5	Generally low levels of disruption
customer acceptance	1 (low) to 5 (high) score	3	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.
savings on bills	1 (low) to 5 (high) score	1	Only likely to save significant energy/carbon in limited applications e.g. replacement of old storage heaters. Generally uncompetitive against other common forms of heating i.e. gas boiler.
maintenance requirements	1 (high) to 5 (low) score	1	Very low maintenance requirements.
health/wellbeing/comfort	1 (high negative impact) to 5 (high positive impact) score	3	Can provide a warm, comfortable, relatively easily controlled internal environment.
Existing consumer protection? (Adequacy?)	1 (low) to 5 (high) score	3	Electrical installation competent person schemes already exist.
		20	

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Opportunities / risks		Scoring		Score		Comments
Critical success factors/watch points		List/Describe				
other relevant considerations/risks/opportunities		List/Describe				
adaptability / future proofing		List / Describe				In the future there is likely to be potential for storage heaters to be used to store energy at times when renewable generation is greater than demand.

87

Waste water heat recovery

Recovery of heat from waste water (e.g. a shower waste pipe) to pre-heat the incoming cold water serving the shower mixing valve.

Technical	Scoring	Score	Comments
Technology readiness	TRL score 1-9	9	Systems commercially available
Efficiency (product / technology efficiency)	1 (low) to 5 (high) score	1	Relatively efficient capture of heat that would otherwise be wasted, particularly if the showers are of long duration. Less efficient if showers are of short duration.
Reliability	1 (low) to 5 (high) score	5	Technology is passive and therefore reliable
(level of) Compatibility with existing systems	1 (low/poor) to 5 (high/good) score	3	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.
complexity of systems/ their integration	1 (complex) to 5 (simple) score	2	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.
risk/severity of unintended consequences	1 (high) to 5 (low) score	3	No significant risks to property or health identified.
		23	

Environmental	Scoring	Score	Comments
(in-use) carbon saving potential	1 (low) to 5 (high) score	2	Low-medium. Potential for cost effective savings in high use showers e.g. swimming pools or sports facilities, where throughput of water is prolonged.
whole life environmental impact	1 (high) to 5 (low) score	2	Some typically made of copper or PVC / plastics.
		4	

Policy / Regulation	Scoring	Score	Comments
compatibility with Scottish policy	1 (low) to 5 (high) score	2	Compatible, although relatively low potential for reducing emissions. More suited to new build.
compatibility with current regulation	1 (low) to 5 (high) score	5	Suitably acceptable within current regulations.
compatibility with current assessment methodologies	1 (low) to 5 (high) score	4	No significant issues. SAP has established methodologies for acknowledging performance uplift.
		11	

Monetary	Scoring	Score	Comments
capital costs	1 (high) to 5 (low) score	3	Typical domestic system for shower is circa £400 plus installation.
life cycle costs	1 (high) to 5 (low) score	4	Operational cost savings vary depending on shower use. Typical domestic product can save circa 400 kWh / year.
carbon cost effectiveness (£ per tCO2 saved)	1 (low) to 5 (high) score	4	Savings can be relatively substantial for heavy duty showers.
(potential for) economy of scale (to drive down costs)	1 (low) to 5 (high) score	2	Relatively simple, reasonably low cost product presently, so only limited opportunity.
		13	

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Capacity/ Supply Chain	Scoring	Score	Comments
applicability	1 (low) to 5 (high) score	4	Applicable to heavy duty showers and many domestic showers, but cannot be installed in low-pressure gas showers. Many are now being installed in new build dwellings, less are being retrofitted.
existing Scottish capacity/skills	1 (low) to 5 (high) score	3	Existing installer capacity and skills exists.
Scottish content	1 (low) to 5 (high) score	1	Some UK based products but not Scottish based. However, plumbing and heating skills exists in Scotland.
potential for cross-sector involvement/benefit	1 (low) to 5 (high) score	1	No / low potential for cross sector benefit.
Scottish economic impact potential	1 (low) to 5 (high) score	2	Relatively low as savings are relatively small and retrofitting increases costs which impacts on cost effectiveness.
		11	

Consumer	Scoring	Score	Comments
user friendliness / practicality	1 (low) to 5 (high) score	5	The user doesn't need to interact with it, and may not even know they are there.
disruption	1 (high) to 5 (low) score	3	access typically needed to waste stack / pipe on the floor below a shower so retrofitting can be disruptive.
customer acceptance	1 (low) to 5 (high) score	4	Unobtrusive, passive in operation, user friendly.
savings on bills	1 (low) to 5 (high) score	1	Relatively small savings in a domestic property. This increases with shower duration/ length. Increased opportunity for savings in sports centres, swimming pools, etc.
maintenance requirements	1 (high) to 5 (low) score	5	No maintenance required post installation.
health/wellbeing/comfort	1 (high negative impact) to 5 (high positive impact) score	3	No significant positive /negative impacts other than cost savings.
Existing consumer protection? (Adequacy?)	1 (low) to 5 (high) score	4	No specific consumer protection required. Typically fitted by a plumber.
		25	

Opportunities / risks	Scoring	Score	Comments
Critical success factors/watch points	List/Describe		
other relevant considerations/risks/opportunities	List/Describe		Ideally suited to heavy-use showers
adaptability / future proofing	List / Describe		
		87	

Passive flue gas heat recovery

Passive Flue Gas Heat Recovery (PFGHR) / economisers involves recovering waste heat from flue gases which are produced during combustion and would otherwise be lost to atmosphere

Technical	Scoring	Score	Comments
Technology readiness	TRL score 1-9	9	Technology is widely used throughout the UK.
Efficiency (product / technology efficiency)	1 (low) to 5 (high) score	2	Improvements to efficiency depends on how inefficient existing boiler is to begin with. Older more inefficient boilers offer the best potential for efficiency improvements.
Reliability	1 (low) to 5 (high) score	5	Products are reliable with low risk of failing due to not containing any moving/mechanical parts.
(level of) Compatibility with existing systems	1 (low/poor) to 5 (high/good) score	3	Retrofit / add-on units are typically manufacturer-specific for domestic boiler, less so for commercial boilers.
complexity of systems/ their integration	1 (complex) to 5 (simple) score	3	Systems are generally straightforward to install, however not suitable for all boiler types. Space restraints around boiler may restrict feasibility since most PFGHR systems sit on top of existing boiler.
risk/severity of unintended consequences	1 (high) to 5 (low) score	3	Need to make sure boiler is suitable for PFGHR to be fitted since not all boilers are. Otherwise no significant risks to property or health identified.
		25	

Environmental	Scoring	Score	Comments
(in-use) carbon saving potential	1 (low) to 5 (high) score	1	Improved overall efficiency means less fuel is needed to heat water to desired temperature therefore reducing overall carbon dioxide emissions. The environmental impact of adding PFGHR depends primarily on how inefficient boiler is to begin with. Old boilers with efficiencies <70% will benefit far greater than boilers that are >90% efficient.
whole life environmental impact	1 (high) to 5 (low) score	4	Relatively simple product typically constructed using conventional, well known, and relatively low impact materials
		5	

Policy / Regulation	Scoring	Score	Comments
compatibility with Scottish policy	1 (low) to 5 (high) score	3	compatible, although relatively low potential for reducing emissions
compatibility with current regulation	1 (low) to 5 (high) score	5	Suitably acceptable within current regulations
compatibility with current assessment methodologies	1 (low) to 5 (high) score	4	No significant issues. SAP has established methodologies for acknowledging performance uplift
		12	

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Monetary	Scoring	Score	Comments
capital costs	1 (high) to 5 (low) score	3	Costs can be circa £600 plus installation on a suitable domestic boiler with payback typically being in the order of 6-10 years. Commercial system can payback in 2-5 years depending on the type of boiler and how often it is used.
life cycle costs	1 (high) to 5 (low) score	4	Operational cost savings vary depending on boiler type to which system is fitted. Older and non-condensing boilers offer the best opportunity for savings whereas modern condensing boilers offer less potential due to the already high efficiency.
carbon cost effectiveness (£ per tCO2 saved)	1 (low) to 5 (high) score	3	More inefficient boilers offer the greatest opportunity to reduce carbon dioxide emissions.
(potential for) economy of scale (to drive down costs)	1 (low) to 5 (high) score	2	PFGHR devices are already produced on a large scale so costs are unlikely to be reduced further with respect to economy of scale.
		12	

Capacity/ Supply Chain	Scoring	Score	Comments
applicability	1 (low) to 5 (high) score	3	Many boilers are suitable for PFGHR devices although not all. There are potentially tens of thousands of boilers which could benefit from being upgraded with PFGHR in domestic / non-domestic settings in Scotland - although arguably these could benefit further from replacement with a new boiler, heat pump, etc.
existing Scottish capacity/skills	1 (low) to 5 (high) score	3	Existing installer capacity and skills exists
Scottish content	1 (low) to 5 (high) score	2	Low / limited regarding UK based products. However, electrical installation skills exists in Scotland
potential for cross-sector involvement/benefit	1 (low) to 5 (high) score	1	No / low potential for cross sector benefit
Scottish economic impact potential	1 (low) to 5 (high) score	2	Limited potential - realised from consumer energy savings.
		11	

Consumer	Scoring	Score	Comments
user friendliness / practicality	1 (low) to 5 (high) score	5	No change to user end. Boilers will continue to be controlled in the standard way.
disruption	1 (high) to 5 (low) score	4	Minor disruption when device is being fitted. Space above the boiler is typically needed.
customer acceptance	1 (low) to 5 (high) score	4	Non-disruptive device with no operation requirements by user. Customers will be accepting if device is cost effective i.e. the capital costs will be quickly recovered via energy savings due to improved efficiency of boiler.
savings on bills	1 (low) to 5 (high) score	3	Low-medium potential if boiler is very inefficient to begin with. Savings can still be made by adding a PFGHR system to a more modern efficient boiler, however savings will be proportionally less.
maintenance requirements	1 (high) to 5 (low) score	5	Low maintenance requirements as no moving parts within device.
health/wellbeing/comfort	1 (high negative impact) to 5 (high positive impact) score	3	No significant positive /negative impacts other than cost savings.
Existing consumer protection? (Adequacy?)	1 (low) to 5 (high) score	5	Gas safe / oftec regulations in place and established
		29	

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Opportunities / risks		Scoring		Score		Comments
Critical success factors/watch points		List/Describe				
other relevant considerations/risks/opportunities		List/Describe				- PFGHR is not suitable for all boiler types - PFGHR may not be cost effective for already efficient boilers
adaptability / future proofing		List / Describe				Greater boiler heat recovery from flue gasses and general efficiency improvements likely to restrict long term opportunities for PFGHR add-on systems as new boiler will likely be developed with this technology built-in.
				94		

Active flue gas heat recovery

Recovery of heat from commercial boilers hot flue gasses (using heat pumps, or other active means) and transfer of the energy to the input ('return') water supplying the boiler to save energy

Technical	Scoring	Score	Comments
Technology readiness	TRL score 1-9	7	
Efficiency (product / technology efficiency)	1 (low) to 5 (high) score	2	Typically, the efficiency of a large (non-condensing) boiler can be improved by up to 10%. This efficiency improvement arises from flue gases being cooled from >100C down to about 40C.
Reliability	1 (low) to 5 (high) score	4	Products are generally reliable with low risk of failing due to not containing many moving/mechanical parts.
(level of) Compatibility with existing systems	1 (low/poor) to 5 (high/good) score	3	Typically retrofit / add-on units and therefore compatible with most boilers. Greatest effect is with large, older boiler and boilers which run often.
complexity of systems/ their integration	1 (complex) to 5 (simple) score	3	Systems are generally straightforward to install, however not suitable for all boiler types. Space restraints around boiler may restrict feasibility
risk/severity of unintended consequences	1 (high) to 5 (low) score	3	No significant risks to property or health identified.
		22	

Environmental	Scoring	Score	Comments
(in-use) carbon saving potential	1 (low) to 5 (high) score	2	Energy efficiency improvements of 10% typical for large boilers.
whole life environmental impact	1 (high) to 5 (low) score	3	Relatively simple product typically constructed using conventional, well known, and relatively low impact materials
		5	

Policy / Regulation	Scoring	Score	Comments
compatibility with Scottish policy	1 (low) to 5 (high) score	3	compatible, although relatively low potential for reducing emissions
compatibility with current regulation	1 (low) to 5 (high) score	5	Suitably acceptable within current regulations
compatibility with current assessment methodologies	1 (low) to 5 (high) score	2	Currently no methodology for calculating efficiency in energy performance of non-domestic building assessment methods.
		10	

Monetary	Scoring	Score	Comments
capital costs	1 (high) to 5 (low) score	2	Capital costs are relatively high because systems are designed and pre-treated to resist corrosion by flue gases. Typical capital costs have been reported at (approx. 60 - 1040 £/kW) .
life cycle costs	1 (high) to 5 (low) score	3	Can offer relatively short payback periods for heat recovery from large boilers (One paper suggests the innovative use of flue gas heat recovery heat pump can have payback periods of only 2 or 3 years for some large boilers (~2000 kW) with typical annual maintenance costs being of the order of 5-10% of the capital cost).
carbon cost effectiveness (£ per tCO_2 saved)	1 (low) to 5 (high) score	3	More inefficient boilers offer the greatest opportunity to reduce carbon dioxide emissions. Also higher carbon cost effectiveness from oil or LPG boilers.
(potential for) economy of scale (to drive down costs)	1 (low) to 5 (high) score	1	Already produced at relatively large scale and limited to larger boilers (of which there are relatively fewer).
		9	

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Capacity/ Supply Chain	Scoring	Score	Comments
applicability	1 (low) to 5 (high) score	2	Recovering heat from flue gas is only likely to be worthwhile when the flue gas is relatively plentiful and hot, such as in a large existing building or district heating boiler.
existing Scottish capacity/skills	1 (low) to 5 (high) score	3	Existing installer capacity and skills exists
Scottish content	1 (low) to 5 (high) score	2	Low regarding UK based products. However, electrical mechanical skills exists in Scotland
potential for cross-sector involvement/benefit	1 (low) to 5 (high) score	1	No / low potential for cross sector benefit
Scottish economic impact potential	1 (low) to 5 (high) score	2	Relatively low as small number of old, large boilers offering most potential.
		10	

Consumer	Scoring	Score	Comments
user friendliness / practicality	1 (low) to 5 (high) score	3	No major issues identified. Users / consumers will be unaffected.
disruption	1 (high) to 5 (low) score	4	Low. System may need to be installed in summer or at a time when heating is not required
customer acceptance	1 (low) to 5 (high) score	4	Non-disruptive device with no operation requirements by user. Customers will be accepting if device is cost effective i.e. the capital costs will be quickly recovered via energy savings due to improved efficiency of boiler.
savings on bills	1 (low) to 5 (high) score	3	Low-medium potential if boiler is very inefficient to begin with. Savings can still be made by adding a PFGHR system to a more modern efficient boiler, however savings will be proportionally less.
maintenance requirements	1 (high) to 5 (low) score	4	Relatively low. Maintenance is likely to depend very much on the corrosiveness of the flue gases and moving parts of system.
health/wellbeing/comfort	1 (high negative impact) to 5 (high positive impact) score	3	No significant positive /negative impacts other than cost savings.
Existing consumer protection? (Adequacy?)	1 (low) to 5 (high) score	5	Gas safe / oftec regulations in place and established
		26	

Opportunities / risks	Scoring	Score	Comments
Critical success factors/watch points	List/Describe		
other relevant considerations/risks/opportunities	List/Describe		Needs lots of flue gas to make it worthwhile, so a focus on large boilers is recommended initially.
adaptability / future proofing	List / Describe		
		82	