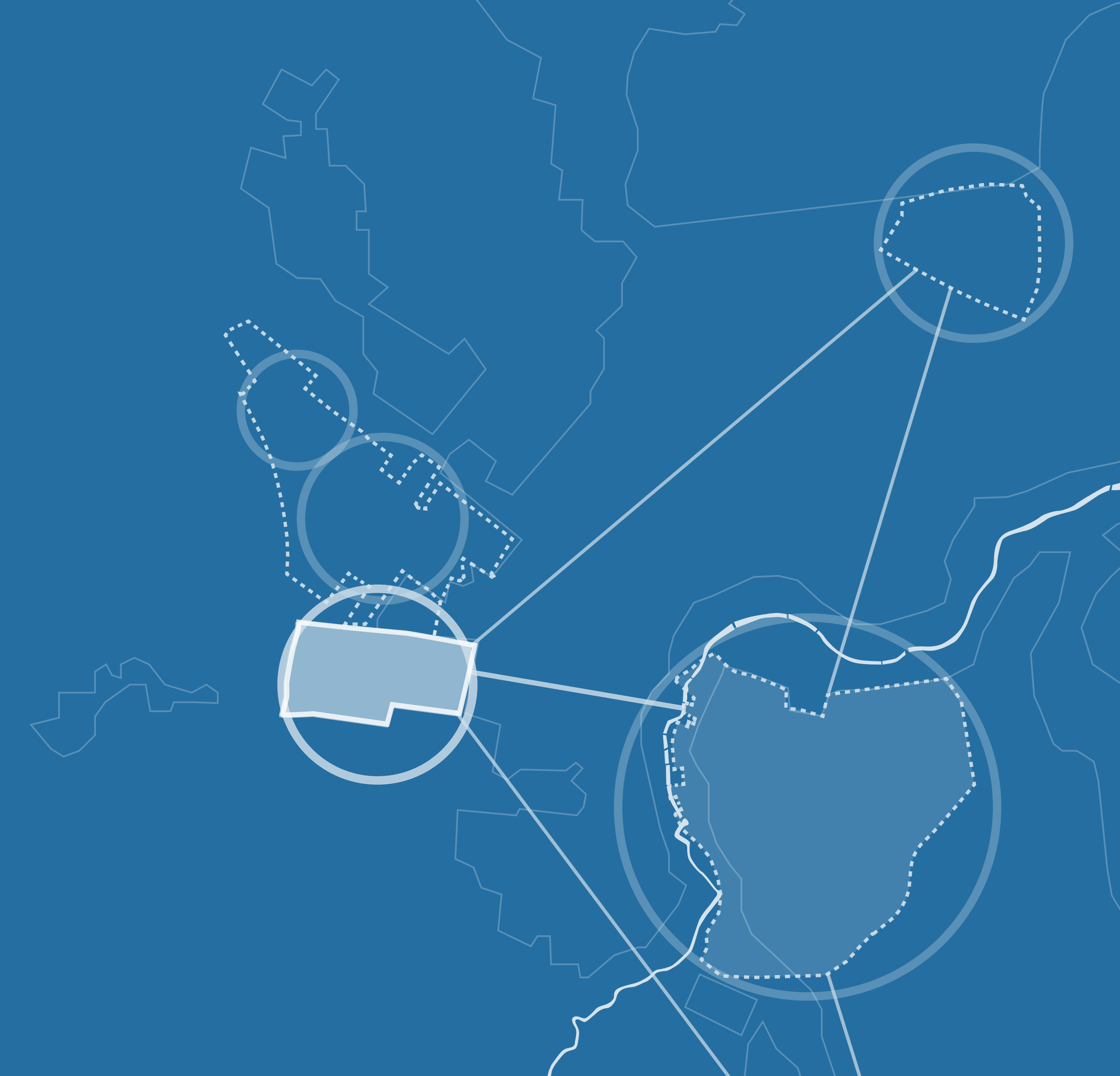

# WEST CAMBRIDGE

## OUTLINE PLANNING APPLICATION

## ENERGY STATEMENT ADDENDUM

UNIVERSITY OF CAMBRIDGE

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# 1 Introduction and Context

This technical note addresses issues that have emerged relating to the energy strategy since the submission of the Planning Application in 2016. This includes the original feedback to the Outline Planning Application for West Cambridge from Cambridge City Council (CCC) and discussions in the meeting held with CCC on 11/11/16. In particular these reflect:

- Ongoing concerns about the opportunity to export electricity from the site, because of problems with UKPN. This reduces significantly the viability of proposals for an energy centre based on CHP;
- The University not being in a position to commit to the delivery of an energy centre at a specific date;
- The decision by some early buildings not to use the planned energy centre in the short term, and
- The recognition, as specified in the energy strategy, that fossil gas CHP is not expected to be a low carbon solution in the medium term.

At the meeting with CCC, it was agreed that we should approach the updated energy strategy to include the principle of a hierarchy of approach:

1) Fully site wide, then if not
2) Clusters or precincts linking several buildings, then
3) Building by building

This technical note sets out the approach and the implications of it.

# 2 Proposed energy hierarchy

The preferred energy solution for the West Cambridge development is to deliver a fully site-wide solution in line with the original proposal and the policies of CCC. However, it is recognised that there may be problems with the commercial viability of this option partly due to issues with the local electricity grid and its capacity to accept power from any electricity generation proposals (e.g. CHP plant or PV). It is therefore proposed to adopt an energy hierarchy to allow for the potential that it may not be possible to deliver the preferred solution.

The hierarchy is to deliver an energy solution that is:
1) Fully site wide, then if not
2) Using clusters or precincts linking several buildings, then if not
3) Building by building solutions.

The site wide solution remains as put forward in the planning application in 2016, with the buildings linked together via a heat network, and a single large energy centre proposed to deliver most of the heat to the site. This would be served by gas CHP in the short to medium term, but with the option to replace this with another technology at a later date when this becomes preferable. Note that the viability of this option is affected by the inclusion of provision for a private wire system to connect the electricity supplies of University buildings and further examining thermal storage.

The cluster or precinct solution recognises the benefit of linking a number of buildings together. These apply particularly where they are close together and ideally having differences in their requirements for heat and cooling that may enable further efficiency savings. There could be options to serve these clusters either with gas CHP or heat pumps, and the relative benefits of these are reviewed in section 5.

The individual building approach may make sense for some particular buildings which are further away from others and have very low energy demands. This may mean that the benefits of linking them to others would not be sufficient to overcome the cost of the physical link between them. The individual building approach is reviewed further in section 6.

# 3 Introduction to types of heat pumps

All heat pumps operate in the same way, in that they use electricity to drive an evaporation / condensation cycle to move heat from one side of the system to another. They are in basic operation identical to a chiller that provides cooling in a building or a fridge. They differ in terms of the way in which they are used. When a heat pump is used only for heating, it must have some method to warm the cold side of the system, otherwise it would become too cold for the process to work. The source of this warming is used to label the different types of heat pump – depending on whether air, water or ground is used. These options are discussed in the following sections.

### 3.1 Air source heat pumps (ASHP)

Within an air source heat pump system, the source of heat is the air outside the building. Therefore they require continuous heat rejection to air in the form of:

- Access to free moving air – typically on the roof of a building,
- A large enough area to achieve sufficient heat exchange, and
- Fans to encourage efficient heat exchange.

As a result ASHP systems have a requirement for significant amounts of roof space which may conflict with other building uses, may result in visual impact and may cause problems with noise and vibration.

Another key feature of an ASHP is that the efficiency depends on the temperature of the air, and so they are *least* efficient at delivering heat at times of greatest demand, i.e. when the air is at its coldest. However, with sufficient air movement there is effectively no limit to the amount of heat that can be extracted, unlike with ground energy systems.

### 3.2 Ground source heat pumps (GSHP)

A GSHP system uses the same basic type of heat pumps as an ASHP, but it is connected to one of two main types of system to collect heat from the ground:

- Open loop, or
- Closed loop.

In an open loop system a borehole is drilled down to reach a large body of water (aquifer), and water is then pumped up to the surface and used to warm the cold side of the heat pump. The cooled water is then re-injected into the ground through a second borehole at sufficient distance from the first to avoid a 'short-circuit' with the same water being made colder and colder.

In a closed loop system a number of boreholes are drilled and pipes are inserted. A fluid is passed through these to extract warmth from the ground, and this fluid is used to warm the cold side of the heat pump. There is no direct contact with ground water.

The main benefit of an open loop system is that when there is good availability of water, it can be more cost effective than a closed loop system at larger scales. There are risks however in the availability of water, and in gaining permissions for its extraction due to the small risk of contamination of ground water.

Closed loop systems have the benefit of not having the same requirement for permissions, and they don't require the availability of ground water. The disadvantage is that a relatively large area needs to be available for the boreholes as there is a limit to the heat that can be extracted from a single borehole, and this is much less than can be achieved from groundwater in an open loop system.

Both systems share a benefit over ASHP and CHP systems in that they can benefit from the transfer of heat from summer to winter. When cooling is required in summer, the heat can be rejected into the ground, which is then at a higher temperature for when it is needed the following winter. All

GSHP systems benefit from having reasonably balanced heating and cooling loads over the year as a whole, so that the ground does not become too cold in winter or hot in summer.

In contrast to the ASHP there is in general no requirement to use space on the roof for heat exchange and the plant can be located wherever is most appropriate. Clearly there must be a connection to the boreholes (known as the ground loop), but this can all be hidden below ground.

# 4 Site wide option with heat pumps

The smallest change from the current design would be to replace the CHP engines in the proposed energy centre with a similar capacity of heat pumps. These would need to be connected to either an air or ground source heat exchange system. Whilst both are technically possible, there are significant challenges in both.

## *4.1 Heat pump options for the site wide solution*

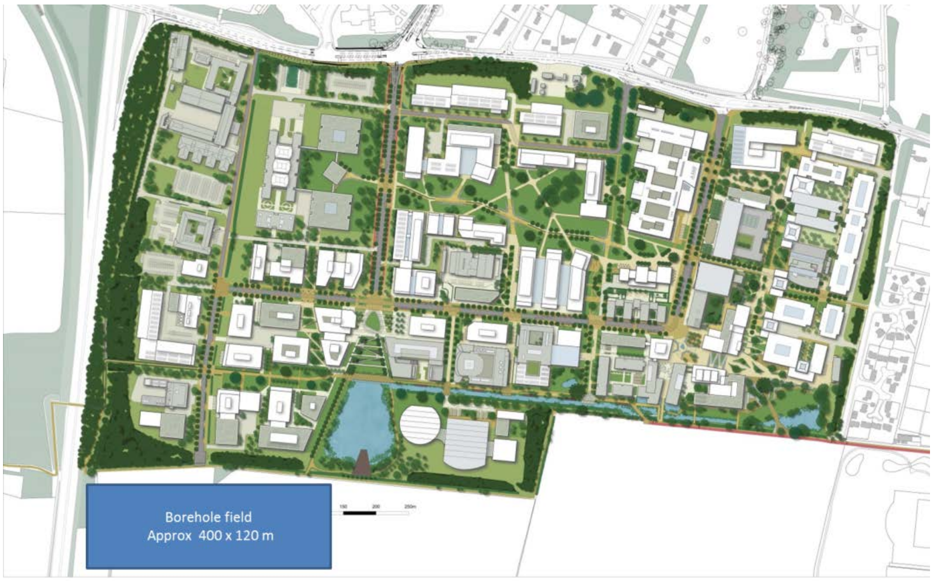
### 4.1.1 Air source option

For an air source solution, an approximate calculation suggests that around 3,000 $m^2$ of equipment would be needed to support the heat collection requirements. These would be of the type shown in the image below, and would result in a significant noise impact and require a large area to be dedicated to them. However if these could be accommodated near to the Motorway such that the noise was less of an issue, they would avoid the need for other buildings to be affected.


### 4.1.2 Ground source option

An alternative solution would replace the air heat exchangers with a ground loop. In this solution boreholes are drilled into the ground, pipes are inserted and backfilled. Fluid is then pumped through them and this gathers heat from the ground to warm the cold side of the heat pump. This option is estimated to require around 800-900 boreholes of 120m depth. Based on a typical separation of 6-7m between boreholes this would suggest a borehole field of between 3 and 5 Ha. It may be better to increase the separation, and hence the area, in order to improve the performance.

Whilst this area is unlikely to be practical to achieve on the site, in engineering terms it could be sited on the fields neighbouring the site. The possibility of this in planning and ownership terms remains to be demonstrated. The approximate scale of this required borehole field is indicated on the diagram below.

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The option for an open loop system should also be investigated, as if good water flow can be achieved it can be delivered at a lower cost than a large scale closed loop system, and should be able to be contained within the site. We are not aware that this option has been investigated through any ground water surveys.

A key step in the next phase of work will be to test the ground to understand the rate at which heat can be recovered and if any difficulties occur with the borehole drilling process.

### 4.1.3 Options for the delivery of heat

There are two main options for the delivery of heat around the site. In one the heat pumps are based in the energy centre, and provide heating across the whole site through a heat network in exactly the same way as the CHP solution would. This requires the heat pumps to raise the temperature of the supply into the network to a relatively high temperature to ensure the delivered heat is sufficient to supply domestic hot water, and this reduces the efficiency of the heat pumps.

This solution therefore requires:

- Heat pumps and peak gas boilers in an energy centre,
- Either an air or a ground heat exchange system, and
- Insulated pipes to link the buildings together, as for the CHP solution, with pumps to circulate the fluid.

An alternative solution, but one that is rarely used at present, is to circulate fluid at a much lower temperature around the site, and place the heat pumps in each building that needs them. This is known as a condenser loop, and has a particular benefit where heating and cooling loads are quite similar in scale. This is because a building that needs cooling heats the circuit, increasing the condenser loop temperature and therefore efficiency for another building that needs heating.

This solution therefore requires:

- Heat pumps and peak gas boilers within each building,
- Either an air or a ground heat exchange system, and
- Un-insulated pipes to link the buildings together, as for the CHP solution, with pumps within a reduced size energy centre.

# 5 Cluster or precinct approach

From the current indicative masterplan it is evident that there are areas of the site that would form more naturally into clusters. Clearly the detailed development of the site will evolve over time, and these may therefore change, but the principle will remain valid.

Based on the current masterplan, the following clusters are possible to allow discussion of how this approach might be implemented.


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The clusters marked 1 and 2 have significant elements to be built in Phase 1, and therefore can be brought forward first. Cluster 3 is partly phase 1, but mainly in phase 2. Cluster 4 is partly built already, with elements to be added in phases 1 and 2. Cluster 5 is mainly built already, but adding new building later may allow a local network to be established. Cluster 6 is expected to be built last.

## 5.1 Discussion of CHP options at cluster level

Combined Heat and Power systems benefit from increased scale due to the inherent higher efficiency of the available equipment for larger loads, and the greater diversity across more buildings meaning that the engine is meeting a smoother demand. Reducing to a cluster level approach will incur cost and carbon penalties compared to the site wide approach. This is expected to be partly offset by the reduced losses associated with a smaller total length of heat network. There are also potential benefits in phasing, as a more compact network can be delivered and operational in less time, linked in with the delivery of a smaller number of buildings.

An important change in applying CHP at a cluster level is that there will be more, smaller energy centres or plant rooms, with one located within each cluster. This also means that there will be emissions from more locations to be considered, although the total for the site will be similar to that for the site wide solution.

A further element to consider is that clusters could be linked at a later date to create the whole site system.

In general larger CHP engines will deliver higher energy and cost efficiencies due to economies of scale, and so it would be expected that a series of smaller CHP engines would give a worse performance in terms of carbon emissions than the whole site solution. This would be partly compensated for by reduced losses in heat transmission, but this is not expected to be sufficient to make this solution preferable.

Furthermore, the challenge of exporting electricity will remain whether there are many smaller engines or fewer larger ones. It also results in NOx emissions from more locations and hence more flues will be required. For these reasons this option is not proposed to be taken forward.

## 5.2 Discussion of heat pump options at cluster level

Although larger heat pumps do deliver slightly better performance than smaller ones, the impact of this is not as large as for CHP, and so a heat pump solution can be better suited to clusters of buildings than a whole site solution. At this scale they are still able to benefit from differences in demands between buildings. In particular if one building needs cooling whilst another is being heated there is capacity to benefit from this – this applies to any network that includes heating and cooling.

Heat pumps are less efficient when required to operate delivering higher temperatures, and so a lower temperature network is a significant benefit, e.g. delivering heat at 50-60$^{o}$C rather than the more typical 80-90$^{o}$C found in most heat networks or existing buildings. The implications of this are a requirement for larger flow rates to deliver the same amount of heat, and modifications to existing buildings to allow them to operate with the lower supply temperature.

As with the site wide systems, there are two main potential sources for heat collection / rejection for this site: air and ground. There is a small potential to use the lake to the edge of the site, but this has only limited capacity and so is not included at this stage as it would only be relevant to one building at most.

### 5.2.1 Provision of peak heating requirements

Because heat pump systems are significantly more expensive per kW than gas boilers, it is current normal practice to include gas boilers to help to meet peak heating loads. This saving is due to both the lower cost of the boiler compared to the heat pump, but also the removal of the need for additional heat collection equipment.

It may be possible for many buildings to include design for significant reduction in peaks, such that peak heating with gas is not needed. This would require larger thermal stores, further improvement in building thermal performance and an agreed approach to building management. The building management would contribute by recognising when outdoor temperatures are low and starting the heating much earlier than normal, reducing the peak demand that typically occurs when re-heating a building for the start of the day.

In the approximate analysis used here at masterplanning stage it is assumed that these approaches will be taken, such that the heat pumps can deliver around 90% of all of the heat needed. Further analysis within the specific buildings and clusters would be needed to establish whether this can be taken further and the need for gas boilers eliminated completely.

### 5.2.2 Ground source option for clusters

For the cluster solution an open loop solution is less likely to be used, as if this is available it would be suited better to a whole site system as the initial capital costs are typically large, and they require a large system to repay the investment.

The site has been reviewed to identify the areas of the site that are appropriate for the location of boreholes. This is restricted because it is best when possible to avoid:

- Areas close to trees, due to potential damage to roots, or damage by roots of the system,
- Areas where buildings will be built later, due to likelihood of damage to the boreholes, and
- Areas underneath regularly used roads where any access needed for maintenance will be disruptive.

In more detailed work it would be necessary to plan for coordination with utilities on the site, and to consider if any of the boreholes can be positioned under buildings at the time of construction. It is noted that this option makes maintenance very difficult.

Using this basis the site has been reviewed for potential locations for boreholes. An extract of this is shown below for the central part of the site adjoining Madingley Road:

In this diagram the blue dots are potential borehole locations within the development plots, whilst red dots are those outside development plots, so within public realm areas. Across the site as a whole slightly more (around 975 compared to 850) are found within public realm areas. The site wide borehole study can be found in Appendix 1.

This borehole area is potentially sufficient for all of the requirements of the site, and would be useful to address the concerns around excessive use of air source systems even if the costs are high. The capital cost of ground source systems is generally higher than those for air source systems, but there is usually also a slightly better performance from a ground source system.

### 5.2.3 Air source option for clusters

In the later discussion of using heat pumps for each building on its own, the estimate is reported that around 5% of the area of a typical building is needed for heat exchange equipment. By clustering buildings it becomes possible to place this on a smaller number of buildings. This has the benefit of:

- A reduction in the equipment needed due to diversity,
- Simplifying maintenance as there are fewer locations to manage,
- Allowing more sensitive buildings to have no heat rejection plant, and
- Allowing buildings closer to sensitive receptors (usually residential) to have no heat rejection plant.

The disadvantages of this approach lie in:

- Greater concentration of noise which may make it more conspicuous, and
- Heat losses from distribution.

### 5.2.4 Analysis of cluster option

If the cluster solution is adopted, there would need to be detailed design of both of the appropriate clustering, and the system for each cluster.

It is not straightforward to estimate the benefits associated with clustering buildings for heat pumps when so little is known about the expected use of the buildings. The key issues are that where buildings are clustered there is potential for savings due to:

- Reductions in peak plant needs as not all buildings will be at peak at the same time,
- Reductions in peak plant as resilience can be achieved across several buildings,
- Efficiency gains as one building may need heat whilst another needs cooling, and
- Reduced costs of thermal stores as these are cheaper per MWh as they become larger.

The extent of these benefits is not easy to calculate. However it might be expected to approximately compensate for the additional cost of distribution between the buildings, meaning that the overall cost should be similar in each case.

# 6 Building by building approach

Although it is not the preferred option, some buildings may be best served on an individual basis, particularly if they have low heat demands and / or are remote from other buildings.

Essentially the same options are available for delivering low carbon heat to a building as to a cluster, and with the same issues arising, amplified by the smaller scale of a single building.

Generally CHP is less attractive for a single building as the loads are usually too small and variable to support the efficiency savings associated with CHP, which will not be required to run at the constant high rate needed to achieve optimal operation.

Heat pumps are therefore more likely to be appropriate as they can be fitted to the scale more effectively than CHP.

The challenge of this approach is achieving the same levels of carbon saving as the site wide solutions can offer. This may require additional PV on some buildings to achieve an equivalent carbon saving. There is also likely to be increased cost due to making provision in every building.

The key benefit of the building by building approach is that costs are only incurred when that building is delivered, and it can use the best options available at that date.

The main disadvantages are around losing economies of scale and the opportunity to share provision for peak demands. Furthermore, all buildings will need plant including usually roof top plant which will have visual and noise impacts and or more internal plant space. There is also less flexibility to switch fuel types in future than when multiple buildings are linked together.

# 7 Conclusions

Whilst the site wide heat network remains an option, it is important to prepare for the possibility that it may not be deliverable. The energy hierarchy introduced here allows for this by setting out a clear approach.

In the event that a cluster based solution is adopted, the analysis suggests that at present the preferred option would retain a mix of air and ground source systems to give maximum flexibility.

Each option has the potential to deliver the same amount of carbon savings but each comes with specific impacts. These impacts for both of the cluster and individual options are:

CHP

- NOx emissions from more locations although overall emissions will not change
- Visual impact from more flues

ASHP

- Building height impact – additional roof top plant
- Noise from heat exchange systems
- Possible need for peak boilers with flues

GSHP

- Borehole space needs (assuming closed loop)
- Aquifer impacts and permissions (assuming open loop)
- Possible need for peak boilers with flues

The solution could be a mixture of these, as appropriate to the different clusters. At this stage the cluster solution is expected to be the most practical to deliver. The option would then remain to link the clusters to each other to form a whole site system, should circumstances change.

The CHP option within a central energy centre remains an option, but this is difficult to deliver at this stage. However there is an alternative to move to a heat pump based option. This note suggests that operating this on the basis of a number of clusters of buildings is expected to be the most cost effective and practical way to deliver this. It is expected to be able to meet the same level of carbon savings in the short term as the CHP option, and to be better than the CHP option in the longer term as the carbon factor for grid electricity continues to fall.

## Appendix 1 – Site Wide Borehole Study


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