Assessment of Options for Reducing the University of Cambridge's Use of Natural Gas

EXECUTIVE REPORT

UCAM EM/16/2019

Contents

Revision	Author	Version	Issue Date
1	MME, NFE	First Draft	10.03.20
2	NFE, MME	Second draft	10.03.20

1. Introduction

1.1. Project Background & Context

The University of Cambridge has commissioned Bouygues E&S to undertake an assessment of the options for reducing their use of natural gas. The University recognises that a significant reduction and ultimately, the cessation of their use of natural gas will be necessary in order to deliver their commitment to achieve absolute zero carbon emissions by 2048. A series of interim targets and aspirations for the reduction in carbon emissions have been set to drive a programme of actions and investments over the next three decades.

Natural gas is currently used as the primary source of heat across the University's estate and accounts for approximately 38%[1] of its total carbon emissions (scope 1 & 2). However, this percentage is likely to increase in future if the status quo is maintained, due to the projected decarbonisation of the electricity grid (whilst the decarbonisation of gas is less certain). The replacement of gas-fired plant with alternative low-carbon and renewable heat sources will be highly challenging and will require strategic direction and investment, significant resource allocation and planning.

The scope of this commission is to aid the University in understanding the overall feasibility, technology options, costs, constraints, risks and barriers associated with decarbonisation of heat, such to inform strategy and master-planning. The outcomes of this work are designed to be provide direction in the next phase of work and offer useful tools that may be utilised by the UoC as the programme progresses.

1.2. Key Deliverables

- Menu-of-options tool: a numerical simulation that collates estate-wide baseline data, cost / economic models and energy performance models and carbon calculations to derive projections of key metrics.
- Modelling Scenarios: using the menu-of-options tool, a selection of different scenarios that assesses the various technology options and influencing variables.
- Risk assessments: captures strategic / universal, organisational, site-specific and technology-specific risks associated with the development, implementation and operation of technology scenarios.
- Recommendations: Based on modelling outputs, site-surveys and engineering analysis, a series of high-level recommendations, including estate-wide strategies, prioritisation of sites and immediate actions.

1.3. Bouygues E&S & Element Energy

Bouygues E&S is a subsidiary of Bouygues Construction. We are a global leader in energy, digital and industrial transformation, delivering engineering innovation across the built-environment. Our Cambridgeshire energy team is focused on the development and delivery of energy efficiency and renewable energy projects.

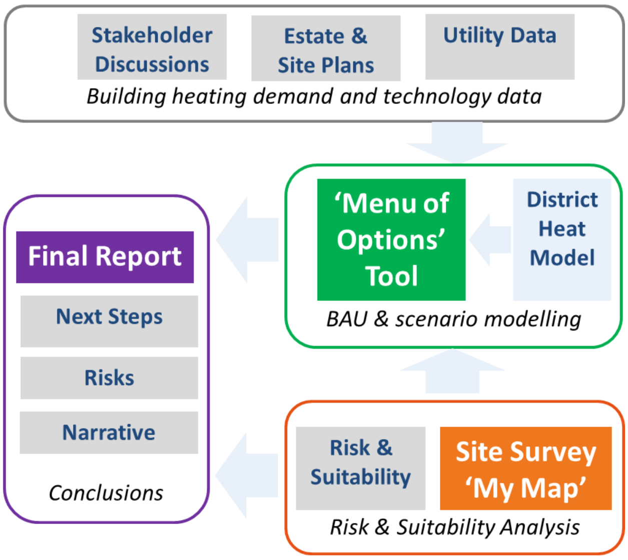
Bouygues E&S has partnered with Element Energy to form a project team that offers the full breadth of knowledge and skills to deliver all aspects of the University's brief. Element Energy brings industry-leading market research, analysis and modelling capabilities, whilst Bouygues E&S brings world-class engineering and construction expertise, focused in the field of renewable energy and energy efficiency. Key delegates from each organisation are based in Cambridge and have a knowledge of the sites and share a common interest in Cambridge City's transition to a low-carbon economy.

Element's role is focused on the gathering and analysis of data and preparation of the models. Bouygues' role is focused on the analysis of technical feasibility, identification of potential risks and barriers and other real-world factors that might affect overall viability. The combination of these activities has resulted in a study that provides both high-level strategic outcomes and site-specific appraisals.

This report documents the findings and recommendations of the investigation and outcomes of the models. It supports the key deliverable of this work, namely a bespoke 'menu of options' tool, which provides a numerical assessment of the impacts associated with various combinations and scenarios of deployment of low-carbon heat generation technologies across the Estate.

[1] The University of Cambridge's Environmental Sustainability Report 2018

2. Project Tasks



The project was split into several primary tasks, generally aligning with the original tender brief.

Generally, the tasks comprised a series of information gathering exercises, data filtration and analysis to feed into the Menu-of-Options tool. The results of the scenario modelling would then feed into the main report, as set out in the figure to the left.

2.1. Stakeholder Engagement

A series of meetings and workshops were held with key UoC stakeholder representatives, including Estates Management teams, site project managers, department heads and programme sponsors. The objective of this task was to identify and capture information about the existing estate, future development plans and strategies, to refine expectations and deliverables.

Several key decisions were made during these sessions, including:

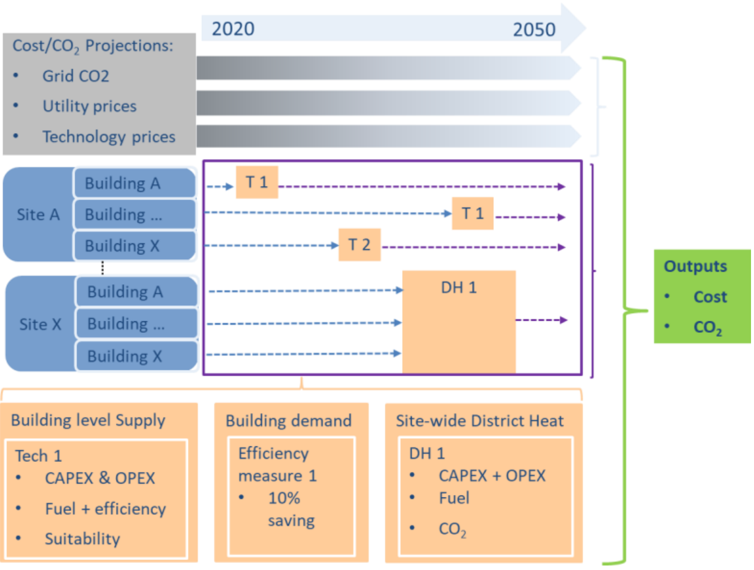
- All buildings in the estate need to be considered, not just the focus sites as originally agreed, with the exception of the Biomedical Campus, which is to be removed from the scope
- Only heating technology options that completely move the University off natural gas and oil should be considered, noting that partial / hybrid solutions could be viable or necessary in practice
- Flexibility should be built into the model to allow for costs to be updated upon further feasibility
- Costs on energy efficiency are highly variable, but are likely to be significantly higher than UK benchmark values, especially listed buildings
- All aspects of cooling are out of scope of this study. However, the co-benefits of heating and cooling should be considered in the narrative
- New Museums Site should be targeted for options for a site-level heat network due to the timing of major redevelopment

Workshops	**Modelling Concepts – Roundtable**	**Energy & Emissions Strategy**
	Data Gathering: Existing Buildings	**The Future of the University's Estates**
Calls	**Data Gathering: Existing Buildings**	**Future of the Estate CBC Focus**
	New Museums Energy Strategy	**Addenbrookes Hospital Future plans**
Presentations	**POG Meetings**	**ESSC**
	Estate Management	**Fortnightly Progress Update**

2.2. Information Gathering & Analysis

Working closely with UoC project representatives, the team collated, reviewed and analysed relevant asset and energy data, prior investigations and feasibility studies, energy audits, masterplans, lifecycle and maintenance plans.

This enabled the formalisation of baselines, business as usual projections, identification of target sites for surveys and opportunities for intervention. Where relevant and practicable, the datasets and information has been incorporated into the menu-of-options tool. However, it is also noted that, whilst available, certain site-specific information was too complex to fully incorporate, such as asbestos management surveys. Where possible, these have been referenced in the evaluation of risks.



It is noted that several prior studies have been carried out to look at the potential for heat networks across different sites. Each study determined a different level of feasibility and associated costs, showing a high level of uncertainty in the existing district heat costs.

Figure 1 (right) Menu of Option tool functionality allows user to choose decarbonisation measures and timeframes and to see the impact on costs and carbon

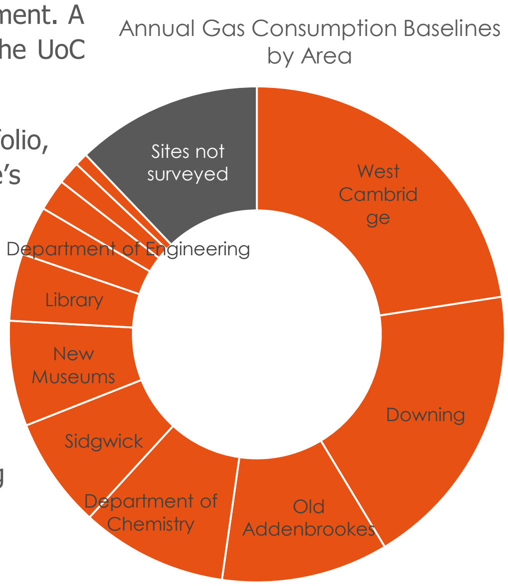
2.3. Site Surveys

A series of high-level site surveys have been undertaken by Bouygues E&S' Energy Engineers. The purpose of these surveys was to obtain physical information about the buildings, their energy infrastructure and their surroundings. This information would aid in understanding the potential opportunities, barriers, constraints and risks associated with the implementation of the technologies under consideration. A knowledge of the condition of the existing energy infrastructure would also enable prioritisation of upgrades and identification of pilot schemes.

The surveys targeted sites with the highest gas consumption, noting that these sites are likely to represent the greatest impact in terms of both carbon abatement and investment. A total of thirty-four buildings were shortlisted across five areas of the UoC estate.

Whilst the surveys only covered a fraction of the UoC's building portfolio, they collectively account for approximately two thirds of the estate's total annual gas demand baseline (56.2GWh/annum of circa 86.6GWh/annum). Moreover, the Sites cover almost 80% of the baseline, noting that the smaller plantrooms within these sites were not surveyed.

The information captured from these surveys has been presented in a series of survey reports and incorporated into a bespoke map, driven from GoogleEarth^{TM}. This is transferred to the UoC for continued development as surveys are undertaken for remaining properties.



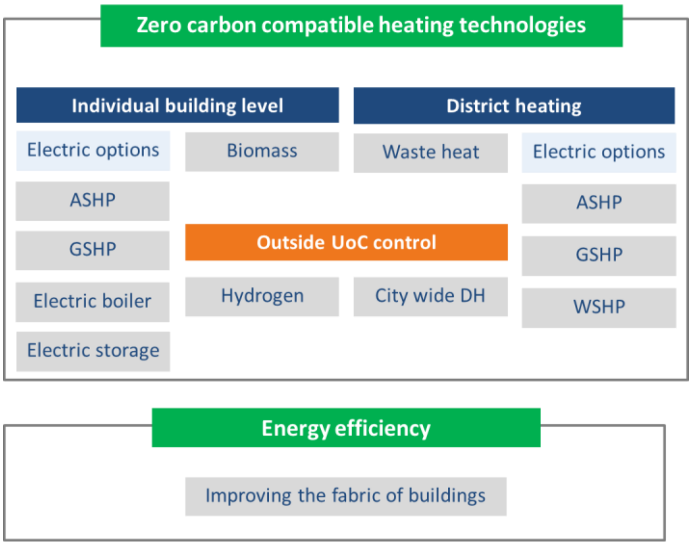
2.4. Menu of Options Tool

The purpose of the 'Menu of Options' tool is to help the University consider impacts of implementing different combinations of measures at various scales. The tool has been developed to compare how different scenarios will help UoC reach their net zero targets in terms of both cost (£) and carbon (tonnes/yr) compared to the business as usual (BAU).

The tool uses a range of technology and fuel costs and suitability metrics to apply high-level values of cost and carbon for each building, based on the selected scenario; however these values are based on data currently available (predominantly benchmark values*) and do not reflect the true costs at a building level (which is beyond the scope of this study). For those sites surveyed, appropriate adjustments are made to compensate for site-specific constraints and to eliminate unfeasible technologies. However, this is still based on initial survey observations. A key functionality of the model is the ability for the University to update values in future, as more information becomes available.

As shown in Figure 1 above, to compare scenarios the user can select intervention technologies, energy efficiency packages, and timeframes for each scenario via a scenario builder. The user can choose to apply each intervention across the whole estate or define the selection at a building level. The user can also test sensitivities for price and emissions across the scenarios to see the impacts if the cost reductions or decarbonisation of the grid is different than expected. The values are compared to the BAU as well as other scenarios on the dashboard.

2.5. Scenario Modelling



The model has been developed and refined in an iterative manner, based on the risks and barriers as well as opportunities identified through stakeholder engagement, data gathering and site surveys. Then, various scenarios were modelled to consider how the university should go about achieving their carbon targets for least cost. The scenarios modelled considered heating supply technologies as well as demand reduction measures at the building level, site level, and city-wide level. In addition, the scenario modelling considered the timeframes for intervention necessary to meet the University's carbon targets and the impacts on the cost. These results were used to determine the recommendations and a set of four 'preferred scenarios'.

2.6. Risks, Barriers & Constraints

A core part of this commission was to perform an assessment of the significant risks, issues and barriers associated with the transition from the existing natural gas fired heating and hot water systems to alternative, often innovative low-carbon heating solutions. The University wished to obtain an understanding of these critical issues and what measures might be implemented to mitigate them.

A systematic approach was taken to classify, appraise and treat risks, issues and barriers. This sought to assess their timing, noting that those left untreated to late in the development cycle, the impacts would inevitably be more severe. Information captured from stakeholder engagement, data provided by the university, site surveys, research into technology options, known local and national issues was used to form the basis of this risk assessment. At the request of the University, we also explored the 'unintended consequences' of the transition, namely the potential external impacts associated with implementation.

A detailed description of the methodologies adopted in the evaluation of risk is provided in the main report. A risk register is appended, which documents all applicable high-level risks, constraints and barriers. Those most significant risks highlighted through this assessment are summarised in Section 4 of this Executive Report.

2.7. Report

The main report provides a comprehensive description of our research, the methodologies, observations and outcomes of each key task, conclusions and recommendations. It is supported by several appendices, including a risk register, survey reports and map (described above).

3. Scenario Model Results

The approach to presenting results of the techno-economic assessment is based predominantly on cumulative, undiscounted costs across the 30-year model duration. We also show the discounted costs and both discounted and undiscounted NPV for the 'preferred' scenarios, using a discount rate of 5.25%. The discount rate of 5.25% is based on the University's discount rate of 7.25% with a 2% inflation rate removed. Costs are discounted annually starting from 2020. The results of the scenarios can be seen in Table 1.

Table 1 Comparison of undiscounted and discounted cumulative costs of different scenarios compared to the BAU

		Discounted (NPV)				**Undiscounted**			
		Additional CAPEX over BAU	Additional OPEX over BAU	Total Additional Cost over BAU	% additional costs over BAU	Additional CAPEX over BAU	Additional OPEX over BAU	Total Additional Cost over BAU	% additional total costs
		(£m)	(£m)	(£m)	%	(£m)	(£m)	(£m)	%
Individual building level technology	High T GSHP	114.87	- 1.42	**113.45**	+142%	270.56	- 5.59	**264.97**	+155%
	GSHP	90.72	- 6.01	**84.72**	+106%	214.56	- 20.99	**193.58**	+113%
	High T ASHP	73.02	1.42	**74.44**	+93%	173.19	1.97	**175.16**	+103%
	ASHP	59.37	1.20	**60.56**	+76%	138.22	1.68	**139.90**	+82%
	Electric Boiler	34.00	34.32	**68.33**	+86%	80.27	92.57	**172.83**	+101%
	Electric Storage	58.80	32.77	**91.57**	+115%	123.85	88.31	**212.15**	+124%
	Electric Resistive	49.69	33.67	**83.36**	+104%	109.61	90.80	**200.41**	+117%
	Biomass boiler	63.37	2.90	**66.28**	+83%	148.26	6.35	**154.61**	+90%
Outside of University Control	Hydrogen	10.14	6.81	**16.96**	+21%	27.84	25.34	**53.18**	+31%
	Citywide DH	0.52	13.85	**14.36**	+18%	-7.08	38.67	**31.59**	+18%
Preferred Scenarios	Act early	82.25	4.04	**86.30**	+108%	158.92	6.15	**165.07**	+ 97%
	ASHP	59.37	1.20	**60.56**	+76%	138.22	1.68	**139.90**	+82%
	DH (NM + WC)	73.05	0.96	**74.01**	+93%	150.70	0.95	**151.64**	+89%
	DH Extensive	66.97	1.06	**68.04**	+85%	121.07	0.61	**121.67**	+71%

3.1. Business As Usual (BAU)

The 'Menu of options' tool provides a projection of the expected heat demand and the cost and carbon emissions associated with meeting the demand. In the Business as Usual (BAU) scenario, the model assumes like-for-like technology replacement at the end of the technology lifetime. The space heating demand is kept constant for existing buildings, but the addition of new buildings using gas and electricity for heating leads to an overall increase in both gas and electricity demand out to 2050.

To meet this demand, as show in Figure 2, the BAU is expected to cost £171 million from 2020 to 2050. The majority, ~80%, of these costs are associated with fuel. The fuel costs are made up of mostly gas with some electricity, with both predicted to rise out to 2050.

Under a BAU scenario, heating alone will account for 508,000 tonnes of cumulative carbon emissions from 2020 to 2050. The annual carbon emissions will decrease by ~6% from 2020-2050 due to the relatively small amount of electric heating in the BAU which benefits from decarbonisation of the electricity grid. However, in the BAU, 330,000 tonnes of CO2 (+275%) will be emitted over and above UoC's target reduction curve between 2020 and 2050, and 16,200 tonnes of CO2 per year will still need to be offset in 2050.

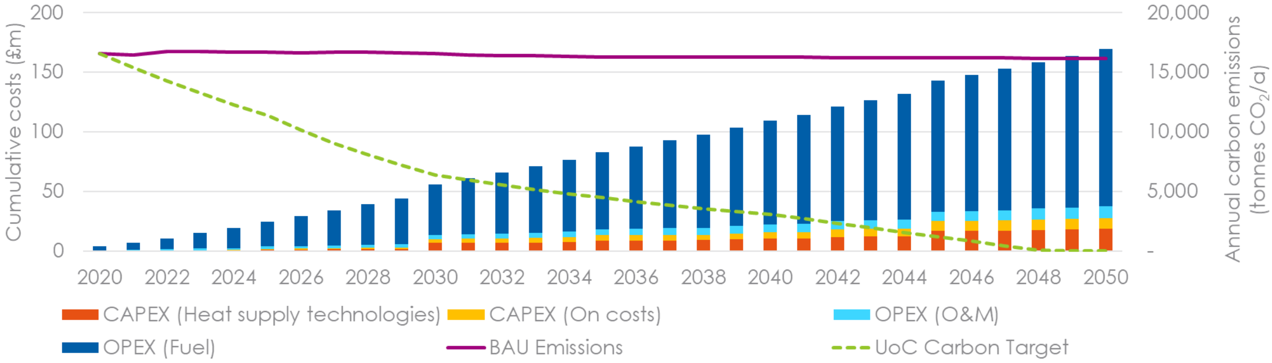


Figure 2 BAU Cumulative undiscounted costs and Annual CO2 emissions

3.2. Scenarios

The 'Menu of Options' tool can be used to compare the cost and carbon emissions associated with a range of different technologies (see Figure 3 below). When applied at the individual building level (i.e. excluding district heating), all low carbon technology scenarios result in costs of at least 80% more (in undiscounted terms) than the Business as Usual because of the increase in heating system CAPEX, building conversion costs and potentially higher fuel costs. The results below are based on scenarios where intervention occurs only when the Business as Usual technology would first be replaced, thus the savings in fuel costs for heat pumps over direct electric and the BAU will be more apparent over longer timeframes.

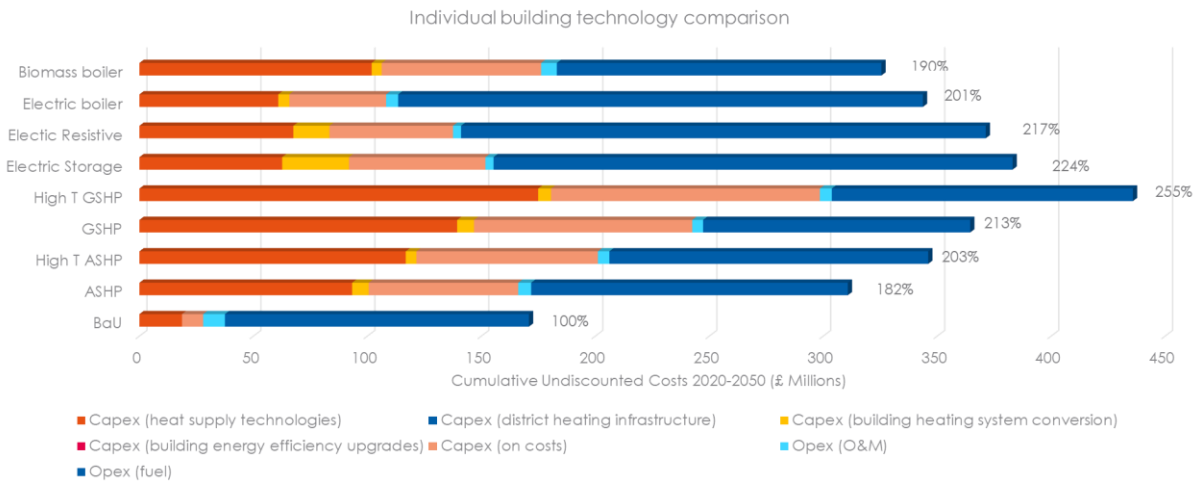


Figure 3 Comparison of building-level heating technologies

The low temperature air source heat pumps (ASHPs) are the lowest cost option at £310 million undiscounted cumulative costs, they are 82% or £140 million more expensive over the thirty years than the Business as Usual. The ASHP has lower capex than the ground source heat pump (GSHP) which outweighs the lower efficiencies that are achieved by ASHP. However, GSHPs will have a key role in delivering low carbon heat where inter-seasonal storage is beneficial and where there are severe acoustic or space constraints. High temperature ASHPs have lower efficiencies than low temperature ASHPs, however they reduce the need for potentially costly conversion of existing heat distribution systems and the need for increased energy efficiency of the building to allow for low temperature operation whilst maintaining thermal comfort, and thus may be a viable alternative to low temperature ASHPs.

ASHPs will result in 322,000 tonnes of CO2 saved over the 30 years (63% more than the BAU). However, GSHPs have higher efficiencies, and thus both low temperature and high temperature GSHPs – low temperature GSHPs saving 329,000 tonnes (65%) and high temperature GSHPs saving around 324,0000 tonnes (64%). In cumulative and annual terms, this means GSHPs will get the University closer to their carbon the cumulative emission reduction target (330,000 tonnes) as seen in the orange bar in the graph below. However the ASHP is more cost effective at abating CO2 at ~£440/tonne CO2, while the cost effectiveness for the GSHP scenario is ~£600/tonne CO2.

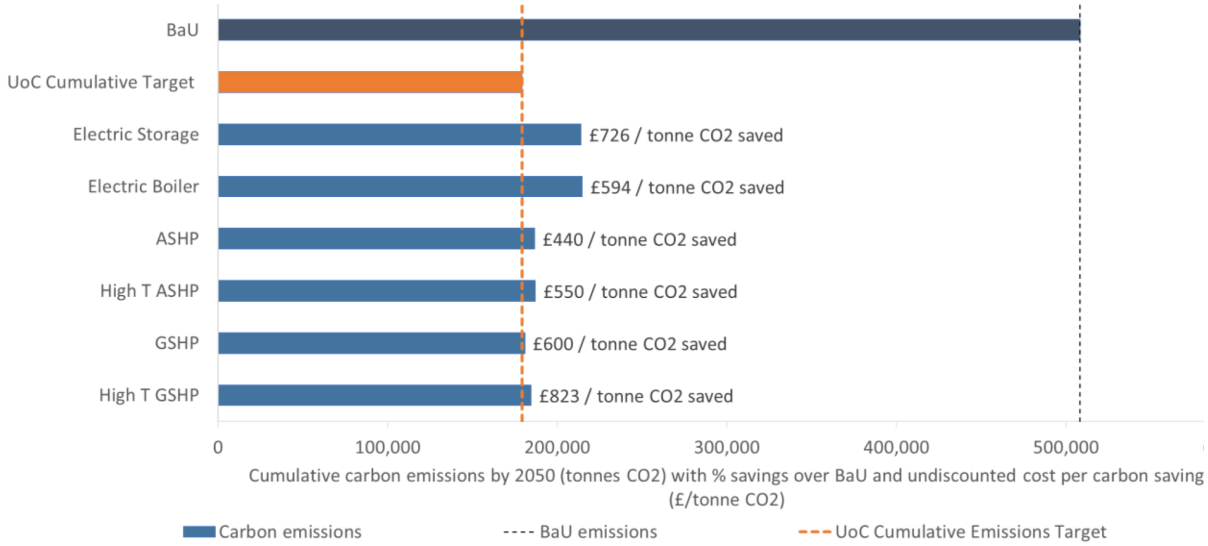


Figure 4 Cumulative carbon savings (tonnes) and cost effectiveness (£/tonne CO2) of individual building level technologies

Energy efficiency packages have also been applied in the 'Menu of Options' tool for comparison. The energy efficiency measures have a substantially higher cost than the low carbon heating technologies for less carbon savings due to the high upfront cost and relatively low ongoing fuel savings. The low energy efficiency package (10% reduction in space heat demand) with high T ASHPs costs ~300% more than the BAU. However, the need for energy efficiency to maximise the efficiencies of heat pumps, increase comfort levels, and reduce the amount of low carbon electricity the university needs to purchase, should be assessed through detailed feasibility at an individual building level.

Two scenarios were run to determine the potential impact of decarbonisation scenarios that we deem outside of the University's control but that could become viable options in the medium to long-term. These two scenarios were: The gas network is converted to low or zero carbon Hydrogen in 2040 and Cambridge City builds a low carbon heat network to supply heat to buildings across the city by 2030.

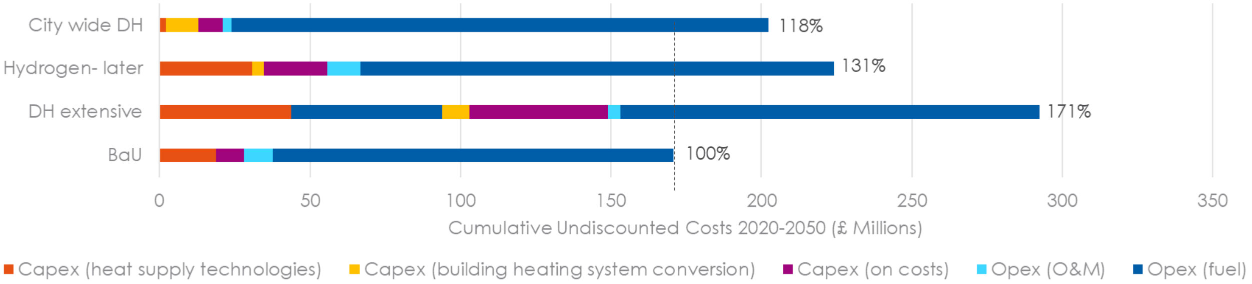


Figure 5 Comparison of cumulative (undiscounted) costs of external control scenarios

The model shows the clear benefit of these scenarios as potential low-cost solutions for the University with each only ~20-30% more costly than the BAU in undiscounted terms. However, the costs for heat and hydrogen are highly uncertain, along with the risk that these options might not materialise. In addition, the carbon emissions of the heat or hydrogen will be entirely outside of the University's control.

3.3. Preferred Scenarios

The model has been developed and refined in an iterative manner, based on the risks and barriers identified. After stakeholder consultation and data gathering from the University as well as site surveys, a 'suitability' matrix, 'added costs' matrix and default technologies in the model were developed. The tool was also refined to include opportunities that were identified. To do so, the tool has four 'preferred' scenarios that are pre-populated in the tool based on the initial modelling results as well as the findings from site surveys and stakeholder engagement. The 'preferred' scenarios have been selected based on:

- Lowest cumulative costs – based on 'Menu of Options' model results
- Lowest cumulative carbon (and able to meet 2030 & 2048 carbon targets) - based on Menu of Options results
- Greatest feasibility to implement - based on site surveys
- The ability of the University to control the results - based on surveys & stakeholder feedback
- The alignment with existing timeframes for development - based on surveys & stakeholder feedback
- As a result, four 'preferred' scenarios have been selected and are presented below.

The costs associated with moving off gas are highly scenario dependent but in all cases are higher than the business as usual. Of the scenarios within the University's control, Air-source heat pumps offer the lowest cost, highest carbon savings, especially when run at low-temperature although the cost of converting existing heat distribution systems to operate at lower temperature may be prohibitive in some buildings. Energy efficiency upgrades have poor carbon abatement economics and scenarios outside of the University's control are highly uncertain. Thus, the preferred individual building level scenarios include:

- **Scenario 1: "Individual building - ASHP lead"**: At the end of the existing technology lifetime each heating technology replaced with an ASHP where suitable.

While this scenario 1 was highlighted as the best intervention measure within the control of the University to be used on an individual building basis in terms of both cost and carbon, it does not meet the annual emission savings targets until 2030. For this reason, a more drastic scenario was chosen that pushes forward the dates of interventions for key sites which can act as test sites. New Museums site was prioritised at the time of the project due to site planning timelines, however due to changing circumstances it will be deprioritised in place of the Sidgwick site.

- **Scenario 2: "Act Early" in individual buildings**. This scenario is similar to Scenario 1, but involves changing to low carbon heating technology sooner for three key sites identified in the recommendations, West Cambridge + Maths + New Museums. For these sites, the conversion to low carbon heating is assumed to occur in 2023 for all buildings regardless of the remaining lifetime of the existing technology and would use High T ASHPs whilst the feasibility of low operating temperatures is proven in one or more buildings. Following the early sites, Sidgwick, is assumed to switch over in 2025 to mostly low temperature ASHPs and in 2026-2027, Old Addenbrookes and Scroope switch. Will other sites would convert at the next replacement year.

District heat networks tend to have higher costs on a site-by-site basis because they include the cost of building the heat network itself. However, some of these costs are offset by the value of combining demand and as such introducing economies of scale and diversity allowing for lower total installed capacity. In addition, for many of the University sites, space will be limited and changes to the building may be difficult. District heat may offer a lower disruption option than expanding plantroom, and allows for the ease of replacing heating technologies later on. There are two high level district heating options in the preferred scenarios.

- **Scenario 3: "DH - minimal":** New Museums and West Cambridge with DH networks in 2025. The rest of the buildings are done on an individual building basis, replacing BAU technology with high T ASHP at end of lifetime. While New Museums is a likely candidate for district heating, changing circumstances may lead to Sidgwick being prioritised in the near term in its place. Further work may be done to update the district heat modelling to include this additional scenario.

- **Scenario 4: "DH - Extensive"**: includes West Cambridge and a city centre heat network, including New Museums, Downing, Old Addenbrookes, Scroope and Sidgwick (including Maths but excluding the University Library) all done in 2025. The rest of the buildings are done on an individual building basis, replacing BAU technology with high T ASHP at end of lifetime. While the 'extensive' case would in reality likely occur as an expansion from a smaller network over time, for simplicity, a single conversion year is assumed.

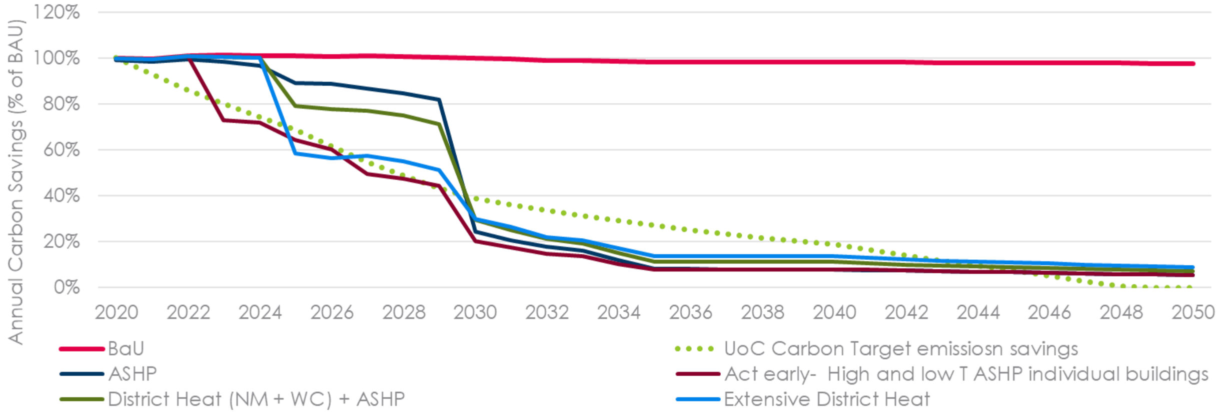


Figure 6 Annual carbon emissions of preferred scenarios

The carbon reduction potential is the key priority of the scenarios. The University has a cumulative carbon reduction target of 330,000 tonnes from 2020-2050. The annual emissions reduction necessary to meet this target can be seen on the dotted line in the figure below. The sooner the university acts, the higher the cumulative emissions savings but the also the higher the discounted costs. The "Act Early" scenario (maroon line) is able to meet or surpass the targets from 2023, allowing it to exceed the cumulative emissions goals with 360,000 tonnes saved.

Whilst meeting the UoC's decarbonisation targets is technically possible, action at the earliest opportunity will be required to ensure the 2030 target is met and to minimise cumulative emissions. However, none of the scenarios achieve zero emissions. The complete decarbonisation of the electricity grid is unlikely to occur ahead of 2050 and as such, the University will need to source alternative, zero carbon electricity in order to meet its absolute zero carbon target in 2048 or before.

The preferred scenarios will cost between £120-165 million more than BAU in undiscounted terms and between £60-86 million more in discounted terms than the BAU. This places them in the lower range of all the scenarios within the university's control. Acting early has a comparatively higher % increase over BAU in discounted terms as the costs will be paid in the early years.

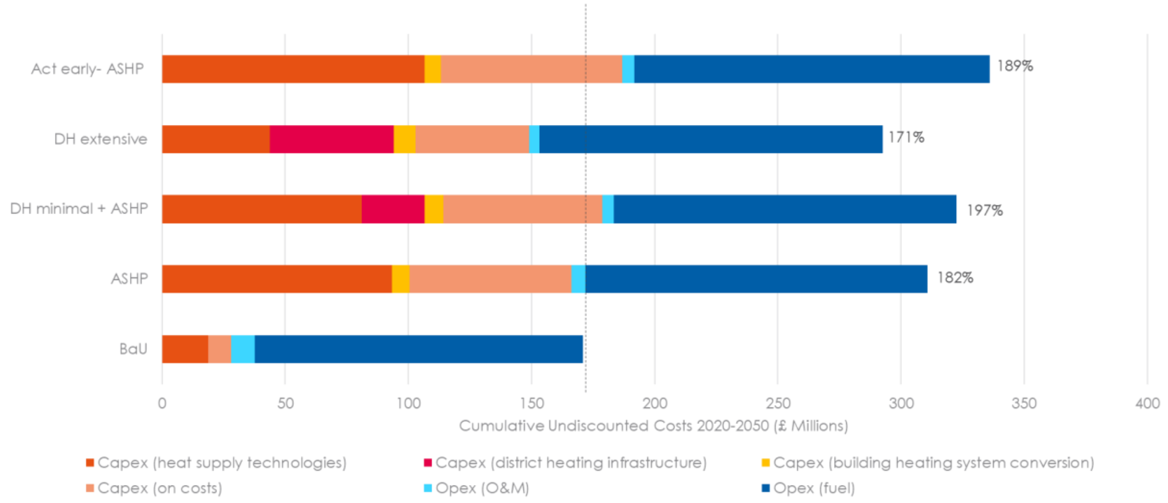


Figure 7 Comparison of Cumulative costs of the four preferred scenarios

The 'DH-extensive' is the lowest cumulative cost scenario because the district heat network allows the heating system technology to achieve lower price CAPEX and OPEX along with higher efficiencies due to scale. While district heating costs are highly sensitive to a number of key factors, our modelling suggest is option will cost ~£300 million in undiscounted costs (~£120 million more than BAU). The 'DH-extensive' scenario is very similar in total cost to installing individual ASHP in each building.

However, the 'DH – Minimal' scenario that installs DH only in New Museums and West Cambridge may be a more likely scenario in the short term based on high space and conservation constraints for New Museums and large redevelopment potential for West Cambridge. However, the costs are higher when the heat network CAPEX is not spread across more sites as in the extensive district heat case. While the 'DH – Extensive' scenario costs around £372/tonne CO2 abated, the 'DH – Minimal' scenario costs around £100 more per tonne at £477/tonne CO2.

The act early scenario is the most expensive. It has higher CAPEX than the ASHP because it does not benefit for future cost reductions to CAPEX or fuel. The higher cost should be balanced with the impact of reducing emissions earlier, allowing the University to meet annual carbon targets sooner and thus meet their cumulative carbon emissions targets by 2050. In terms of cost effectiveness, the two scenarios are similar although the ASHP case is still ~£40/tonne cheaper at £423/tonne CO2 abated.

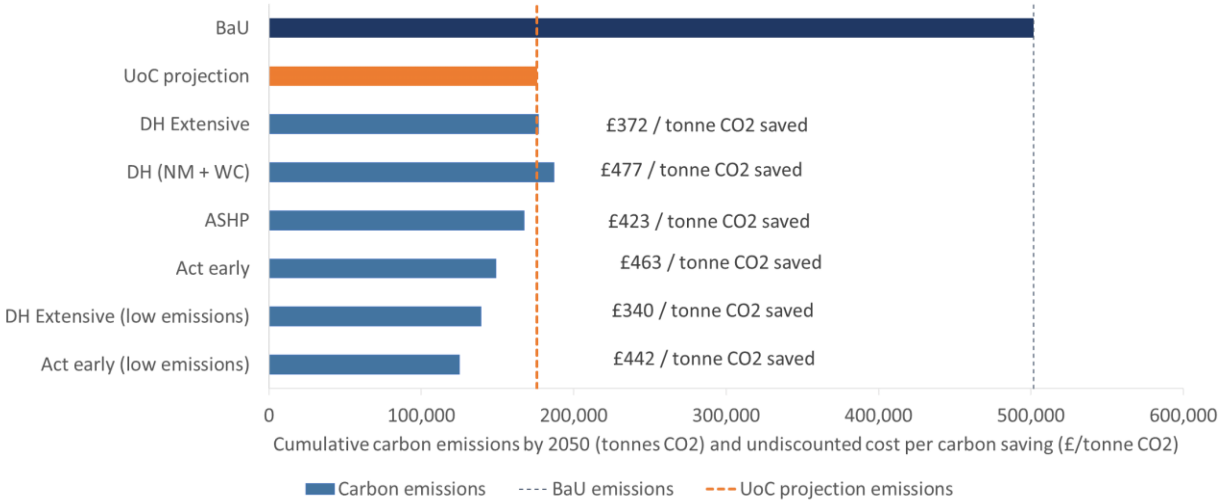


Figure 8 Cumulative Emissions savings (tonnes) and cost effectiveness of preferred scenarios (£/tonne CO2)

4. Key Risks, Barriers & Constraints

As noted above, by virtue of the number of variables and magnitude of uncertainties at the inception stage, a plethora of risks, barriers and constraints exist. Accordingly, a methodological approach was taken to this task, setting out the techniques that the University might consider in assessing risks as the programme progresses. Whilst the appended risk-register documents the assessment of risks, only top level strategic risks have been summarised below.

	Event / Item	Trigger	Primary Impacts	Mitigation / Qualification
External	Legislative	A change in law, such subsidies or taxation	change in the programme's viability	Targeted and continual research into future changes in law
	Infrastructure Availability	Insufficient utilities infrastructure to support technology alternatives, most notably, the electricity networks	Delayed implementation, prohibitive enabling / reinforcement cost, cessation	Early engagement with relevant utilities infrastructure operators to share programme requirements
	Future Energy Price	Deviations from the forecasted energy prices	higher than expected operational costs	Continual energy market research, sensitivity model, procurement strategy
	Future Carbon Projections	Deviations from the forecasted primary utility carbon emissions factors	A failure to achieve commitment of absolute zero carbon by 2048, continued global warming impact	Continual primary utility carbon emissions research and sensitivity modelling, local generation, procurement strategies
	Climate Change Impact	Severe weather events, systems unable to perform as expected	Closure of buildings - operations and revenues	Design 'fit for the future', contingency / back-up supply
Internal / Organisation	Resources (non-fiscal)	Insufficient resources made available to the programme	Delayed implementation, failure to achieve quality expectations	Master-planning, high-level governance & sponsorship, projects team formation
	Funding	Insufficient budget available to fund the programme	Total or partial cessation of programme	High-level sponsorship, early identification of budgets and alternative funding routes.
	Transformation	Change in organisation's operations, strategic objectives, sponsorship, leadership	Obsolescence of solutions, delayed decision-making or implementation	Awareness of, coordination, alignment or amalgamation with planned or existing transformations
	Approval processes	Approvals process is overbearing, decision making is protracted	Failure to meet programme milestones, delays or cessation	Upfront agreement on decision gateways, delegation, binary criteria
	Student expectations	A failure to meet existing or prospective student expectations for minimising carbon emissions	Reputational, loss of revenue	Ensure that student expectations are understood, that achievement of such expectations are publicised
Site-Specific	Technical Incompatibility	Retrofit technology is incompatible with existing systems	Significant enabling work – cost, operational disruption and programme delays	Comprehensive early feasibility and optioneering, incorporate into wider refurbishment programme.
	Spatial Incompatibility	Insufficient space in buildings to accommodate retrofit technology	Project deemed technically unfeasible	Heat networking, remote or shared plant, incorporate refurbishment
	Heritage	Historic aspects of the site may not be altered to facilitate retrofit technology	Project deemed technically unfeasible, LBC refused, additional cost associated with alternatives	Appropriate contingency made for heritage conservation works, early engagement of conservation officer
	Environment	Local environmental impacts associated with the retrofit technology are unacceptably high (compared with gas boiler option)	Project deemed technically unfeasible, planning application refused, additional cost associated with alternatives	Awareness of potential impacts of technology options are fully understood, analysed and mitigated throughout all stages of project
	Operations	Retrofit results in prolonged loss of building availability	Operational, revenue, reputational, health & safety	Advanced planning, parallel installation, contingency plans
	Hazardous Materials	Presence of hazardous materials, such as asbestos, lead, mercury	Additional enabling cost, programme delay, feasibility constraint	Ensure information available and accounted for at early stage of project.
Tech. Specific	Performance Uncertainty	Lack of supporting evidence to convince stakeholders of reliability	Failure to achieve approval to proceed, cessation.	Early tech. due diligence, commercial performance risk transferral
	Technology Availability	An emerging market – limited or no supply-chain, monopolised solutions	Extended lead times, lack of competition / higher cost, increased obsolescence	Early soft-market engagement and supply-chain network, identification and analysis of gaps or exclusivities
	Obsolescence	Selected technology becomes obsolete before end-of-life	Replacement	Focused and continual research into prospective technological advances
	Advancement procrastination	Implementation is delayed in anticipation of a technological advancement	Progress is stifled, abortive development work, failure to meet interim targets and commitments	Ensure that benefits of potential advancement are sufficiently robust and certain to warrant the delay.

5. Conclusions & Recommendations

5.1. Key Messages

- **Meeting the University's science-based emission reduction targets is technically possible for space and hot water provision.** However, the timescales are particularly challenging – early adoption is required in order to achieve interim targets. An overarching estate-wide approach will need to be adopted at the earliest opportunity and must be continuously reviewed and updated as the national and local decarbonisation of heat progresses.
- **The most economically favourable scenario is based on Air Source Heat Pump (ASHP) as the primary technology.** It is noted that this approach may not be feasible in all cases and hence, other heat-pump based technologies, or heat networking (remote / shared plant) may be necessary in order to overcome local constraints.
- **Complete conversion to a low-carbon heat source is likely to result in a substantial increase in overall capital and operational expenditure, compared with business as usual.** The menu-of-options tool estimates an additional undiscounted cost of between ~£140M and ~£250M (~£60M and ~£115M discounted) between now and 2048, compared with a ~£170M baseline. The funding requirement may not align with existing or conventional investment criteria and budgets. The 'gap' in funding between ECRP / LTMP budgets needs to be considered, noting that without subsidies or significant technology advances, the University is unlikely to see a return on the additional investment.
- **All existing gas boilers must be replaced with low carbon alternatives at the next replacement or earlier, wherever practicable.** This will be essential both to ensure the pace of decarbonisation tracks the science-based target and to avoid stranded assets given the 15-20 year lifetime of gas boilers. The development and delivery timescales associated with conversion from natural gas to a low-carbon alternative will be significantly greater than a like-for-like replacement. Design processes, planning applications, electrical connections agreements, enabling works and equipment lead times must be factored.
- **All new developments must be designed without gas heating.** Whilst this may seem obvious, a basic assessment of property data shows a steady, yet considerable increase in gas baseline consumption over the past century. Hence, an immediate arrest in growth in gas consumption would be a significant departure from the long-term trend.
- **Surveys highlighted significant and often unique constraints across the Estate.** Unique design solutions must be sought for retrofitting existing sites and buildings - there is no single retrofit solution that is suited to all. Whilst the menu-of-options tool provides high-level appraisal of different technology approaches, each site will require a targeted feasibility study to establish the best available technique. This may promote the use of novel technologies, which will necessitate additional due diligence, commercial governance and risk transferral.
- **In particular, heat-pump co-generation of heating and cooling may offer an opportunity for improved returns.** The capital and operational costs associated with heat pumps may be offset if used to provide both heating and cooling – this may also result in the achievement of exceptional efficiencies. Whilst beyond the scope of the menu-of-options tool, site-specific assessments revealed several opportunities for such applications, particularly at target sites (extensive need for cooling).
- **Hydrogen injection to the natural gas grid is unlikely to deliver the University's objectives.** Whilst there is a significant difference of opinions across industry as to the potential extent to which the national gas infrastructure may be repurposed for hydrogen distribution and the associated carbon reduction, our research suggests that it is highly unlikely to achieve zero carbon by 2050.
- **Energy efficiency should be considered at an individual building level basis and, where viable, should be implemented at the earliest opportunity**. Whilst, in many cases, the return on investment is unlikely to achieve typical investment thresholds, the resultant long-term reduction in heat loads may improve technical feasibility due to the lesser plant capacity requirement.

- **Sources of zero carbon electricity should be investigated and considering with regard to the increase in electricity demand resulting from electrification of heat.** Whilst the national electricity grid is rapidly decarbonising, current projections suggest that the timeline for complete decarbonisation of the grid will not allow the University to achieve absolute zero emissions from heating, even if highly efficient heat pumps are used, by its 2048 target. Hence, direct sourcing and generation of renewable electricity will be needed.
- **Lessons should be learnt from one or more 'priority sites' within the University Estate.** One or more of the core sites should be prioritised for early decarbonisation of heating across the site. Lessons should be learnt from the entire process from feasibility to installation and operation of the low carbon heating technologies to ensure the best approach is taken for decarbonisation of subsequent sites.
- **Certainty on the future of key buildings and sites is critical in making long-term investment decisions.** It is noted that several key buildings and sites are subject to potential major refurbishment, redevelopment or disposal, which may delay or halt investment in low-carbon heating plant. Whilst the menu-of-options assessment is based largely on the existing and in-construction estate, it may be updated to account for and assess the impacts of major future changes (for example, the relocation of the Department of Chemistry).

5.2. Next Steps

- **Develop an overarching masterplan for decarbonisation of heating across the estate with associated strategic groups.** Whilst detailed feasibility studies will need to be undertaken at a site wide and in some cases at an individual building-level basis, an overarching strategy will be required to ensure a co-ordinated approach, to maximise opportunities, share resources and to continue learning and improving as the decarbonisation progresses. We recommend setting up an internal strategic group to co-ordinate the approach.
- **Finalise selection of 'priority sites' and undertake detailed feasibility studies.** Based on the above recommendations, one or more sites should be prioritised to be taken forward in the short term. For each priority site(s), detailed feasibility studies will need to be conducted at the earliest opportunity.
- **Strategic early engagement with key stakeholders:**
  - **UK Power Networks (UKPN)** Since it is likely that the 'preferred' decarbonisation option for the majority of sites will predominantly involve electrification of heat, further detailed assessment of the electricity grid constraints, mitigation and associated costs will be needed in collaboration with UKPN. We therefore propose that a strategic group is formed with UKPN to ensure ongoing interaction and alignment with wider infrastructure needs.
  - **Local Authorities** The revised Local Plan for Greater Cambridge (including Cambridge City and South Cambridgeshire) is currently under consultation and is due to be adopted in 2023. As a major heat user in the City, it will be vital for the success of both the University's decarbonisation strategy and that of the Councils that a joined-up approach is taken. It is also noted that all developments will be subject to planning permission and hence, both alignment with the Local Plan and national planning policy will be required.
- **Ongoing review of Local and National policy and direction of decarbonisation.** The University's decarbonisation strategy will need to be continually refined and updated to ensure alignment with Local and National policy and to exploit opportunities that arise from wider decarbonisation of the electricity and / or gas grid and any financial incentives. The UK Government's current subsidy for renewable heat, the Renewable Heat Incentive, is due to end in April 2021, too soon for any new projects to come forward. At the time of writing, no announcements have been made to clarify the future of this scheme, or any replacement. However, it is expected that the forthcoming budget will provide an indication of whether support will continue beyond April 2021.

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