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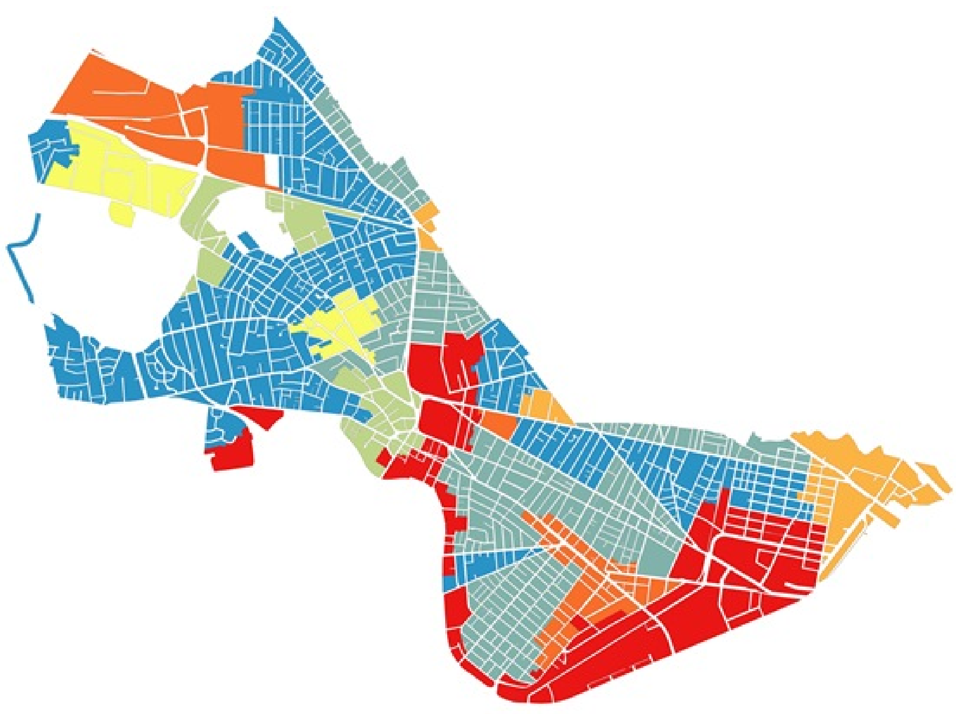
LOW CARBON ENERGY SUPPLY STRATEGY
OUTLINE OF REDUCED LIST OF SUPPLY SCENARIOS



RAMBOLL

LOW CARBON ENERGY SUPPLY STRATEGY
OUTLINE OF REDUCED LIST OF SUPPLY SCENARIOS

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Ramboll
Hannemanns Allé 53
DK-2300 Copenhagen S
Denmark
T +45 5161 1000
F +45 5161 1001
www.ramboll.com

TABLE OF CONTENTS

TABLE OF FIGURES

TABLE OF TABLES

APPENDIX

Appendix 1
Scenario Scoring Template

Appendix 2
WP 2 Decision Gate Meeting Minutes 05.16.2017

Appendix 3
LCESS Scenario Selection Meeting 1 April 25th

Appendix 4
cenario Long List Report R02

Appendix 5
LCESS AC Meeting Minutes May 16th

Appendix 6
LCESS Workshop 3 AC Presentaiton May 16th

Appendix 7
LCESS AC Meeting Minutes February 15th

Appendix 8
LCESS Workshop 2 AC Presentation February 15th

Appendix 9
Scenario Selection Process Document WP2 Rev 1

Appendix 10
Scenario Selection Process Document WP2 Rev 2

Appendix 11
Scenario Selection Process Document WP2 Rev 3

1. INTRODUCTION

Following Work Package 1 which analyzed the existing factors and barriers to a low carbon energy supply in the City of Cambridge, Ramboll proceeded with Work Package 2 (WP2). The objective of WP2 is to ultimately derive 1-3 low carbon energy supply scenarios for detailed analysis under Work Package 4. Table 1-1 below outlines the WP2 process.

This document outlines the reduced long list of scenarios identified by the project team as per Step 3 below, following internal workshops and an initial workshop with the City. Step 4 in this process involves AC review of this memo and scoring of scenarios in the excel template provided. The scenarios outlined herein will then be presented and discussed further in Step 5 with the Advisory Committee in order to select scenarios for progression to WP4.

Table 1-1Work Package 2 Process

Step	Process	No. Scenarios	Input
Step 1	Ramboll team establish a long list of opportunities through internal workshops – ideas will be derived using the detailed GIS maps prepared under WP1. **Output** Summary memo outlining scenarios: Description of the various technologies proposed, the proposed percentage energy supply split for each technology for that scenario, and whether it meets City goals. Technology descriptions should take account of the City goal/criteria which will be considered when rating.	9-12	Ramboll
Step 2	Ramboll will present the longlist of scenarios in the summary memo submitted to CCDD and walk through them. CCDD will have one-two weeks to read and consider scenarios. CCDD and Ramboll then meet to score the scenarios together, receive feedback on any idea omissions. **Output** Reduced number of scenarios.	9-12	Ramboll & CCDD
Step 3	Ramboll will prepare a more detailed summary memo on the selected scenarios for agreement for progression to WP4 assessment. No IRR, NPV – still qualitative level. **Output** Summary memo outlining remaining scenarios in more detail.	<9-12	Ramboll
Step 4	AC review summary memo and score remaining scenarios in excel template (Appendix 1) over one week. Scenario's to be graded 1-5, worst to best.		AC/CCDD
Step 5	Scenarios and AC allocated scores discussed at AC meeting to build consensus on scenarios for progression to WP4.	2-3	Presented to AC
Step 6	CCDD and Ramboll meet again to score the scenarios together to select scenarios for progression to WP4. **Output** Reduced number of scenarios.		Ramboll & CCDD
Step 7	Agree WP4 assessment criteria for final scenario assessment.		Ramboll & CCDD

Each scenario is described as follows:

- Technologies identified for supply with description
- Percentage energy supply to be provided by that technology
- How the scenario meets the City's goals

How the scenario meets the City's goals is important as it will be used by the City and project team during this project stage for scenario evaluation and shortlisting. In order to identify if the proposed scenario complies with the Goals of the City as outlined below, a table has been developed for ease of visual assessment under the headings of low, medium or high approximation to the City's goals.

1.1 Classification of scenarios in relation to the City's goals

In order to identify if the proposed scenario complies with the Goals of the City. Table 1-2 has been developed for ease of visual assessment. The City goals1 considered when evaluating the scenarios are:

- **Clean**: Reduce carbon emissions and toxic pollutants created by the system.
- **Reliable**: Minimize system downtime from outages and ensure high quality of power delivered.
- **Affordable**: Keep rates as low as possible and maintain competitiveness.
- **Predictable**: Minimize rate volatility.
- **Transparent**: Consumers can understand their power costs and what drives changes in costs.
- **Local Control**: Give residents greater control over their energy resources and energy choices.
- **Wealth Creating**: Keep more energy revenue in the local economy instead of exporting it to outside suppliers — to help drive local economic development, create new businesses and jobs.
- **Innovative**: The system spawns innovation, intellectual property creation, and entrepreneurship.
- **Just**: The system promotes "energy equity," protecting vulnerable populations from undue hardship, and promotes energy literacy.

Each of the City goals is classified according to a low, medium and high evaluation. For ease of identification, the classification is colored accordingly:

- Low: **Red color**
- Medium: **Yellow color**
- High: **Green color**

The classification is not based on an economic assessment of costs and benefits of each scenario. Instead, the scenarios are evaluated on a best estimate based on the project groups experience with energy projects. The scenarios selected by the City of Cambridge will later in WP4 be classified by an economic assessment study.

[1] In accordance with the RFP and the Carbon Neutral Cities Alliance

Table 1-2: Example of Scenario classification

Goals	Meeting the City Goals?
Clean	
Reliable	
Affordable	
Predictable	
Transparent	
Local Control	
Wealth Creating	
Innovative	
Just	

2. CITY ZONING PROCESS

In order to understand the consumption of energy within the City, Ramboll prepared a City Zoning Map based on heat consumption. As heating and cooling consume 60% of the city's energy consumption today, it is important to understand where this is specifically being consumed within the City to consider alternative methods of supplying this demand.

The maps produced show zoning in the following ways:

- MWh per consumer. This is the total demand within a zone divided by the total number of consumers (connection) within the zone.
- kBTU per consumer. Same as above, but in kBTU
- MWh/ha: The total thermal usage within a zone divided by the zones area in hectares (ha).

Following the analysis of the zoning maps, the City was divided into various zones based on existing consumption. This zoning is outlined in Figure 2-1 below. The initial long list of scenarios were developed were based on the zones defined and how to meet the required demand for each zone with low carbon alternatives. Zone 1 has the highest heat density and is presumably suitable for district heating. Zone 2 has a lower heat density and individual heating is most likely the best solution. Zone 3 and zone 4 are development areas, which in the future can be supplied like zone 1.

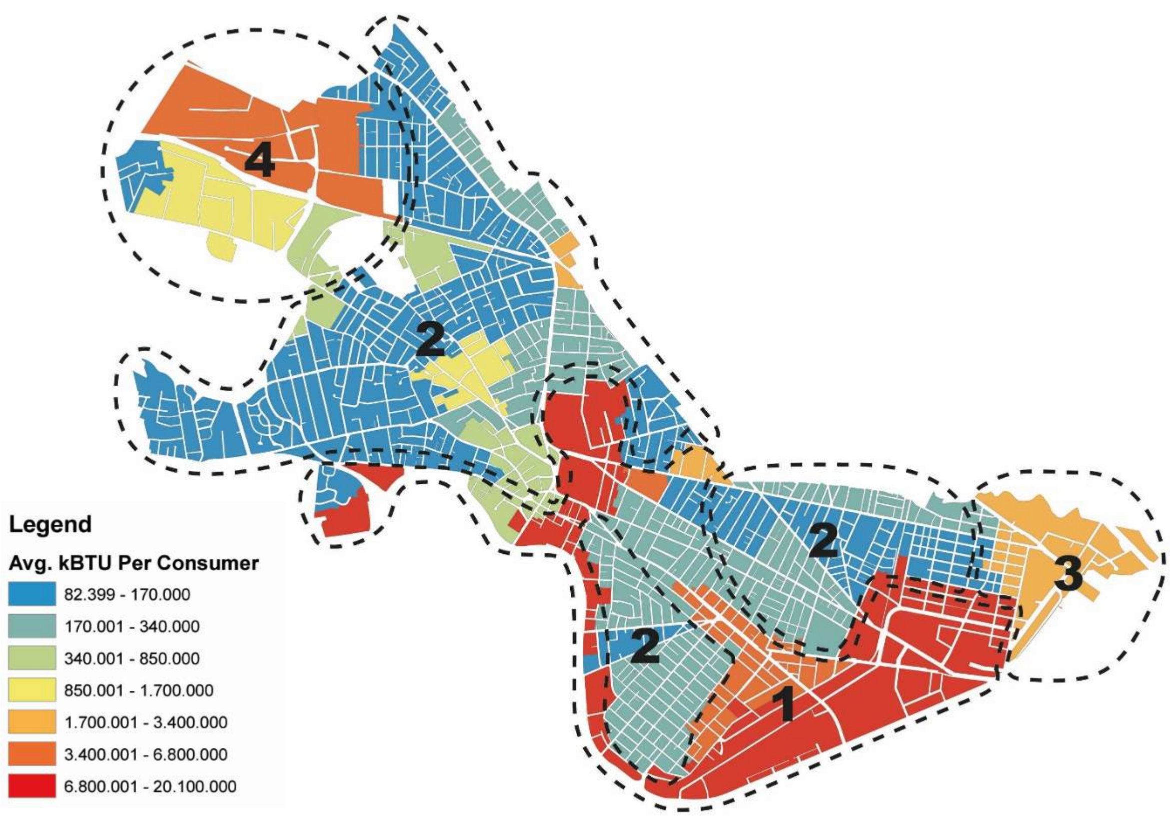

Figure 2-1: City Zoning Map

Following the initial zoning process and initial scenarios review, the zones were further defined as shown in Figure 2-2 below.

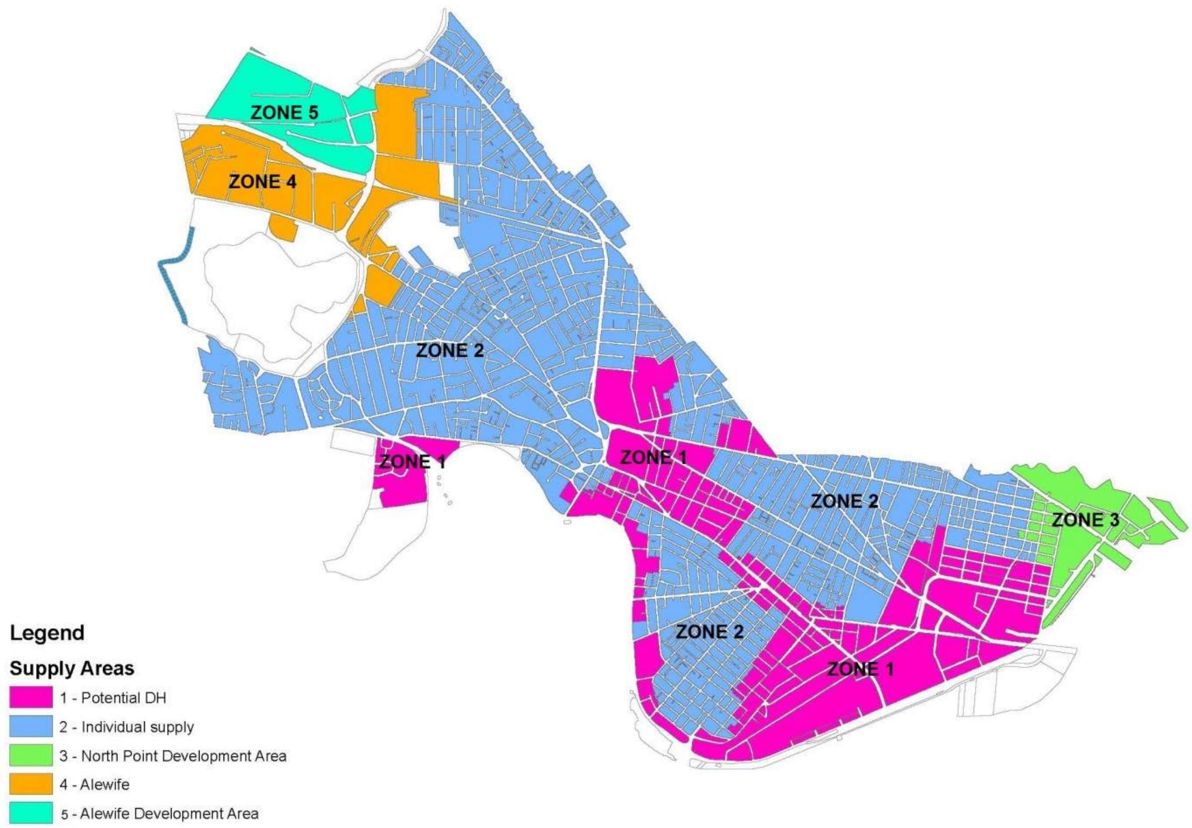

Figure 2-2: City Zoning Map

The zones indicated in the above figure have heat loads as outlined in Table 2-1 below.

Table 2-1 Total zone thermal demand

Zone	Existing Thermal Demand (kBTU)	Existing Thermal Demand (MWh)
1	3,359,779,636	984,654
2	2,056,627,561	602,738
3	293,099,080	85,899
4	216,701,465	63,509
5	122,941,619	36,031

3. ALTERNATIVE ENERGY SOURCES

The Work Package 1 report outlined the existing energy supply for the City of Cambridge and potential alternative sources to replace this supply. These are outlined on Figure 3-1 below. In advance of the initial scenario development process and in order to inform the development process more, Ramboll assessed the alternative energy sources of Cambridge further.

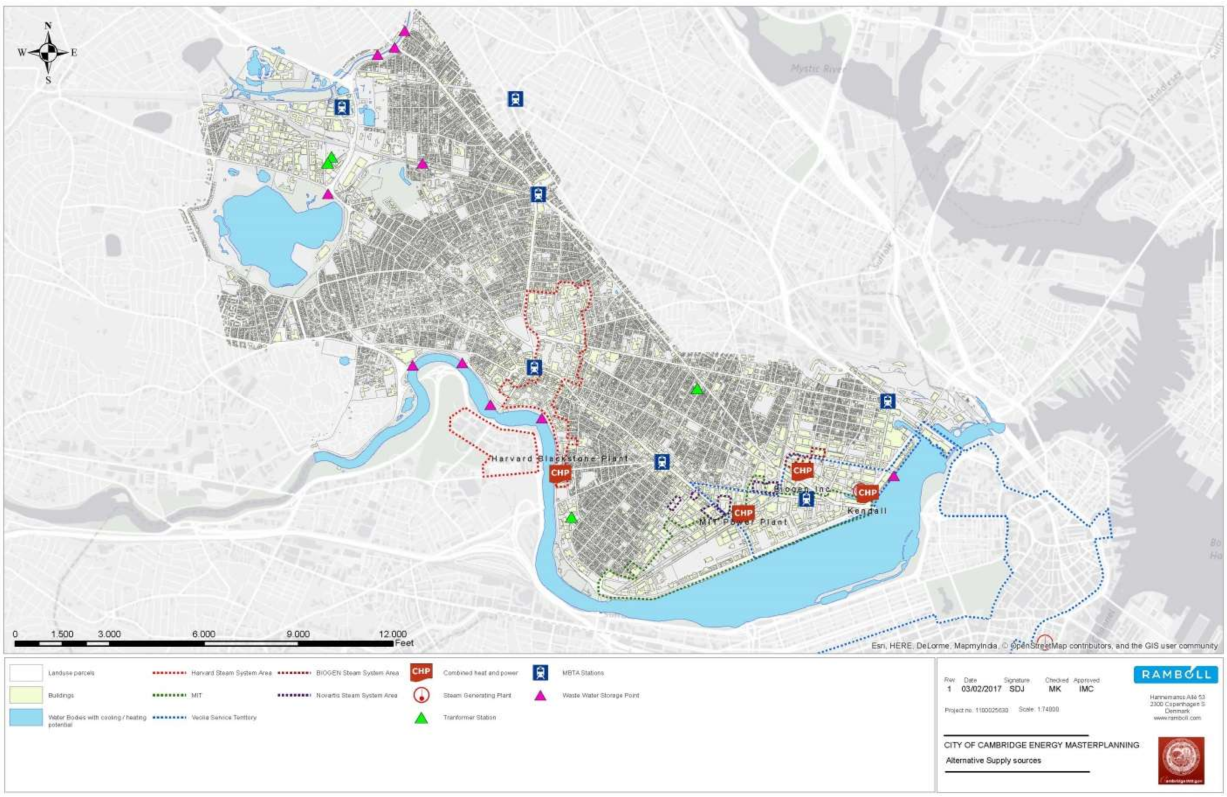

Figure 3-1: Existing and Alternative Supply

<u>Photovoltaic (PV):</u> In terms of renewable energy generation, the City has limited space for large scale Solar PV within the City boundary. However, solar PV panels can still be located on building roofs inside the city. It has not been investigated if the local electricity grid can withstand the increased solar production nor the economic feasibility.

<u>Floating PV on Fresh Pond:</u> As decentralized renewable energy electricity generation is limited within the City, all surface areas where PV can be installed should be considered to contribute to the demand required. If it is assumed that 30% of the surface area of the pond is covered with floating PV, approx. 5% of the City's total electricity demand could be met. This is considered included in all scenarios and will be a sub-scenario of the final preferred solution to determine potential viability.

<u>Microgrids:</u> Can save on distribution costs (as the micro-grid owner does not have to pay grid operator their set tariff) and provide resilience in black out situations, however they are considered an enabling technology and not a low carbon energy supply technology. Microgrids enable electricity generating plants to achieve better rates for the electricity they generate. Typically microgrids would be considered as a way to add value and contribute towards the business case for a combined heat and power or renewable energy plant. In a situation where dual located networks (microgrid and existing

grid) are operating, energy losses from supply can be increased. Consideration of microgrids in this project will be driven by the identified supply technologies.

Battery technologies: Current technologies can provide storage of significant quantities of energy, however charges can only be held for short periods 1-2 hours and the size and cost of the batteries are significant.

Such battery technology can be charged during high renewable energy generation periods when demand is low, however they need to dispatch this energy soon after due to their storage capability at City scale.

Battery technology is useful for providing resilience in blackouts and for providing peak shaving in periods of high electricity demand, but contributions to a low carbon energy supply are limited by storage durations and the low carbon electricity still has to be created.

Battery technology at the scale required for Cambridge is currently prohibitively expensive and would require significant amount of space for a city scale project. The technology has advanced rapidly in recent years and costs and space requirements are expected to decrease as the technology continues to develop. Battery technology may also act as a technology enabler, facilitating more PV generated electricity utilization for instance, and will form part of the low carbon energy supply transformation process. For this reason consideration of the future potential shall be discussed as the project develops.

Wind turbines: The wind potential and available locations for wind farms has also been identified as limited inside the city. However, buying wind certificates or installing wind turbines outside the city are an option.

Deep geothermal potential: Further investigation of the deep geothermal potential of the aquifers below the city was also conducted. Ramboll contacted the Geological Energy Systems dept. at the University of Glasgow, Scotland (which shares a geological history with Massachusetts) and the University of Massachusetts. The University of Massachusetts conducted the Massachusetts Geothermal Data Project, which has produced maps outlining the geothermal potential of the existing aquifers in the state. Based on the work they have done, the argillites in the Cambridge Basin are not an obvious deep geothermal target, and are currently not on their list of potential Massachusetts targets (even when considering low temperature requirements of around 140^{0}F/60^{0}C). It is likely that there are granites and gneisses beneath the basin. However, when looking at the heat production maps produced by the Massachusetts Geothermal Data Project, none of the surrounding granites have high heat production value. Following these discussions and analysis, it is clear that further costly site investigation will be required to ultimately rule out the aquifers beneath Cambridge as a useful energy source; however as it stands the likelihood of this is low.

Note that deep geothermal energy supply discussed here is distinct from ground source heat pumps, which use the shallow ground as a heat source/sink to increase the efficiency of heating systems.

Waste heat from MBTA: A minor heat source is available here with limited potential compared to cost of implementation in Cambridge. This has not been ruled out at this time and will be looked at if a suitable opportunity is available to connect to a heat demand. Many of the waste heat sources may act as enablers and will be considered in more detail in the main scenario assessment under WP4.

Waste heat from sewers: This could be a potential supply source. We don't yet have an idea of whole contribution potential, additional data has been sought. A combined heat pump (both cooling and heating) may have potential if there is a cooling network to connect to. All such supply sources will be considered within each scenario where a heat pump is indicated for inclusion.

Heat sinks (Fresh Pond, Charles River): Similar to waste heat from sewers above. Additional analysis of site feasibility is needed.

4. SCENARIO 1 – INDIVIDUAL ELECTRIFICATION

4.1 Technologies

This scenario consists of building level electrification of thermal energy and cooling demand for all zones and building types. *Following the meeting held on April 25th to evaluate the long list of scenarios produced, it was decided that this scenario should not be progressed further, but that it is included in the WP2 report that this was considered. When comparing this scenario to Scenario's 2 it was clear that Scenario 2 is a stronger option for progression. This electrification scenario does however continue throughout most options for the supply scenario for Zone 2, low density residential.*

The only heat production technology considered as part of this scenario is a heat pump utilizing a low grade heat source, which is upgraded to building operating temperatures by use of electricity. The cooling technologies are individual chillers and air-condition facilities, also supplied by electricity.

The electricity supply will be dependent on external supply of renewable electricity through greening of New England Power Pool (NEPOOL), RECs and/or through investing in a renewable installation outside the city border. Maximum deployment of solar PV within the city boundary is assumed.

Figure 4-1 displays the overall structure of scenario 1. Electricity is supplied by the external electricity grid with production from both conventional- and renewable power stations. Electrical consumption will increase with the introduction of electrically driven heat pumps and chillers as a replacement for gas furnaces. Cambridge city can invest in wind turbines located outside the city, buy green certificates or invest in solar PV mounted on rooftops inside the city. Whilst NEPOOL is expected to increase the proportion of renewable and sustainable power generation it is not expected to achieve 100 zero carbon over the timeframe of the study. The scale of the increase in electricity demand will likely reduce the potential for achieving full de-carbonization, especially in the medium term due to limited renewable energy capacity.

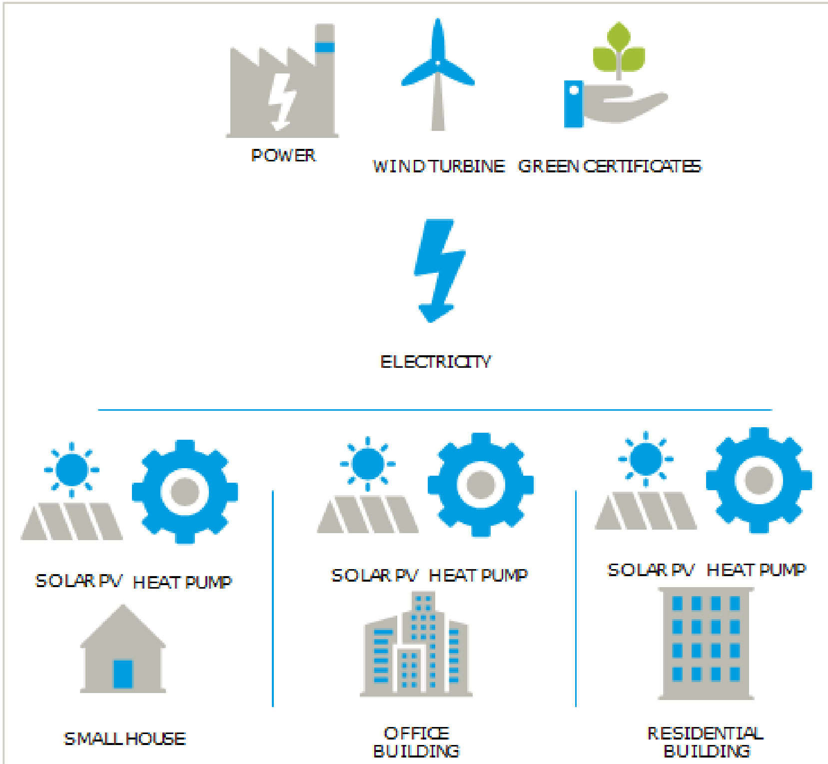

Figure 4-1: Scenario 1 Individual Electrification

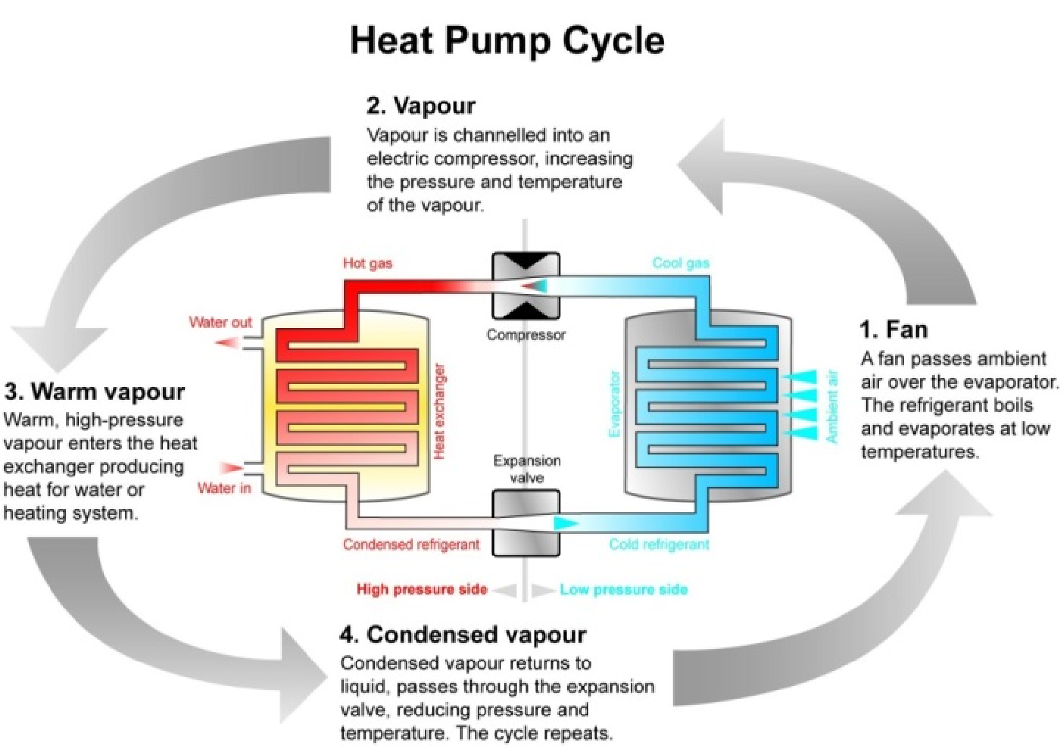

Figure 4-2: Heat Pump Cycle

Electrically driven heat pumps absorb low grade heat from a source such as the air, ground or river and upgrade it via an electrically driven vapor compression circuit to provide space heating and hot water. Figure 4-2 describes the vapor compression circuit that operates within an air source heat pump.

Where there is capacity in the ground or an available pond or river heat source, a ground / water source heat pump will be possible. Otherwise, an air source heat pump will be used. Each residential customer or property will require a heat pump with integrated controls and a domestic hot water (DHW) hot water storage cylinder, which will require an electric emersion heater, to ensure water safety standards are met. Heat pumps operate most efficiently at lower output temperatures. Therefore, in most properties, internal modification may be required, which consist of upgrading radiators, installing a new heat pump compatible hot water cylinder and increased insulation measures. Older properties may also require upgrades to the electrical installation.

For older properties which cannot benefit from increased energy efficiency measures high temperature heat pump options are available. A hot water storage tank with an electric emersion heater will also be required, to ensure water safety standards are met. Heat pumps also contain a fan unit and will thus emit some noise, so location of the equipment may need to be carefully considered. There are no chemical air emissions in normal operation.

In the case of blocks of apartments and larger non-residential units it is envisaged that they would be supplied by a centralized heat pump system which will feed individual Energy Transfer Stations (ETS). Customers will have full control over there heating and hot water via an integrated timer and programmer. Some customers that require higher temperatures, such as hospitals and Research and Development (R&D) facilities, may opt for temperature boosting using electric boilers.
The increased electrical load associated with the introduction of electrically driven heat pumps will require additional capacity or even new substations within the area to meet the increased demand. Reinforcement of the electrical grid will also be a requirement with the widespread introduction of electrically driven heat pump solutions within the area. The transformation away from natural gas will also leave the existing gas network redundant.

The consideration on whether to increase the electrification instead of a community based solution is mainly that the capital costs for the power network reinforcement are expected to be lower than laying out piping in a district heating network. The costs for the additional generation required under an electrification scenario should also be considered.

Individual heat pumps are expensive but also very efficient. The cons are that they will need supplemental heat sources (air, water, ground), which should be included in the capital costs. The investment costs for electric boilers are much lower, but the efficiency is much lower compared to heat pumps.

The viability of a heat pump solution is very much dependent on the availability of abundant low cost electricity. The price of electricity consists of different components e.g. the costs from the power exchange, transportation costs (transmission and distribution), capacity cost, any fees etc. An individual solution will most probably pay quite high prices for the electricity since a smaller heat pump will be connected at a lower voltage level with higher distribution costs. With a heat pump connected centrally it could be connected at a higher voltage level with lower distribution costs. Furthermore, storage options will be limited with individual solutions. Therefore, it will be necessary to have the heat pump in operation even during times of high electricity pricing from the power exchange if there is a demand for heat, and this can often coincide with energy supplied at the highest carbon intensity.

An electrified solution provides limited resiliency for Cambridge and exposes residents to the potential for losing both heat and power in extreme weather events. Battery storage is a very expensive solution to overcome this issue at the moment and the technology is far from achieving the economic level required to compete with power plants.

Heat pump technology on an individual building basis has limited potential for storage to take account of fluctuating electricity supply from renewable energy sources, which result in the need for demand side management on a city wide scale. For this to work, electrification of the energy system will need to be combined with a wide scale roll out of “smart” appliances. Still, the economic benefit of flexible operation from individual heat pumps is much higher for the system than for each consumer. Therefore, an incentive tariff for flexible operation is required to encourage individual consumers.[2]

4.2 Evaluation of Scenario 1

The scenario is evaluated based on the evaluation criterion described in section 1.1.

4.2.1 Energy Supply

The percentage production distribution for scenario 1 is displayed in Table 4-1.

Table 4-1: Energy Supply Scenario 1

	Heating %	Cooling %	Electric System %
Individual Heat Pump	90	40	---
Individual Electric Boiler	10	---	---
Individual Chillers	---	60	---
Solar PV	---	---	10
Electricity Grid	---	---	90

4.2.2 City Goals

The evaluation of scenario 1 is displayed in Table 4-2. The reasoning is described in bullet points.

Table 4-2: Scenario 1 Classification

Goals	Meeting the City Goals?
Clean	
Reliable	
Affordable	
Predictable	
Transparent	
Local Control	
Wealth Creating	
Innovative	
Just	

- **Clean:** Dependent on the city securing “green” electricity. However, unless the individual heat pumps are fully flexible, which several scientific projects show they are not, when considering technical constraints, the revenue from acting flexibly will be too low for the

[2] Absorption heat pumps are also an option, but not considered since they do not use excess electricity production from renewables

owners. The heat pumps can be operated in clusters responding to electricity prices. This scenario is not “clean” compared to the DH&C scenarios.

- **Reliable:** The reliability of technology is good, reliability of the electricity grid would not be sufficient unless the grid is strengthened. There would be no resiliency during power outages
- **Affordable:** Electricity prices are expected to increase in the future, even with the high efficiencies of the heat pumps, costs are still likely to be high.
- **Predictable:** Subject to the pricing of electricity though the high efficiencies of heat pumps levels this out
- **Transparent:** Up to the developer of the plant and energy network – city can exercise some control through permitting and planning
- **Local Control:** Partially – dependent on the greening of NEPOOL and investment in external renewable electricity.
- **Wealth Creating:** Not for Cambridge, yes for Eversource, the electricity supplier, and heat pump companies. Could create local maintenance jobs.
- **Innovative:** Yes as this would be the first full electrification of a city that we are aware of due to the scale.
- **Just:** Yes, in that everyone would be impacted in a similar way by grid issues.

5. SCENARIO 2 – DISTRICT ENERGY ELECTRIFICATION

5.1 Technologies

This scenario is a further development of scenario 1. Following the meeting held on April 25th to evaluate the long list of scenarios produced, it was decided to merge Scenario 2 and 3, as Scenario 2 is a more mature, fully developed, optimum version of Scenario 3.

In this scenario, the buildings in zone 1 and eventually zone 3 and zone 4 will be supplied by a district heating and cooling (DH&C) system which is electrically supplied by heat pumps, electric boilers and chillers – all with thermal storage included. The production technologies for each zone are displayed in Table 5-1.

Table 5-1: Production Technologies for Scenario 2

	Zone 1	Zone 2	Zone 3	Zone 4
DH&C system	X		X	X
Block heating		X		
Heat Pump	X		X	X
Electric Boiler	X		X	X
Chillers	X	X	X	X
Aquifer Thermal Energy Storage (ATES)	X		X	X
Thermal Storages	X		X	X
Individual Heat Pump		X		
Solar PV	X	X	X	X
Small gas boiler		X		

The city will still be dependent on external supply from the external electricity grid. The greening of New England Power Pool (NEPOOL), RECs and/or investments in renewable installations outside the city border is required. Maximum deployment of solar PV within the city boundary is assumed. Figure 5-1 display the overall structure of scenario 2. Electricity is supplied by the external electricity grid with production from both conventional- and renewable power stations. Electrical consumption will increase with the introduction of electrically driven heat pumps and chillers as a replacement for gas furnaces.

Cambridge city can invest in wind turbines located outside the city, buy green certificates or invest in solar PV mounted on rooftops inside the city. Whilst NEPOOL is expected to increase the proportion of renewable and sustainable power generation it is not expected to achieve 100 percent zero carbon over the timeframe of the study. The scale of the increase in electricity demand will likely reduce the potential for achieving full de-carbonization, especially in the medium term due to limited renewable energy capacity. The smaller buildings will still be supplied by individual heat pumps, but the larger buildings with a higher heat density will be supplied from centralized DH&C systems.

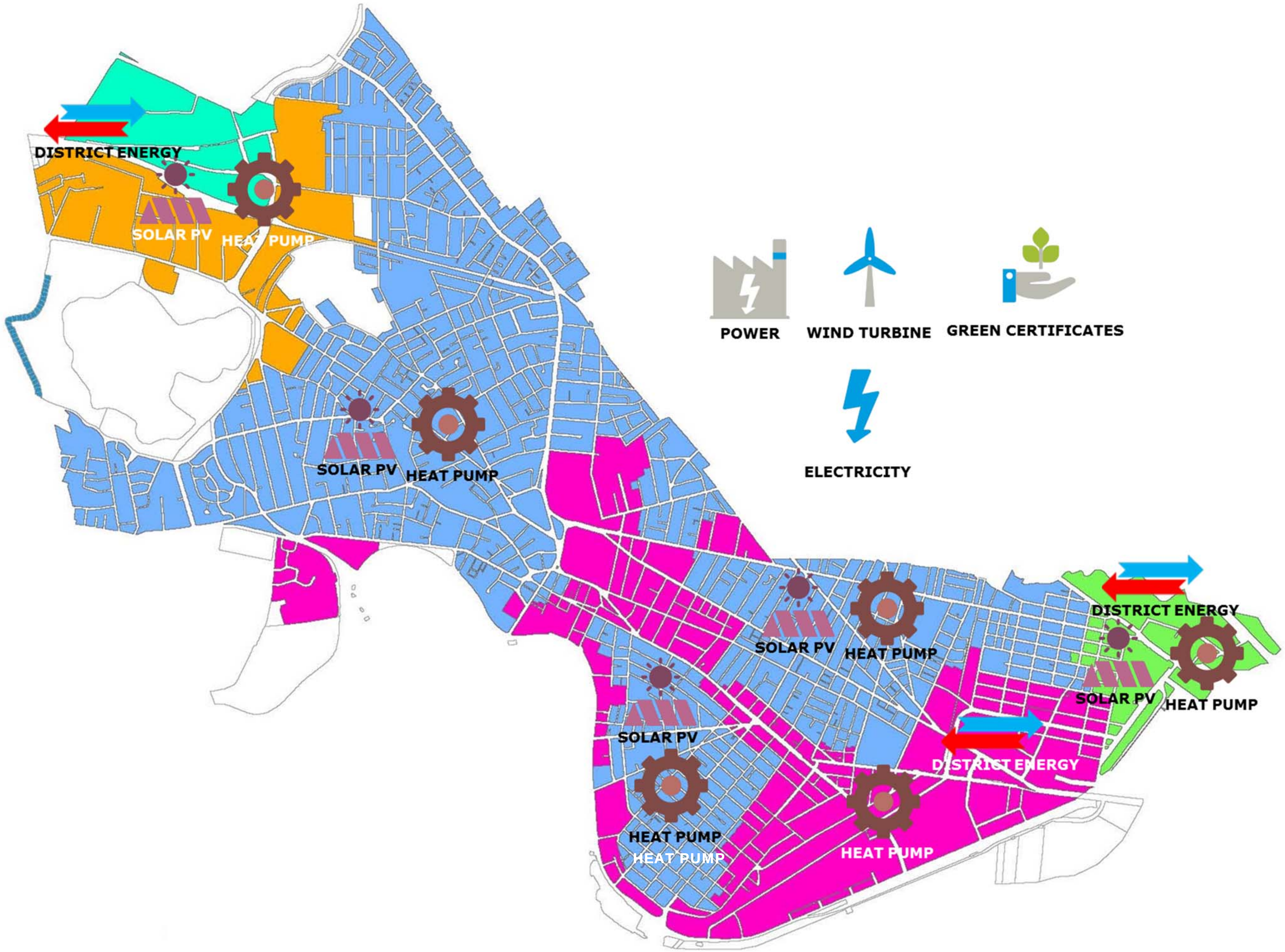

Figure 5-1 Visual representation of Scenario 2

5.2 Evaluation of Scenario 2

To evaluate this scenario further and provide capacity and scale of heat and cooling generating plant required, the zone map shown in Figure 2-2 was developed and based on the total heat demand, cooling demand and electricity demand as well as specific location of consumption at building level. Based on this mapping and resulting location demands it is possible to construct the annual heat load curve which is an important tool to enable to determine the potential production from each technology. Figure 5-2 shows the heat load curve for Zone 1 as indicated in Figure 2-2.

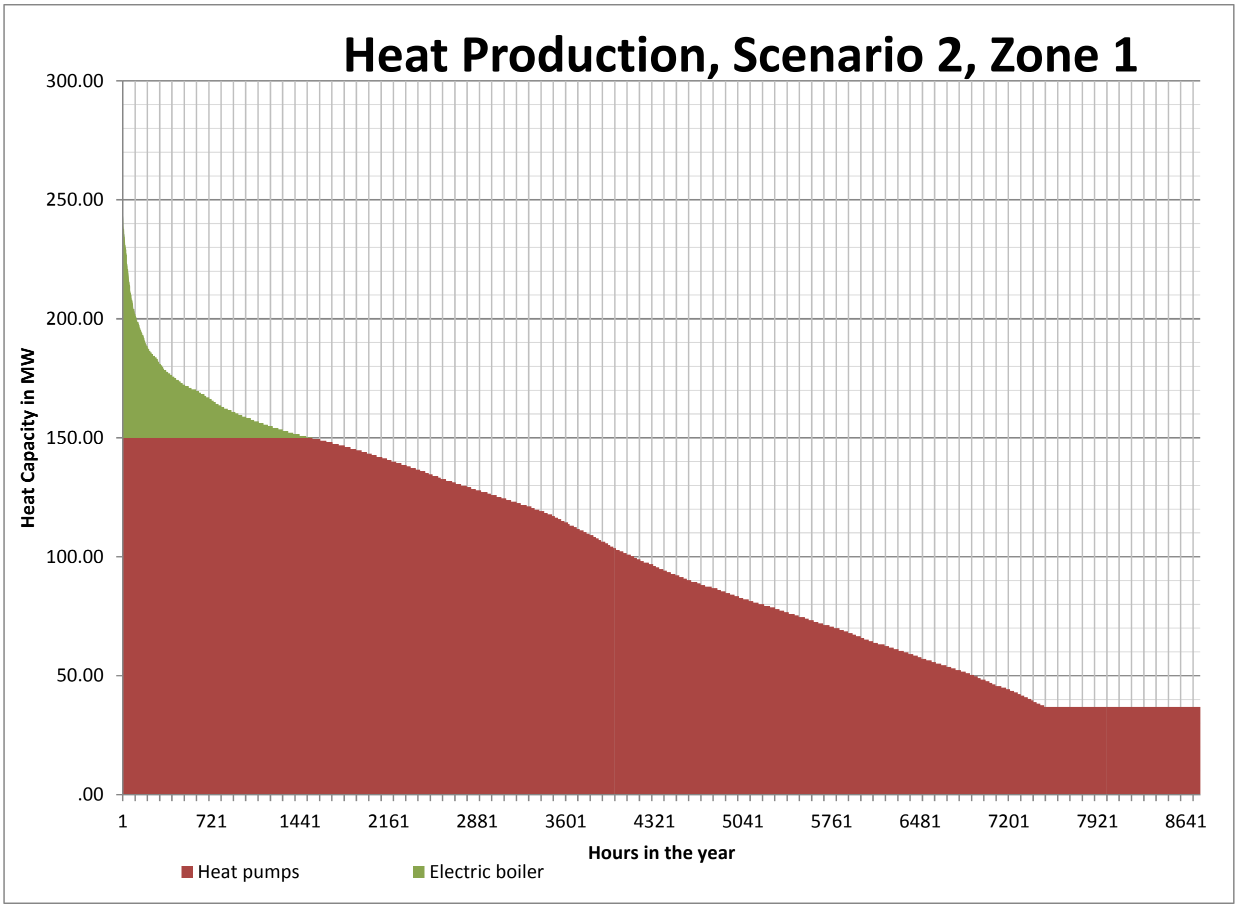

Figure 5-2 Heat curve for Scenario 2, Zone 1

For this scenario total electrification of Cambridge is assumed. In zones with viable district heating (high heat density areas) large heat pumps / chillers /electric boilers are assumed, whereas smaller units are assumed in the low density zones.

Table 5-2 below outlines the generating capacity, the plant space required and a high level cost estimate of the respective components required to supply Zone 1. It is important to note that the investments and required land space requirements are high level estimations which will be developed further should the scenario be progressed to WP4.

Table 5-2 Scenario component generation capacity, physical size and cost estimate

	Capacity	Required space (ft2)	Rough estimate ($ million)
Heat pumps	150 MW	330,000	100 - 150 $
Electric boilers	150 MW	<50,000	10 – 20 $
Back-up on oil, storage	300 MW	40,000	10 – 20 $
Pit Thermal Energy Storage (PTES)	> 260 million gallons	700,000	40 – 60 $
DH network			100 - 150 $
TTES	13,000,000 gallons	8,600	8 – 12 $
TOTAL Costs			250 – 400 $

It should be stressed that the flexibility and resiliency of this scenario is very limited. In case of failure in the electrical grid there will be no back-up technology for the production of heat. A way to address this would be to have very large emergency generators running on natural gas or oil. A way of increasing resilience would be to have oil based emergency back-up to take into account failure in the natural gas system as well. The emergency generator will most likely have very limited hours in operation per year. Therefore, the consumption of fossil fuels would be insignificant. The scenario is evaluated below based on the evaluation criterion described in section 1.1.

5.2.1 Implementation steps

- Upgrade of electricity network to support heat pumps, electric boilers and chillers (power to be supplied by a combination of external renewable energy and solar build out in Cambridge)
- District energy network pipe installation: typically laid at ~600mm below the pavement surface in trenches
- Installation of heat exchangers at each consumer connection for DHC
- Heat pump installation at consumers
- PV installation at available locations

5.2.2 Energy Supply

The percentage production distribution for scenario 2 is displayed in Table 5-3.

Table 5-3: Energy Supply Scenario 2

	Heating %	Cooling %	Electric System %
Individual Heat Pump	40	5	---
Individual Electric Boiler	2.5	---	---
Individual Chillers	---	40	---
DH&C Heat Pump	52.5	20	---
DH&C Electric Boiler	5	---	---
DH&C Chiller	---	35	---
Solar PV	---	---	10
Electricity Grid	---	---	90

5.2.3 City Goals

The evaluation of scenario 2 is displayed in Table 5-4. The reasoning is described in bullet points.

Table 5-4: Scenario 2 Classification

Goals	Meeting the City Goals?
Clean	
Reliable	
Affordable	
Predictable	
Transparent	
Local Control	
Wealth Creating	
Innovative	
Just	

- **Clean:** Dependent on the city securing "green" electricity. However, unless the individual heat pumps are fully flexible, which several scientific projects show they are not, when considering technical constraints, the revenue from acting flexibly will be too low for the owners. The heat pumps can be operated in clusters responding to electricity prices. This scenario is not "clean" compared to the DH&C scenarios.
- **Reliable:** The reliability of technology is good, reliability of the electricity grid would not be sufficient unless the grid is strengthened. There would be no resiliency during power outages
- **Affordable:** DH&C systems should only be constructed when more profitable than individual solutions and provides socio-economic benefit.
- **Predictable:** Subject to the pricing of electricity though the high efficiencies of heat pumps and thermal storages can reduce vulnerability
- **Transparent:** Joint ownership of DH&C systems by consumers can provide a transparent operation and prices through open access data. Still, the company is exposed to the electricity price fluctuations and electricity market gaming
- **Local Control:** Partially – dependent on the greening of NEPOOL and investment in external renewable electricity.
- **Wealth Creating:** Not for Cambridge, yes for Eversource, the electricity supplier, and heat pump companies. Could create local maintenance jobs.
- **Innovative:** Yes, in the sense that a DH&C network is constructed. New production units can later be added to system for reduced costs and higher flexibility
- **Just:** Yes, in that everyone would be impacted in a similar way by grid issues.

6. SCENARIO 4 – DISTRICT HEATING & COOLING SYSTEMS

6.1 Technologies

These scenarios consist of providing district heating and cooling (DH&C) to most of the city. Heat pumps, biomass plants and waste-to-energy plants are being considered for delivery of district heating. The heat pumps will also work alongside chillers to provide district cooling. Thermal storage for both heating and cooling is included.

Following further analysis of the four sub-scenarios developed under Scenario 4 and examination of the resulting heat curves, the scenarios have been reduced to two, one with Waste to Energy (WtE) included as a supply technology along with biomass, and one without WtE as part of the supply.

The heat curves show that a combined heat and power (CHP) biomass only option would be very expensive to meet peak heat demands. Therefore CHP could be supplemented by heat only biomass boilers. As a result the scenario technologies were merged to develop the most economically sensible solution for the long term based on observations made from analysis of the heat curve below. Figure 6-1 and Figure 6-2 show the heat curves for the two scenarios.

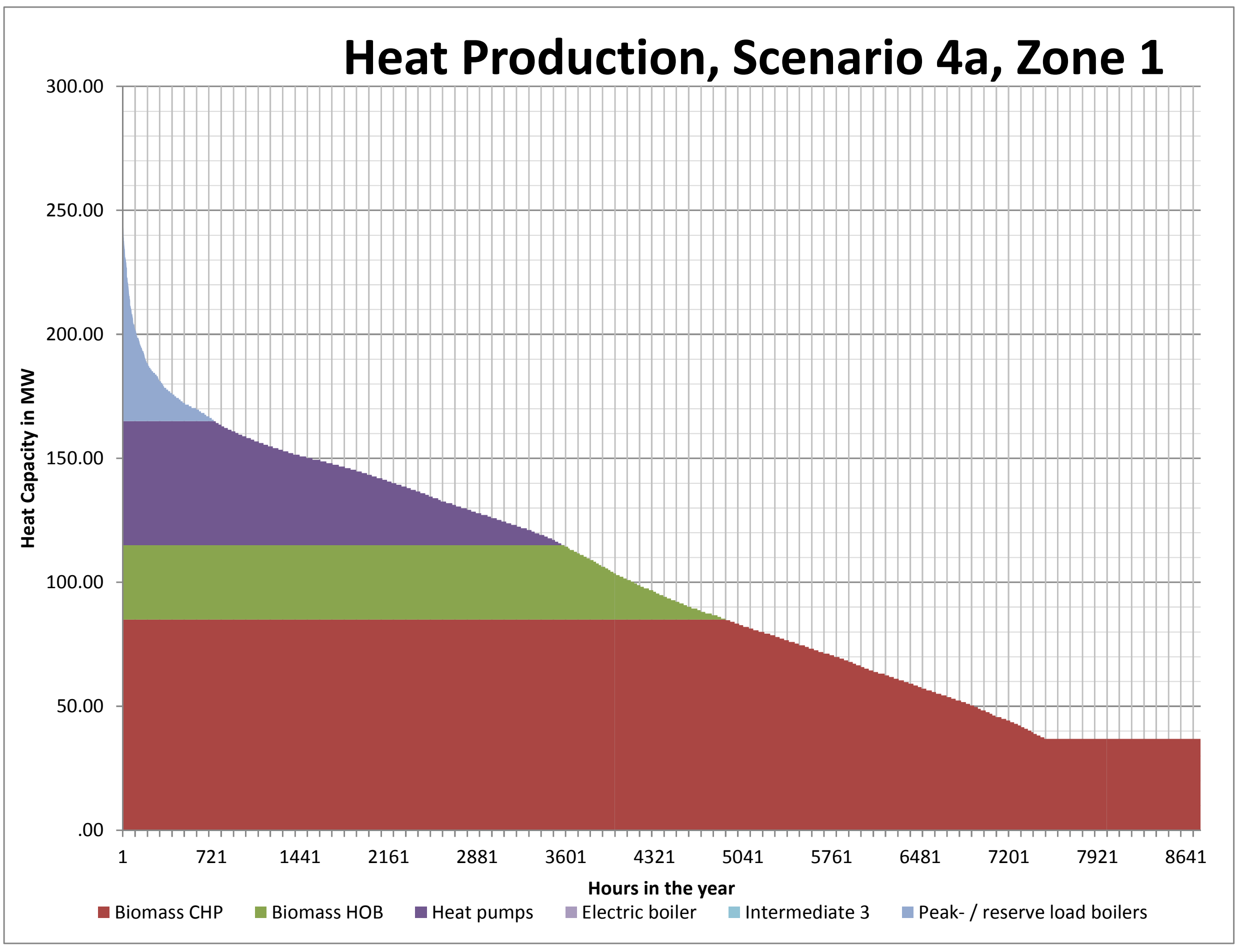

Figure 6-1 Heat Curve Scenario 4a- without WtE, Zone 1

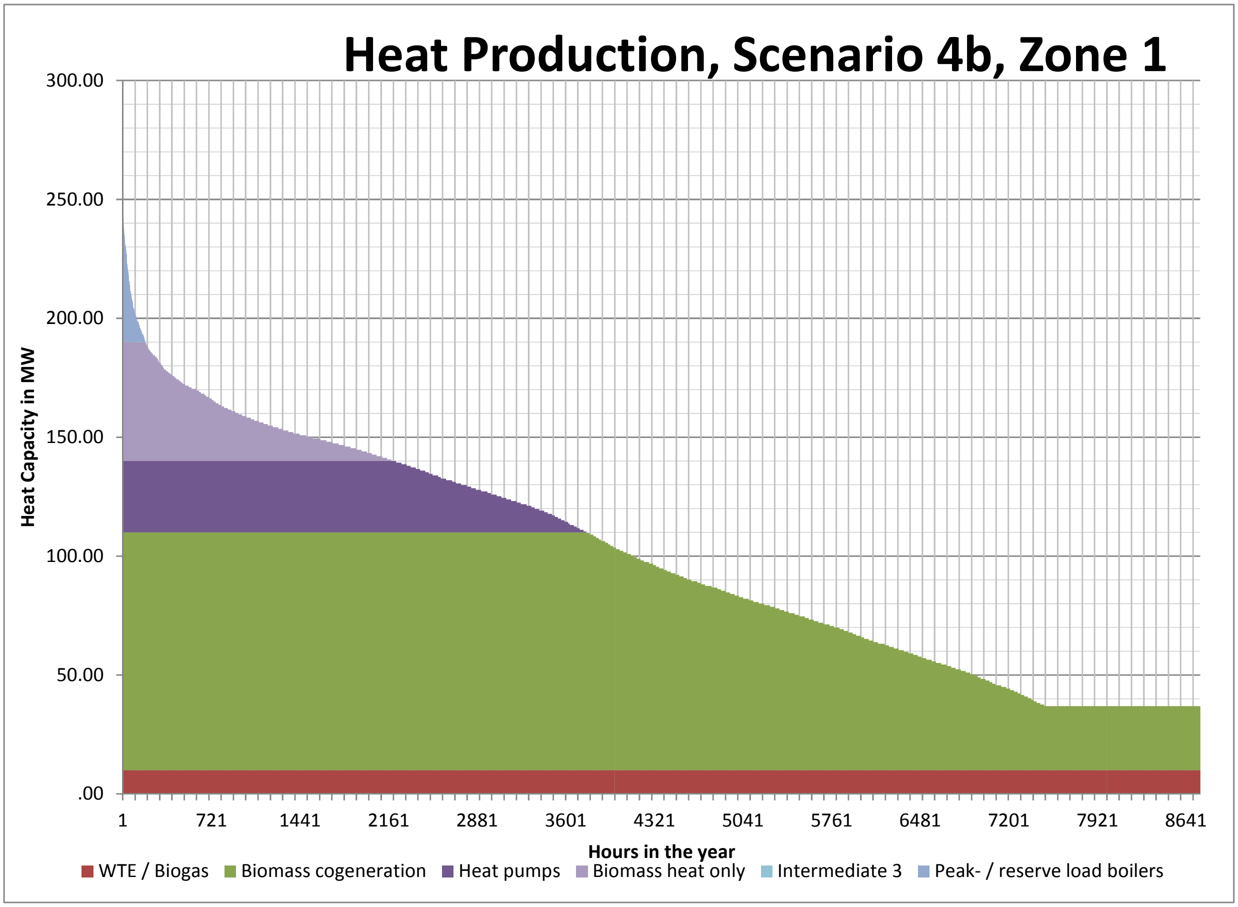

Figure 6-2 Heat Curve Scenario 4b – with WtE, Zone 1

The structure of scenario 4a is shown in Table 6-1 where the technology mix is outlined. Scenario 4b differs from Scenario 4a in a technology perspective only by the inclusion of Waste to Energy

Thermal storage will be used for both district heating and cooling scenarios. An ATES (Aquifer Thermal Energy Storage) system is also included in all scenarios to utilize the synergies between district heating and cooling systems. The electric boiler is a cheap solution for producing heat based on excess renewable electricity production.

Where heat pumps are being used in these scenarios it is assumed that they will utilize the most beneficial and available heat source for their application. This could be the Charles River, waste heat from ventilation shaft, sewers etc. the exact heat source will be determined once the project moves to WP4 stage.

Table 6-1: Production Technologies for Scenario 4a

	Zone 1	Zone 2	Zone 3	Zone 4
District heating	X		X	X
District cooling	X		X	X
Block heating		X		
Heat pumps	X		X	X
Chillers	X	X	X	X
Electric boilers	X		X	X
Biomass CHP	X		X	X
Biomass Boiler	X		X	X
Thermal storage	X		X	X
ATES	X		X	X
Individual HP		X		
Solar PV	X	X	X	X
Small gas boiler		X		

The district cooling system will in all scenarios be constructed in clusters of high cooling density supplied by heat pumps using an ATES system and chillers. Thermal storage will likely be profitable in all scenarios. The electricity consumption can be supplied as outlined under Scenario 1, supplemented by biomass and waste-to-energy plants (under scenario 4b) which will also produce electricity in a combined heat and power (CHP) production. Solar PV mounted on each building is still an option for increased local electricity production. The expansion of district heating and cooling DH&C) into the zones displayed on Figure 2-2 is divided as stated below. The scenarios are also visually represented in Figure 6-3 and Figure 6-4. Locations of infographics in the figures are only to indicate supply technologies proposed for each zone, and do not take into account existing plant and are not representative of actual locations.

- **Zone 1**: DH&C network supplied by a mix of centralized heat pumps and chillers, biomass heat only, biomass CHP or waste to energy CHP (4b) with thermal storage. Electric boilers can also serve to provide peak production in the district heating system, when renewable energy production is high and electricity prices equally low. The thermal storage can consist of storage tanks or an ATES system. It is estimated that approximately 70-80 % of the consumers in the zone can profitably be supplied by DH&C.
- **Zone 2:** All consumers are supplied by individual heat pumps or by block heating systems, when profitable. The heat- and cold density is not immediately high enough to establish a district heating network and district cooling network respectively.
- **Zone 3:** Ultimately to be supplied like zone 1 with a DH&C system.
- **Zone 4:** Ultimately to be supplied like zone 1 with a DH&C system.

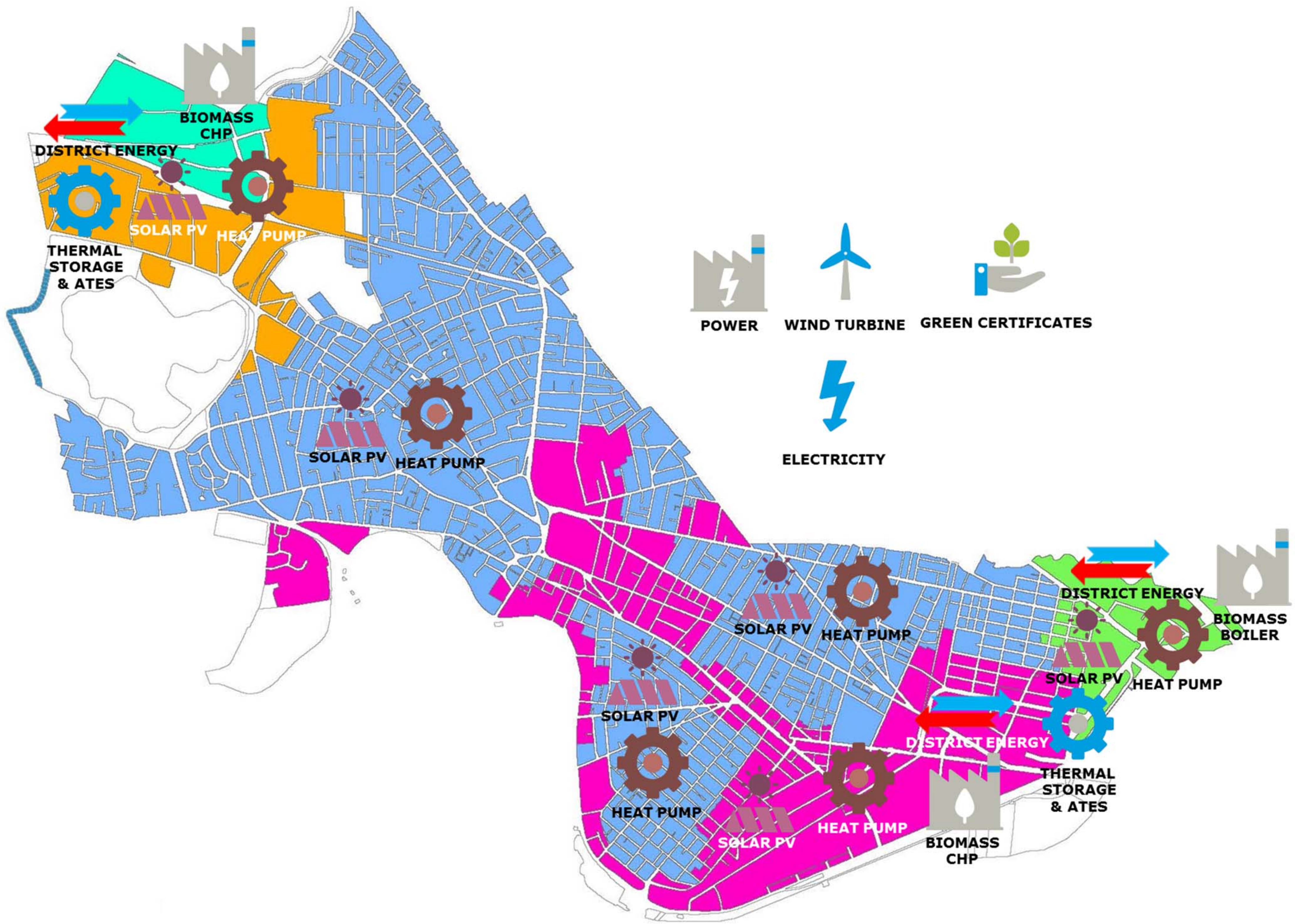

Figure 6-3 Visual representation of Scenario 4a

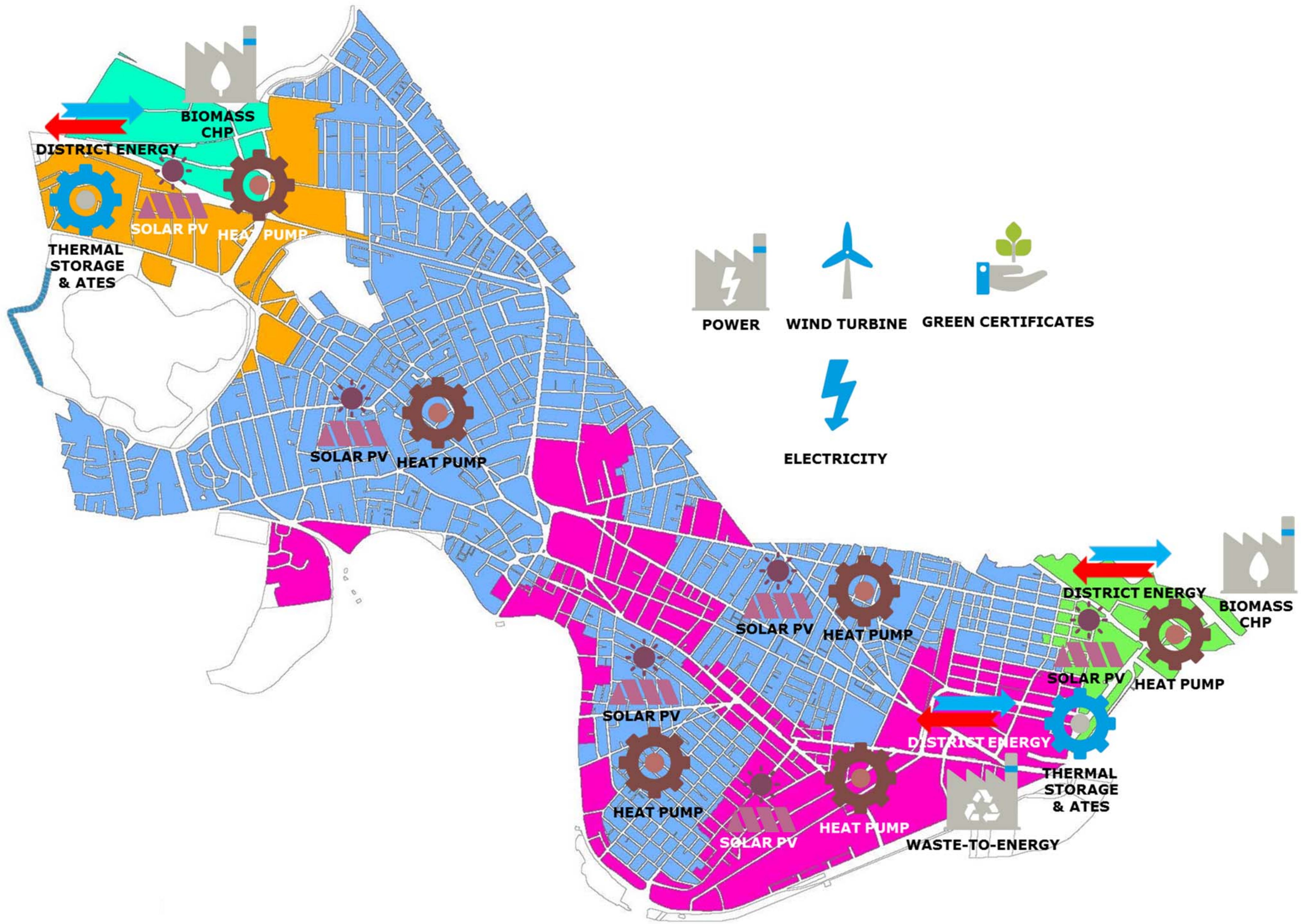

Figure 6-4 Visual representation of Scenario 4b

Figure 6-5: Master Planning a DH&C System in Cambridge

Local solar PV production mounted on rooftops is included in all scenarios. The electrical network may need strengthening and the economic costs may be too high, but the idea is not excluded. The different heat production technologies displayed on Figure 6-3 and Figure 6-4 must be compared to the division by scenario, as seen in Table 6-1. The concept of master planning the DH&C system in Cambridge City is displayed on Figure 6-5. The considered technologies for a combined DH&C system and their relation to the respective energy systems can also be seen. The considered fuels consist of biomass and fossil fuels. However, if a Waste to Energy (WtE) plant is found profitable (as included in Scenario 5b) – required waste must be available – the waste itself will be a fuel source. Keep in mind that the WtE plant can be designed to produce electricity. The relation between thermal energy storage used for both district heating and cooling is displayed in the form of tank thermal energy storage, pit energy storage and an ATES system. All plausible technologies for production of electricity, district heating and district cooling are displayed. One can with certainty argue that wind turbines are not relevant inside Cambridge City. However, wind turbines can be located outside the city producing electricity to the electricity grid, which can possibly be reimbursed in the energy accounts of the city. Each time a DH&C system is proposed in any scenario, the user can return to Figure 6-5 to investigate the possible production units and their system links.

6.2 Evaluation of Scenario 4

Each underlying scenarios are evaluated based on the evaluation criterion described in section 1.1.

Evaluation of Scenario 4a

Table 6-2 below outlines the generating capacity, the plant space required and a high level cost estimate of the respective components required for Zone 1 supply. It is important to note that the investments and required land space requirements are high level estimations which will be developed further should the scenario be progressed to WP4.

Table 6-2 Scenario component generation capacity, physical size and cost estimate

	Capacity	Required space (ft2)	Rough estimate ($ million)
Biomass CHP	85 MW heat	500,000	100 - 150 $
Heat pumps	50 MW heat	150,000	30 - 50 $
Biomass heat only	30 MW heat	50,000	10 – 20 $
Heat only boilers - oil + storage	300 MW	40,000	10 - 20 $
DH network	NA	NA	100 - 150 $
Tank Thermal Energy Storage (TTES)	50,000 m3	800	8 – 12 $
TOTAL Costs	-	-	250 – 400 $

Based on the load curve developed for Zone 1, the initial sizing of Biomass CHP estimated will supply approx. 250,000MWh, which is 20% of the total electricity demand of the City per year.

6.2.1 Implementation steps

- District energy network pipe installation: typically laid at ~600mm below the pavement surface in trenches
- Installation of heat exchangers at each consumer connection for DHC
- Construction of biomass CHP, biomass plants
- Potential reconstruction of waterfront port to enable the supply of biomass
- Heat pump installation at consumers
- PV installation at available locations

6.2.2 Energy Supply

The percentage production distribution for scenario 4a is displayed in Table 6-3.

Table 6-3: Energy Supply Scenario 4a

	Heating %	Cooling %	Electric System %
Biomass CHP	35	---	25
Biomass	15		
Heat Pump	15	5	---
Individual Heat Pump	30	---	---
Electric Boiler	5	---	---
Chillers	---	95	---
Solar PV	---	---	10
Electricity Grid	---	---	65

6.2.3 City Goals

The evaluation of scenario 4a is displayed in Table 6-4. The reasoning is described in bullet points.

Table 6-4: Scenario 4a classification

Goals	Meeting the City Goals?
Clean	
Reliable	
Affordable	
Predictable	
Transparent	
Local Control	
Wealth Creating	
Innovative	
Just	

- **Clean:** The system will reduce the carbon emission and toxic pollutants, assuming biomass is carbon neutral and by utilizing best available technology (BAT) for energy production. Furthermore, the use of primary fuel will be reduced. Still, public regulation to ensure flue gas treatment and energy efficiency is required.
- **Reliable:** The planning of the energy system can be undertaken to ensure a required system resilience (security of supply). Installing more peak capacity into a DH&C system is a small expenditure compared to the total expenditures. Peaking units can be placed locally at hospitals and schools. The delivery of power can also be strengthened by a local biomass CHP plant.
- **Affordable:** DH&C systems should only be constructed when more profitable than individual solutions and provides socio-economic benefit.
- **Predictable:** DH&C systems have the clear advantage compared to individual heating that it is more robust against changes in fuel prices. The DH&C system can switch between several production units or build new production units to hedge against high fuel prices. The rate volatility is therefore expected to decrease.
- **Transparent:** The cost of energy for consumers will presumably still be complex. However, local (joint) ownership of the energy companies can increase transparency and reduce the complexity by public access to data.
- **Local Control:** Only by enforcing local (joint) ownership of the energy companies can local control be increased. This is a keystone in renewable energy systems.
- **Wealth Creating:** The wealth creation will stem from local ownership and knowledge increase. The two universities can benefit from research in renewable energy systems. However, most likely, it will be expensive to have higher ambitions than the rest of the state and USA in general.
- **Innovative:** Enhancing local influence by including local universities, companies and citizens, innovative ideas will emerge. The city can work as example for other cities.
- **Just:** Yes, but local ownership and influence are required. Furthermore, many people owning one large company tends to be more robust than each person owning their own small heat/cold production facility.

Evaluation of Scenario 4b

Table 6-5 below outlines the generating capacity, the plant space required and a high level cost estimate of the respective components required for Zone 1 supply. It is important to note that the investments and required land space requirements are high level estimations which will be developed further should the scenario be progressed to WP4.

For this scenario, the quantity of waste being generated in the City was assessed to determine the size of facility that could be supported in the City. A 10MW heat generating (2MW electricity generating, equivalent to 1% of total electricity demand of City) Waste to Energy facility would be fueled by 50,000 tons of waste, which is over twice the current trash tonnage managed by the City.

Table 6-5 Scenario component generation capacity, physical size and cost estimate

	Capacity	Required space (ft2)	Rough estimate ($ million)
Waste to energy, CHP	10 MW	500,000	40 - 60 $
Biomass CHP	85 MW heat	500,000	100 - 150 $
Heat pumps	50 MW heat	150,000	30 - 50 $
Biomass heat only	30 MW heat	50,000	10 – 20 $
Heat only boilers - oil + storage	300 MW	40,000	10 - 20 $
DH network			M 100 - 150 $
Tank Thermal Energy Storage (TTES)	50,000 m3	800	M 8 – 12 $
TOTAL Costs			M 250 – 400 $

6.2.4 Implementation steps

- District energy network pipe installation: typically laid at ~600mm below the pavement surface in trenches
- Installation of heat exchangers at each consumer connection for DHC
- Construction of biomass CHP, biomass plants
- Potential reconstruction of waterfront port to enable the supply of biomass
- Construction of waste to energy facility
- Configure waste collection system/policy to drive waste towards WtE plant in Cambridge
- Heat pump installation at consumers
- PV installation at available locations

6.2.5 Energy Supply

The percentage production distribution for scenario 4b is displayed in Table 6-6.

Table 6-6: Energy Supply Scenario 4b

	Heating %	Cooling %	Electric System %
WtE	8	---	2
Biomass, Biomass CHP	42		8
Heat Pump	15	5	---
Individual Heat Pump	30	---	---
Electric Boiler	5	---	---
Chillers	---	40	---
Solar PV	---	---	10
Electricity Grid	---	---	80

6.2.6 City Goals

The evaluation of scenario 4b is displayed in Table 6-7. The reasoning is described in bullet points.

Table 6-7: Scenario 4b Classification

Goals	Meeting the City Goals?
Clean	
Reliable	
Affordable	
Predictable	
Transparent	
Local Control	
Wealth Creating	
Innovative	
Just	

- **Clean:** The WtE technology must be treated with care due to toxic pollutants. However, if treated correctly, the technology poses no highly environmental harmful pollutants. The fossil carbon contents in the waste will emit carbon dioxide when burned.
- **Reliable:** Same as 4a
- **Affordable:** Same as 4a
- **Predictable:** Same as 4a
- **Transparent:** Same as 4a
- **Local Control:** Same as 4a
- **Wealth Creating:** Same as 4a
- **Innovative:** Same as 4a
- **Just:** Same as 4a

7. SCENARIO 5 – HYDROGEN CITY

7.1 Technologies

This scenario consists of a restructuring of Cambridge to be a hydrogen city. The main benefit of using hydrogen is that it allows conversion of renewable energy into a vector that allows large scale storage with relatively high energy density. Hydrogen is a flexible fuel and can be converted back into electricity, heat and also used as a renewable, low emission, transport fuel. Hydrogen fuel also offers the potential to be transported in existing gas networks (subject to compliance and appropriate amendment to regulations) and also be compressed for transport in trailers.

It must be stated that some of the technologies required are relatively immature and still in a commercialization phase. Furthermore, the conversion of electricity to hydrogen and back to electricity has a significant loss of energy. The solution will require significant expense, but remove all emissions. Two scenarios, 5a and 5b are described within this scenario.

7.1.1 Scenario 5a

The principle of the Scenario 5a is shown in Table 7-3 and Figure 7-3. Solar PV and wind turbines located outside the city produce hydrogen through an electrolyzer, which is converted back to electricity by a fuel cell located in the city to supply the electricity network and DH&C production facilities as seen in Table 7-1.

Table 7-1: Production Technologies for Scenario 5a

	Zone 1	Zone 2	Zone 3	Zone 4
District heating	X		X	X
District cooling	X		X	X
Block heating		X		
Fuel Cell Power Plant	X		X	X
Solar PV	X	X	X	X
Heat Pump	X		X	X
Electric Boiler	X		X	X
Individual Heat Pump		X		
Chillers	X	X	X	X

The basis of this scenario is the ability to support the deployment of large scale renewable energy technologies within and external to Cambridge and to smooth imbalanced profiles of supply and demand through hydrogen storage. These technologies do not always produce their energy at required times and so often the full potential of these technologies cannot be realized. This can be minimized by using the excess electricity to produce hydrogen when the electricity demand is low, which can be stored and later converted to usable energy via a fuel cell to provide heat and electricity or transport.

The hydrogen would then be transported (in the gas network or by tanker) to a fuel cell location where both heat and electricity would be produced and supplied to a district energy network with power exported to NEPOOL.

The hydrogen production, compression and daily storage could be located in Cambridge. Large scale seasonal storage could be located external to the City with hydrogen stored in caverns (for example former salt mines have been suggested - further research is needed to ascertain existence of such mines in the locality of Cambridge) or in above ground tanks.

The proposal works in conjunction with district heating solutions previously discussed in Scenario 4. This would be supplied by a combination of fuel cells and heat pumps. The areas where district heating is not deemed to be viable (low density heat demand areas such as Zone 2) are assumed to be supplied by individual heat pumps (this is the significant difference between scenario 5a and 5b).

The daily production of the electrolysis plant would need to be of the order of 35 tons of hydrogen per day. The fuel cell plant could be located within the city boundary for resiliency purposes, the indicative capacity of the fuel cell could be 185 MW.

The remaining heat demand would be made up from large scale heat pump technology utilizing the most appropriate energy sources, and using renewable energy produced external to the city in addition to the full Solar PV roll out.

In this scenario chillers are utilized as the primary cooling supply in all scenarios.
Figure 7-2 below shows the concept for this Scenario in flow chart format. The blue line represents electricity, the red line represents district energy and the green line represents hydrogen.

Hydrogen electrolysis and stationary fuel cell technology are still developing at the scale that is required for the transformation of the city of Cambridge. Costs for the entire system are very high and are uncompetitive with other generation technologies at the moment. While some smaller applications have been successful under specific circumstances in other areas, these have been at a much smaller scale and have had a readily available hydrogen source or other enabling factors.

For context the current global fuel cell capacity installed in 2016 was 262MW[3], the application proposed in Cambridge the required capacity would be just under 200 MW. Sizing is based on the hydrogen system being utilized as a means to store renewable energy such as wind and solar power.

Plans for the largest electrolysis plant in the world have just been given the go ahead for a facility to be constructed in Linz, France[4]. This will be a 60 MW facility and thus just over a quarter of the size required for Cambridge. The proposed plant will be based on the same technology proposed here.

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[3] https://www.navigantresearch.com/research/stationary-fuel-cells

[4] https://www.gasworld.com/areva-h2gen-unveils-electrolysis-plant-concept/2012679.article

Figure 7-1: Example of Areva Plant 60 MW Scale (image source Areva H2 Gen)

Similar to battery technology fuel cell technology is expected to develop rapidly in the near future, however this rapid development and subsequent lowering of costs has been expected for some time now and is yet to materialize[5].

2025 is referenced in some quarters as the expected date by when fuel cell technology will have become more established[3]. There is however no consensus on how the technology and market will develop.

7.1.2 Implementation steps

- Investment in hydrogen production, compression, storage and distribution
- Investment in large scale fuel cells
- Investment in large scale heat pump
- Upgrade of electricity network to support heat pumps (power to be supplied by a combination of the fuel cell, external renewable energy and solar build out in Cambridge)
- District energy network pipe installation: typically laid at ~600mm below the pavement surface in trenches
- Installation of heat exchangers at each consumer connection for DHC

[5] https://www.greentechmedia.com/articles/read/Fuel-Cells-2016-Within-Striking-Distance-of-Profitability

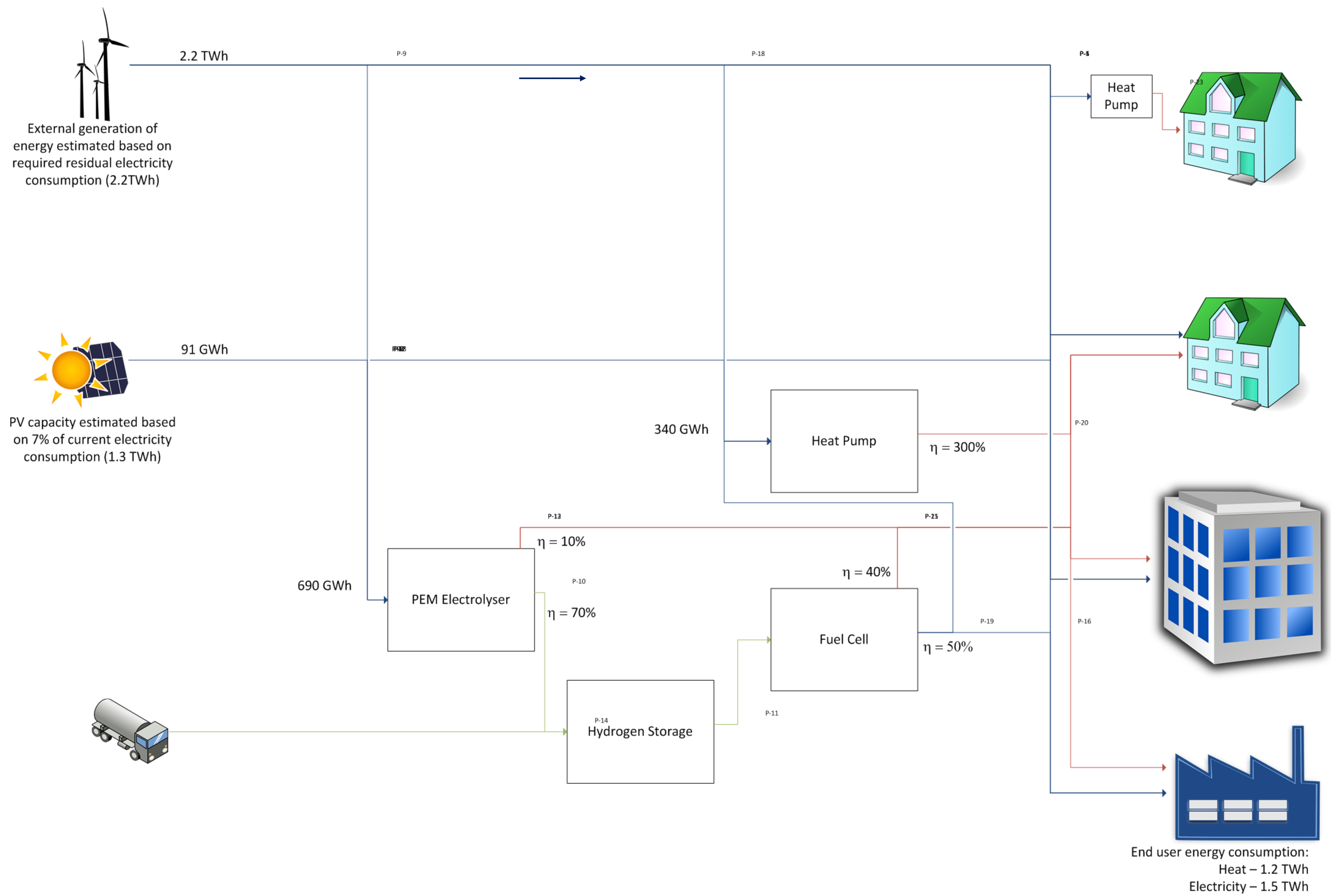

Figure 7-2 Key components included within Scenario 5a

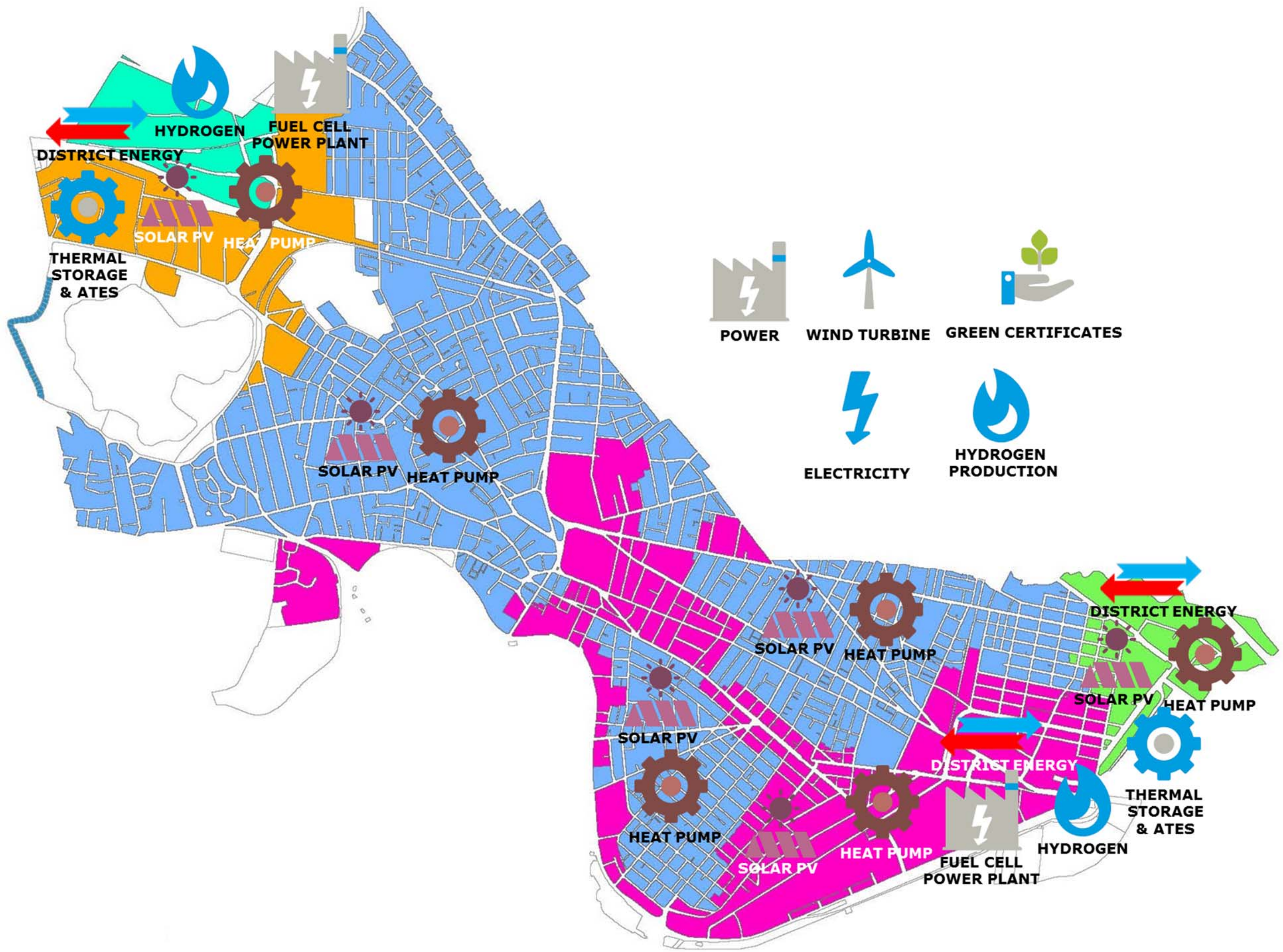

Figure 7-3 Visual representation of Scenario 5a

7.1.3 Scenario 5b

Scenario 5b is a variation of 5a whereby instead of properties in non-district heating areas (such as Zone 2) being supplied by heat pumps, individual buildings have hydrogen boilers or fuel cells installed as direct replacement for existing gas boilers. This is outlined in Figure 7-4 and Figure 7-5.

Hydrogen is still utilized as a means of balancing electricity production from renewable energy sources. District heating remains in this scenario for the high demand zones, however it may be considered appropriate to exclude district heating and fully convert to hydrogen across the gas network.

Hydrogen distribution in the gas network could be phased by blending in early years with natural gas and over time changing the ratio of gas in the network. Regulatory barriers would need to be overcome to allow hydrogen to be conveyed in gas networks and to ensure safety and licensing concerns are properly addressed. The effects of this on network capacity, network materials, energy losses and customer interface and boiler suitability would require greater work. There has been research on this approach in a number of European Countries.

Figure 7-4 below shows the concept for this Scenario in flow chart format. The blue line represents electricity, the red line represents district energy and the green line represents hydrogen.

The size and cost of hydrogen production, compression and storage would remain the same in this scenario, however additional costs would be incurred by the increased hydrogen network and the scale of fuel cell installation if DHC is not included.

7.1.4 Implementation steps

- Investment in hydrogen production, compression, storage and distribution
- District energy network pipe installation: typically laid at ~600mm below the pavement surface in trenches
- Installation of heat exchangers at each consumer connection for DHC
- Phased investment in building or block hydrogen boilers and fuel cells
- Investment in building or block scale fuel cells, in some cases hydrogen boilers may be appropriate
- Investment in building scale heat pumps and chillers for some zones
- Upgrade of electricity network to support heat pumps and fuel cells
- Hydrogen network pipe installation some potential to re-use gas network but this only applies for plastic piping and all fittings would likely need replacing.

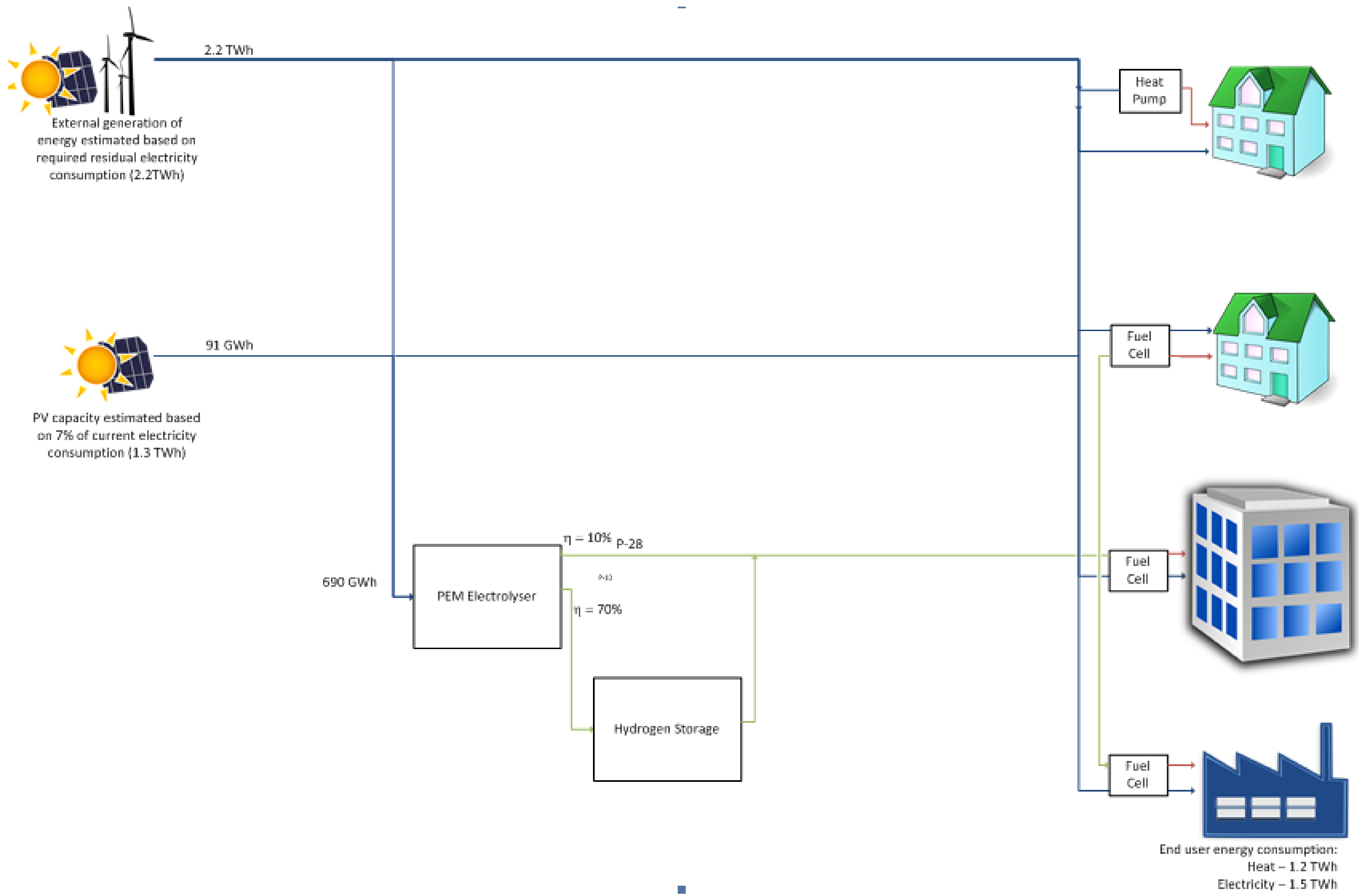

Figure 7-4 Scenario 5b variation of Hydrogen option with building level fuel cells

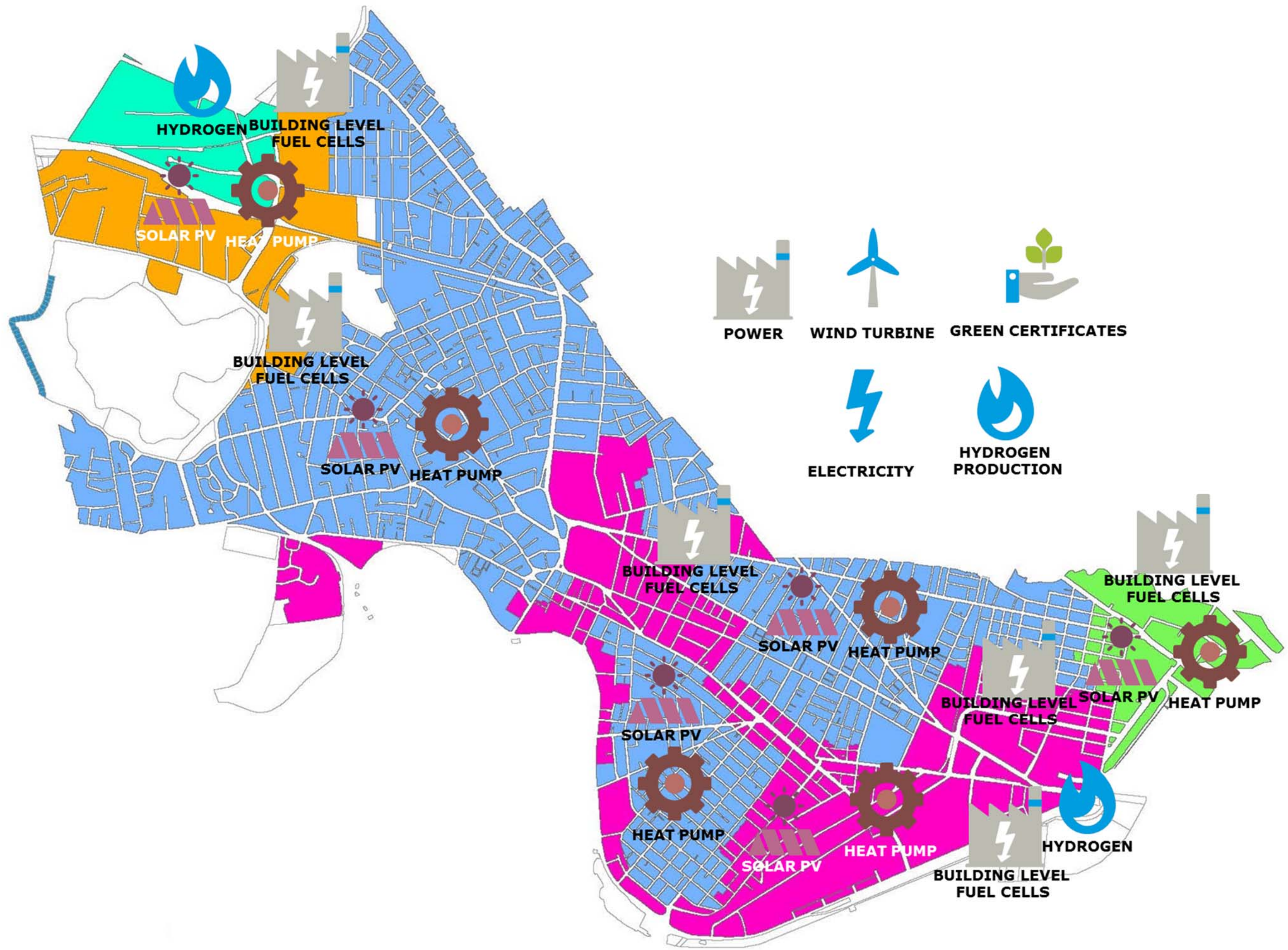

Figure 7-5 Visual representation of Scenario 5b

7.2 Evaluation of Scenario 5

Table 7-2 below outlines an estimate of the costs required to supply enough capacity to supply the City. This is primarily to indicate the current cost levels of this technology, which is one of the significant barriers to its viability currently. Due to the development status of this technology, it is difficult to estimate at this point the physical scale of the plant required to supply the City of Cambridge. Figure 7-1 above does however give an indication of the scale of plant required for a 60MW facility when comparing to the Heavy Goods Vehicle truck exiting the facility. Based on a 200MW demand, the City would need at least three such scale facilities to meet demand.

As stated above, the size and cost of hydrogen production, compression and storage would remain the same for both scenarios. In low density areas (Zone 2), heat pumps would be required for 5a, and hydrogen boilers for 5b. These costs have not been included below. If a DHC network is not included in 5b, this cost could be removed below, but additional capital would be required to upgrade the whole existing gas network for hydrogen supply.

Table 7-2 Hydrogen component requirement costs and capacities

Element	Approximate capital cost ($ million)	Notes
Water electrolysis plant	$71	Indicative cost based on a cost per kg H2 of $900/kW.
Hydrogen compressor	$4.7	Budgetary capex figure for plant needed to compress hydrogen into the buffer store
Hydrogen storage	$11.4	Buffer based on store size for 8.7t H_2. Full plant capacity for 6 hours.
Stationary fuel cell	$1,104	Approx. capex $6,000/kW[6], fuel cell for regeneration of electricity from hydrogen
Centralized Heat Pump	$150	Heat pump capacity of >250 MW output
District heating network	$100– $150	As other scenarios
Total	**$1,500**	

7.2.1 Energy Supply

The percentage production distribution for Scenario 5a and 5b is displayed in Table 7-3.

Table 7-3: Energy Supply

	Heating %	Cooling %	Electric System %
Fuel Cell Power Plant/Local Fuel Cells	10	---	19
Heat Pump	30	50	---
Individual Heat Pump	35	20	---
Electric Boiler	15	---	---
Solar PV	---	---	10
Chillers	---	30	---
External Renewable Energy source			71%

[6] https://www.hydrogen.energy.gov/pdfs/progress12/v_a_3_james_2012.pdf

7.2.2 City Goals

The evaluation of scenario 5 is displayed in Table 7-4. The reasoning is described in bullet points.

Table 7-4: Scenario 5 Classification

Goals	Meeting the City Goals? Scenario 5a	Meeting the City Goals? Scenario 5b
Clean		
Reliable		
Affordable		
Predictable		
Transparent		
Local Control		
Wealth Creating		
Innovative		
Just		

- **Clean:** The system will reduce the carbon emissions and toxic pollutants to almost zero, assuming hydrogen is produced using RE sources.
- **Reliable:** The planning of the energy system can be undertaken to ensure a wanted resilience (security of supply). The task will only be to install sufficient capacity of each technology to meet the supply. A large hydrogen storage facility and a large thermal storage facility are required.
- **Affordable:** The entire system will be extremely expensive to both invest in and operate, due to high energy losses.
- **Predictable:** The system will be robust against variations in fuel prices, as it is self-sufficient. However, any longer outages on facilities will lead to production on alternative building and block level production units.
- **Transparent:** The cost of energy for consumers will presumably still be complex. However, local (joint) ownership of the energy companies can increase transparency and reduce the complexity by public access to data.
- **Local Control:** Yes, but joint ownership is required.
- **Wealth Creating:** The two universities can benefit from research in renewable energy systems. For Scenario 5b there would be additional local job creation for installation and ongoing O&M of
- **Innovative:** Enhancing local influence by including local universities, companies and citizens, innovative ideas will emerge. The city can work as example for other cities.
- **Just:** Yes, but local ownership and influence are required. Furthermore, many people owning one large company tends to be more robust than each person owning their own small heat/cold production facility.

APPENDIX 1
SCENARIO SCORING TEMPLATE

Assessment Criteria	SC1 – Electrification (Not to be scored as eliminated)	SC2 – Electrification with Centralised DHC	SC4a DHC with WtE / AD	SC4b DHC with bio CHP & bio	SC5a H City with heat pumps	SC5b H City with hydrogen boilers
Clean						
Reliable						
Affordable						
SUM						
Predictable						
Transparent						
Local control						
Wealth creating						
Innovative						
Just						
SUM						
TOTAL						

Notes:
Following review of each scenario, please score the scenarios under each of the Assessment Criteria listed from 1-5, one being a low score, 5 being high. The assessment criteria are based on the City goals[7] and are defined as below.

- **Clean**: Reduce carbon emissions and toxic pollutants created by the system.
- **Reliable**: Minimize system downtime from outages and ensure high quality of power delivered.
- **Affordable**: Keep rates as low as possible and maintain competitiveness.
- **Predictable**: Minimize rate volatility.
- **Transparent**: Consumers can understand their power costs and what drives changes in costs.
- **Local Control**: Give residents greater control over their energy resources and energy choices.
- **Wealth Creating**: Keep more energy revenue in the local economy instead of exporting it to outside suppliers — to help drive local economic development, create new businesses and jobs.

[7] In accordance with the RFP and the Carbon Neutral Cities Alliance

- **Innovative**: The system spawns innovation, intellectual property creation, and entrepreneurship.
- **Just**: The system promotes “energy equity,” protecting vulnerable populations from undue hardship, and promotes energy literacy

APPENDIX 2

WP 2 DECISION GATE MEETING MINUTES 05.16.2017

RAMBOLL

ENERGY

MINUTES OF MEETING

Project	**Low Carbon Energy Supply Strategy for Cambridge**
Subject	**Decision Gate Meeting WP2**
Date	**05/16/2017**
Location	**City of Cambridge**
Taken by	**Mairead Kennedy, Ramboll**
Participants	**Susanne Rasmussen, City of Cambridge; Seth Federspiel, City of Cambridge; Bronwyn Cooke, City of Cambridge; Meghan Shaw, City of Cambridge; Ellen Katz, DPW, Cambridge; Isidore McCormack, Ramboll; John Flørning, Ramboll; Daniel Kelley, Ramboll.**

Agenda

1. **AC committee meeting review and discussion**
2. **Scenario Assessment Summary WP2**
3. **Decision Taken on Scenarios to be taken forward to WP4**

Date 05/16/2017

Ramboll
Hannemanns Allé 53
DK-2300 Copenhagen S
Denmark

T +45 5161 1000
F +45 5161 1001
www.ramboll.com

1. AC committee meeting review and discussion

Following the AC committee meeting a discussion was held on the outcome to finalise the scenarios for further progression. The discussion began with a review of the goals of the City of Cambridge and focused on the relevance of these goals in assessing projects, as some goals are considered to be subjective rather than objective key performance indicators suitable for project assessment.

Through extensive discussion the goals that the team felt could be best utilized as a means of quantitative assessment were the “Clean” and “Affordable” goals.

Clean can be measured in terms of GHG emissions
Affordable can be measured in terms of capital costs, ongoing cost, net present value and internal rate of return amongst others.

Guidance on the exact criteria measurement criteria is needed from Cambridge.

This does not mean that other goals will not be considered; rather that their assessment shall be in narrative, qualitative form providing valuable information for the city to consider in selecting preferred solutions.

Rambøll Danmark A/S
DK reg.no. 35128417

Member of FRI

2. Scenario assessment summary WP2

Scenario 2a

It was felt that the concentration on resiliency had been given too much weight in the electrification scenario. Other options for mitigating the impact of grid downtime such as emergency shelter areas could address this.

In light of this the team felt that it would be beneficial to take another look at Scenario 1 – full electrification at a building level in addition to Scenario 2a.

Scenario 5a and 5b

Further consideration of hydrogen at this scale was ruled out as the technology is not at an advanced enough commercial scale to be viable at the moment. The opportunity for hydrogen was identified as its ability to store excess renewable electricity generation and thus increase overall penetration and utilization of renewable electricity into the energy mix. Hydrogen will continue to be considered as a future opportunity only and shall be dealt with in the narrative through future-proofing and safeguarding considerations.

Scenario 4a and 4b

The steering group felt that the similarities of Scenario 4a and 4b were such that these should be considered variations of a single opportunity and progressed to WP4. Special consideration will be given to emissions issues, plant locations and the impact that this would have on Cambridge. Transportation of fuel and the available supply chain will be further considered.

3. Decision taken on scenarios to be brought forward to WP4

1. Scenario 1 – Full electrification at a building level
2. Scenario 2 – Electrification with centralized electrical DHC generation and distribution
3. Scenario 4 - District energy utilizing either biomass or waste to energy with some heat pumps working off low grade heat sources.

APPENDIX 3

LCESS SCENARIO SELECTION MEETING 1 APRIL 25TH

RAMBOLL

ENERGY

MINUTES OF MEETING

Project	**LCESS**
Subject	**WP2 Scenario Review**
Date	**04/25/2017**
Location	**Lync**
Taken by	**Isidore McCormack**
Participants	**Susanne Rasmussen, Seth Federspiel, Ellen Katz, Owen O'Riordan, Tom Grande, Steve Lenkauskas (City of Cambridge), John Flørning, Mairead Kennedy (Ramboll)**
Next meeting	**05/17/2017**

Agenda

1. **Introduction**
2. **Outcome**
3. **Scenario Elaboration Required**
4. **Information to be shared**
5. **Information shared during the meeting**

1. Introduction

This meeting is part of the Work Package 2 (WP2) Process as outlined in the memo issued on March 3rd. The objective of this meeting was to meet to score the scenarios together to focus them into a short list and receive feedback on the concepts put forward for further elaboration.

Initially the scenarios were presented and questions asked and answered throughout on the technologies and approaches involved. This was to ensure a full understanding of the scenarios proposed, and to gain an understanding of the direction in which more detailed scenario development should progress.

Some issues were raised for discussion as to why they were not addressed specifically in the Scenario Long List report R02. These are below. In general the issue is that these were not outlined in detail in the report, however they were not excluded from consideration. Many of the waste heat sources may act as enablers and will be considered in more detail in the main scenario assessment under WP4.

<u>Waste heat from MBTA:</u> Minor heat source available with limited potential compared to cost of implementation in Cambridge. This has not been ruled out at this time and would be looked at if a suitable opportunity is available under Scenario 2.

<u>Waste heat from sewers:</u> Could be a potential supply source. Don't yet have an idea of whole contribution potential, additional data has been sought. A combined heat pump (both cooling

and heating) may have potential if there is a cooling network to connect to. All such supply sources will be considered within each scenario where a heat pump is indicated for inclusion.

Heat sinks (Fresh Pond, Charles River): similar to sewers

Floating PV on Fresh Pond: Decentralized Renewable Energy electricity generation is limited within the City, so all surface areas where PV can be installed should be considered to contribute to the demand required. If it is assumed that 30% of the surface area of the pond is covered with floating PV, approx. 5% of the City's total electricity demand could be met. This is considered included in all scenarios and will be a sub-scenario of the final preferred solution to determine potential viability.

Microgrids: Can save on distribution costs (as don't have to pay grid operator their set tariff) and provide resilience in black out situations, however they are considered an enabling technology and not a low carbon energy supply. Microgrids enable electricity generating plants to achieve better rates for the electricity they generate. Typically microgrids would be considered as a way to add value and contribute towards the business case for a combined heat and power or renewable energy plant. In a situation where dual located networks (microgrid and existing grid) are operating, energy losses from supply can be increased. Consideration of microgrids in this project will be driven by the identified supply technologies.

Battery technologies: Current technologies can provide storage of significant quantities of energy, however charges can only be held for short periods 1-2 hours and the size and cost of the batteries are significant.

Such battery technology can be charged during high renewable energy generation periods when demand is low, however they need to dispatch this energy soon after due to their storage capability at City scale.

Battery technology is useful for providing resilience in blackouts and for providing peak shaving in periods of high electricity demand, but provides limited contribution to a low carbon energy supply due to limited storage durations and the low carbon electricity still has to be created.

Battery technology at the scale required for Cambridge is currently prohibitively expensive and would require significant amount of space for a city scale project. The technology has advanced rapidly in recent years and costs and space requirements are expected to decrease as the technology continues to develop. Battery technology may also act as a technology enabler, facilitating more PV generated electricity utilization for instance, and will form part of the low carbon energy supply transformation process. For this reason consideration of the future potential shall be discussed as the project develops.

2. Outcome

Table 1 below outlines the goals of the city and each scenario proposed. This was used to assist in shortlisting the scenarios.

The assessment process was previously decided to be qualitatively based, using the proximity of the scenario to all of the City's goals as a means of evaluation, as no previous goal weightings had been assigned.

Due to the high level information available for assessment at this stage in the scenario development process, it was decided to evaluate scenarios with similar basis against each other, using the first three goals. As a result scenarios 1-3, scenarios 4a,b,c &d, and scenarios 5&6 where grouped together for comparative evaluation.

Scenario 1
When comparing this scenario to Scenario's 2 & 3 it was clear that they are stronger options for progression. As a result it was decided that this scenario should not be progressed further, but that it is included in the WP2 report that this was considered. This scenario does continue throughout most options for the supply scenario for Zone 2, low density residential.

Scenario 2 & 3
Although the development scale of the scenarios proposed within these scenarios are different, it was decided that these could be considered as a single scenario for evaluation purposes.

Scenario 4 a, b, c and d
It was decided to keep these scenarios for progression, excluding Scenario 4d – geothermal supply. Justification should be included in the WP2 report for this exclusion.

There will be a need to consult with **all** major stakeholders regarding different generation options, such as Waste to Energy, Biomass, Anaerobic Digestion etc. as to their political viability.

Would be useful for scenario to be visually displayed, indicating approx. size of plants required for each zone.

Scenario 5
It was decided to keep these scenarios for progression with further elaboration for the AC meeting.

Scenario 6
As this scenario is a combination of the above Scenario 4 options, with the use of hydrogen fuel cell production to supply electricity when other technologies are insufficient, it was decided to incorporate this scenario with the Scenario 4 options.

3. Scenario Elaboration Required

Visual representation of the scenarios requested – infographics to be included on the city map to indicate where supply proposed for.

What size of seasonal storage pit would be required to be viable?

Indicate scale of plant required for the various zones so it is understood how big these need to be.

Provide an estimation on timelines for upcoming technologies to become viable where applicable or if not.

Include basic transition steps required for scenario implementation where possible (will be further developed under WP3).

4. Information to be shared

City to share waste report to estimate WtE and AD potential.

5. Information shared during the meeting

Link to info re La Jolla Net Zero Energy office building with fuel cells/biogas:
http://greenbuildingnews.com/2014/04/22/largest-net-zero-commercial-building-opens-in-san-diego/
Whole Building Design Guide
http://www.wbdg.org/

Table 1 Scenario and City Goals

	SC1 – Electrification	SC2 – Electrification with Centralised DHC	SC3 - Electrification with decentralised DHC	SC4a DHC with bio CHP	SC4b DHC with bio heat only	SC4c DHC with WtE / AD	SC4d DHC with Geothermal	SC5 H City	SC4e DHC with fuel cells – look at merging with SC4
Clean	2	3							
Reliable	1	3							
Affordable	1	3							
SUM	4	9	7						
Predictable									
Transparent									
Local control									
Wealth creating									
Innovative									
Just									

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APPENDIX 4

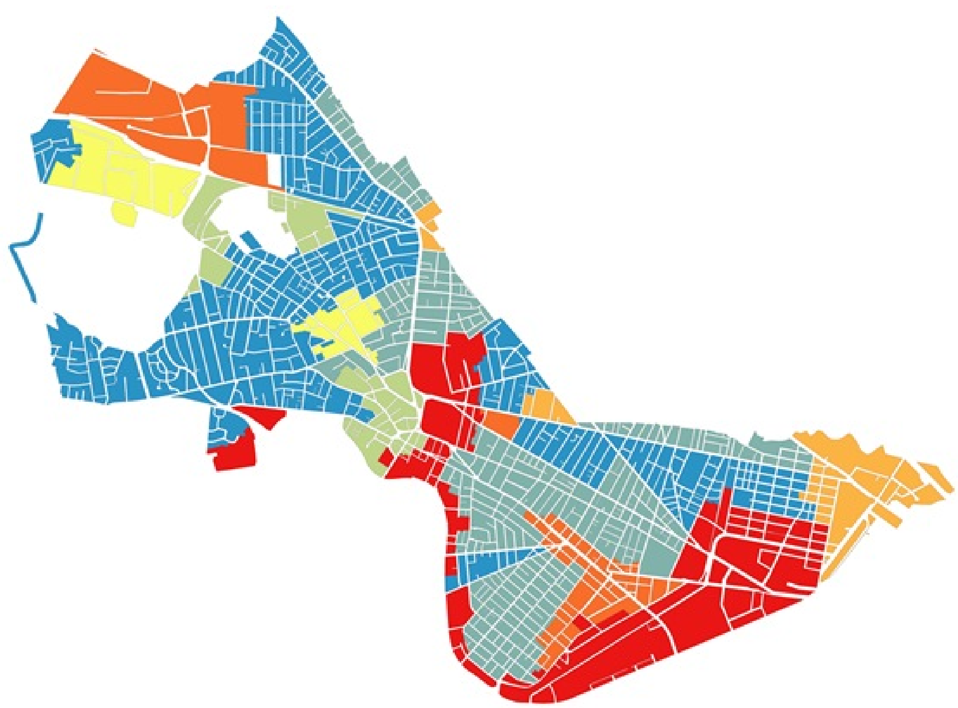
SCENARIO LONG LIST REPORT R02

Intended for
City of Cambridge

Document type
Memo

Date
April, 2017

LOW CARBON ENERGY SUPPLY STRATEGY
OUTLINE OF LONG LIST OF SUPPLY SCENARIOS



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LOW CARBON ENERGY SUPPLY STRATEGY
OUTLINE OF LONG LIST OF SUPPLY SCENARIOS

Revision	**0g**
Date	**2017-04-07**
Made by	**IMC, SMT, PSTEE, JNF, MKENN**
Checked by	**JNF**
Approved by	
Description	**Outline of Long List of Supply Scenarios**

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Document ID	734660-17

Ramboll
Hannemanns Allé 53
DK-2300 Copenhagen S
Denmark
T +45 5161 1000
F +45 5161 1001
www.ramboll.com

TABLE OF CONTENTS

TABLE OF FIGURES

TABLE OF TABLES

APPENDIX

Appendix 1
Memo March 3rd: WP2 Process

Appendix 2
Overview of Technologies proposed for each zone

1. INTRODUCTION

Following Work Package 1 which analyzed the existing factors and barriers to a low carbon energy supply in the City of Cambridge, Ramboll proceeded with Work Package 2 (WP2). The objective of WP2 is to ultimately derive 1-3 low carbon energy supply scenarios for detailed analysis under Work Package 4.

This memo outlines the long list of scenarios identified by the project team following internal workshops in accordance with the memo sent on March 2nd, which outlined the process for WP2. This memo is included in Appendix A.

Each scenario is described as follows:

- Technologies identified for supply with description
- Percentage energy supply to be provided by that technology
- How the scenario meets the City's goals

How the scenario meets the City's goals is important as it will be used by the City and project team during this project stage for scenario evaluation and shortlisting. In order to identify if the proposed scenario complies with the Goals of the City as outlined below, a table has been developed for ease of visual assessment under the headings of low, medium or high approximation to the City's goals.

Appendix 2 gives an overview of each technology proposed for each scenario within each zone.

1.1 Classification of scenarios in relation to the City's goals

In order to identify if the proposed scenario complies with the Goals of the City, Table 1-1 has been developed for ease of visual assessment. The City goals[1] considered when evaluating the scenarios:

- **Clean**: Reduce carbon emissions and toxic pollutants created by the system.
- **Reliable**: Minimize system downtime from outages and ensure high quality of power delivered.
- **Affordable**: Keep rates as low as possible and maintain competitiveness.
- **Predictable**: Minimize rate volatility.
- **Transparent**: Consumers can understand their power costs and what drives changes in costs.
- **Local Control**: Give residents greater control over their energy resources and energy choices.
- **Wealth Creating**: Keep more energy revenue in the local economy instead of exporting it to outside suppliers — to help drive local economic development, create new businesses and jobs.
- **Innovative**: The system spawns innovation, intellectual property creation, and entrepreneurship.
- **Just**: The system promotes "energy equity," protecting vulnerable populations from undue hardship, and promotes energy literacy.

The evaluation and initial shortlisting of scenarios will follow submission and review of this report.

Each of the City goals is classified according to a low, medium and high evaluation. For ease of identification, the classification is colored accordingly:

- Low: **Red color**
- Medium: **Yellow color**
- High: **Green color**

The classification is not based on an economic assessment of costs and benefits of each scenario. Instead, the scenarios are evaluated on a best estimate based on the project groups experience with

[1] In accordance with the RFP and the Carbon Neutral Cities Alliance

energy projects. The scenarios selected by the City of Cambridge will later in WP4 be classified by an economic assessment study.

2. CITY ZONING PROCESS

In order to understand the consumption of energy within the City, Ramboll prepared a City Zoning Map based on heat consumption. As heating and cooling consume 60% of the city's energy consumption today, it is important to understand where this is specifically being consumed within the City to consider alternative methods of supplying this demand.

The maps produced show zoning in the following ways:

- MWh per consumer. This is the total demand within a zone divided by the total number of consumers (connection) within the zone.
- kBTU per consumer. Same as above, but in kBTU
- MWh/ha: The total thermal usage within a zone divided by the zones area in hectares (ha).

Following the analysis of the zoning maps, the City was divided into various zones based on existing consumption. This zoning is outlined in Figure 2-1 below. The scenarios developed were based on the zones defined and how to meet the required demand for each zone with low carbon alternatives. Zone 1 has the highest heat density and is presumably suitable for district heating. Zone 2 has a lower heat density and individual heating is most likely the best solution. Zone 3 and zone 4 are development areas, which in the future can be supplied like zone 1.

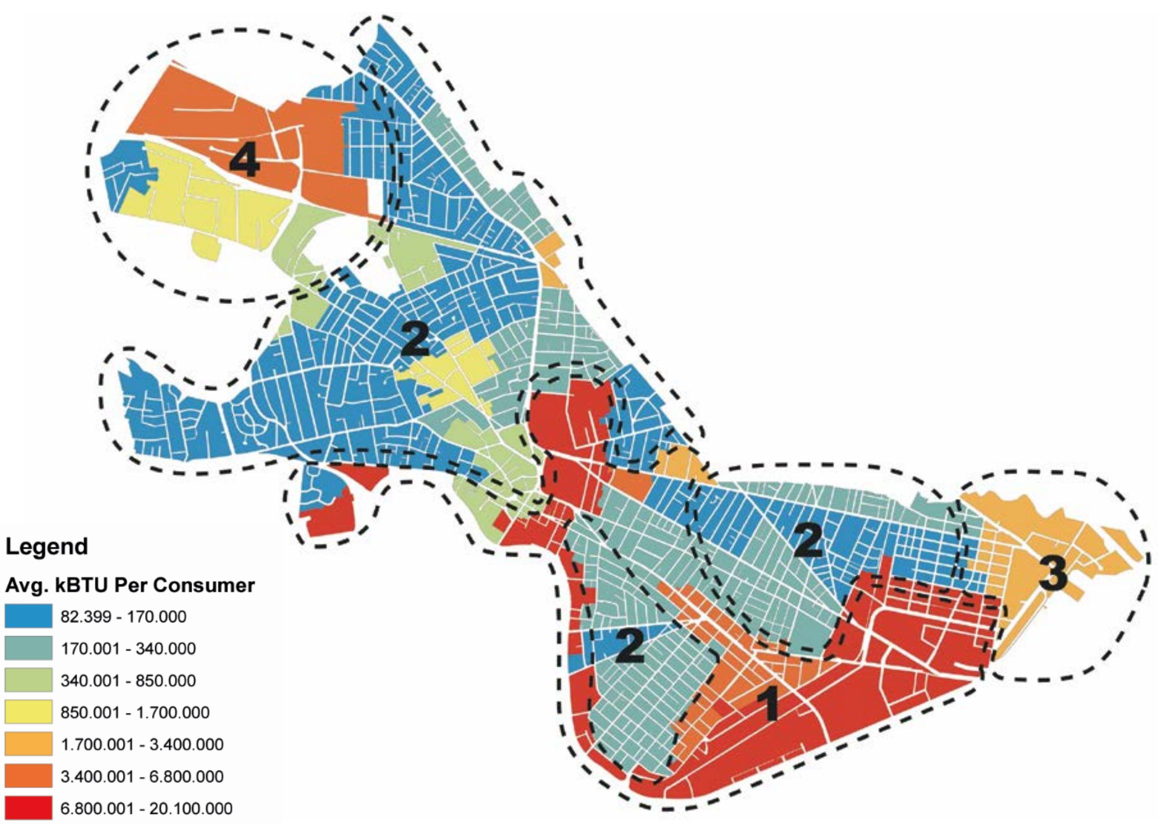

Figure 2-1: City Zoning Map

3. ALTERNATIVE ENERGY SOURCES

The Work Package 1 report outlined the existing energy supply for the City of Cambridge and potential alternative sources to replace this supply. These are outlined on Figure 3-1 below. In advance of the initial scenario development process and in order to inform the development process more, Ramboll assessed the alternative energy sources of Cambridge further.

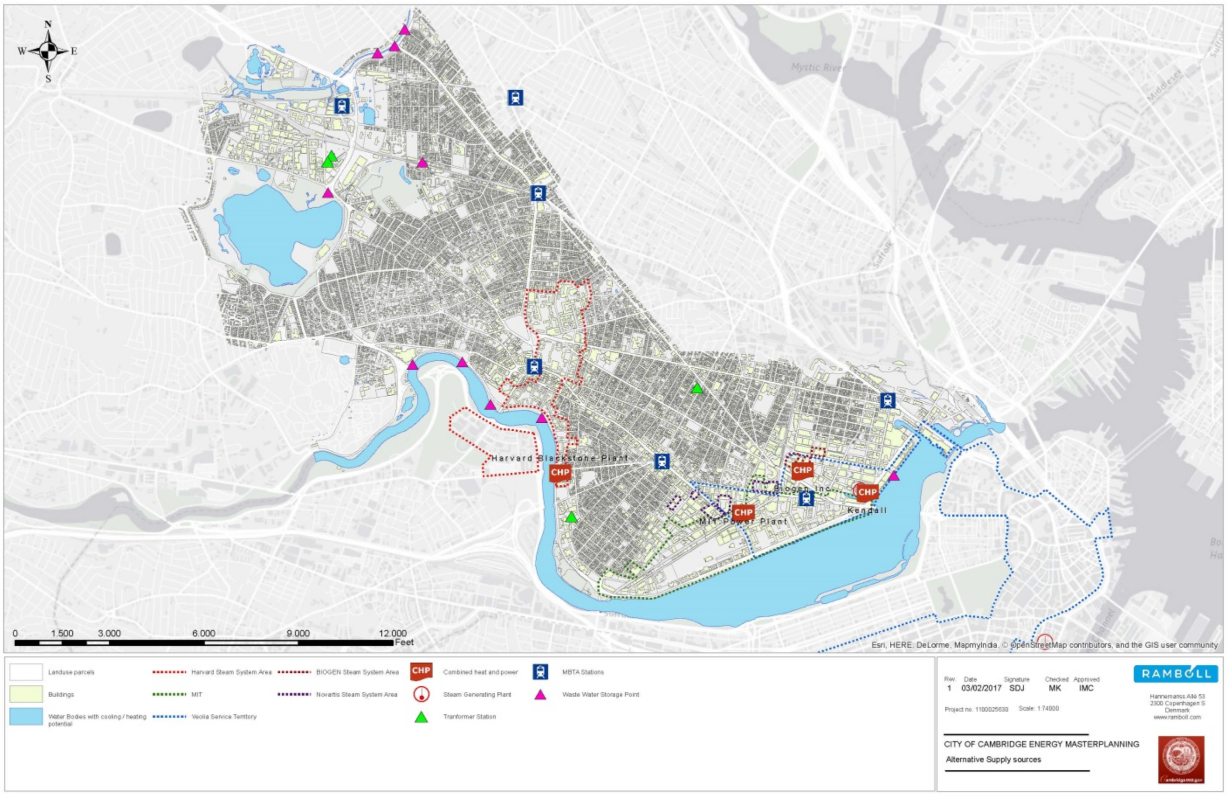

Figure 3-1: Existing and Alternative Supply

In terms of renewable energy generation, the City has limited space for large scale Solar PV within the City boundary. However, solar PV panels can still be located on building roofs inside the city. It has not been investigated if the local electricity grid can withstand the increased solar production nor if it is socio economically profitable. The wind potential and available locations for wind farms has also been identified as limited inside the city. However, buying wind certificates or installing wind turbines outside the city are an option. Further investigation of the geothermal potential of the aquifers below the city was also conducted. Ramboll contacted the Geological Energy Systems dept. at the University of Glasgow, Scotland (which shares a geological history with Massachusetts) and the University of Massachusetts. The University of Massachusetts conducted the Massachusetts Geothermal Data Project, which has produced maps outlining the geothermal potential of the existing aquifers in the state. Based on the work they have done, the argillites in the Cambridge Basin are not an obvious deep geothermal target, and are currently not on their list of potential Massachusetts targets (even when considering low temperature requirements of around 60^0C/140^0F). It is likely that there are granites and gneisses beneath the basin. However, when looking at the heat production maps produced by the Massachusetts Geothermal Data Project, none of the surrounding granites have high heat production value. Following these discussions and analysis, it is clear that further costly site investigation will be required to ultimately rule out the aquifers beneath Cambridge as a useful energy source; however as it stands the likelihood of this is low.

4. SCENARIO 1 – INDIVIDUAL ELECTRIFICATION

4.1 Technologies

This scenario consists of building level electrification of thermal energy and cooling demand for all zones and building types. The only heat production technology considered is a heat pump utilizing a low grade heat source, which is upgraded to building operating temperatures by use of electricity. The cooling technologies are individual chillers and air-condition facilities, also supplied by electricity.

The electricity supply will be dependent on external supply of renewable electricity through greening of New England Power Pool (NEPOOL), RECs and/or through investing in a renewable installation outside the city border. Maximum deployment of solar PV within the city boundary is assumed.

Figure 4-1 displays the overall structure of scenario 1. Electricity is supplied by the external electricity grid with production from both conventional- and renewable power stations. Electrical consumption will increase with the introduction of electrically driven heat pumps and chillers as a replacement for gas furnaces. Cambridge city can invest in wind turbines located outside the city, buy green certificates or invest in solar PV mounted on rooftops inside the city. Whilst NEPOOL is expected to increase the proportion of renewable and sustainable power generation it is not expected to achieve 100 zero carbon over the timeframe of the study. The scale of the increase in electricity demand will likely reduce the potential for achieving full de-carbonization, especially in the medium term due to limited renewable energy capacity.

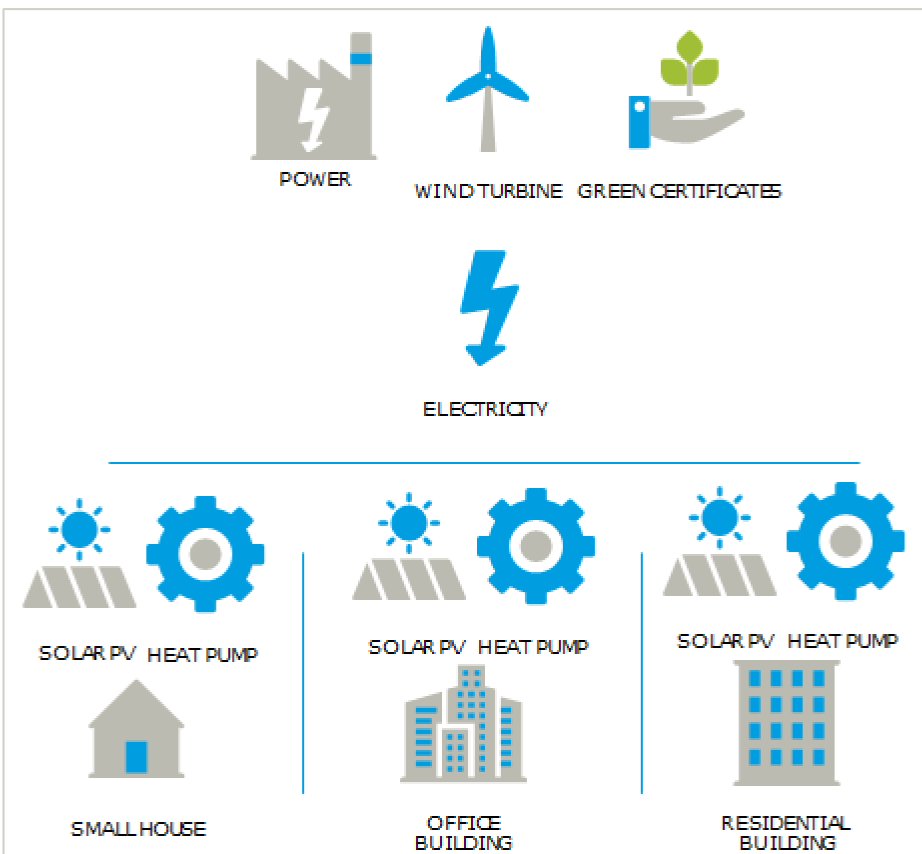

Figure 4-1: Scenario 1 Individual Electrification

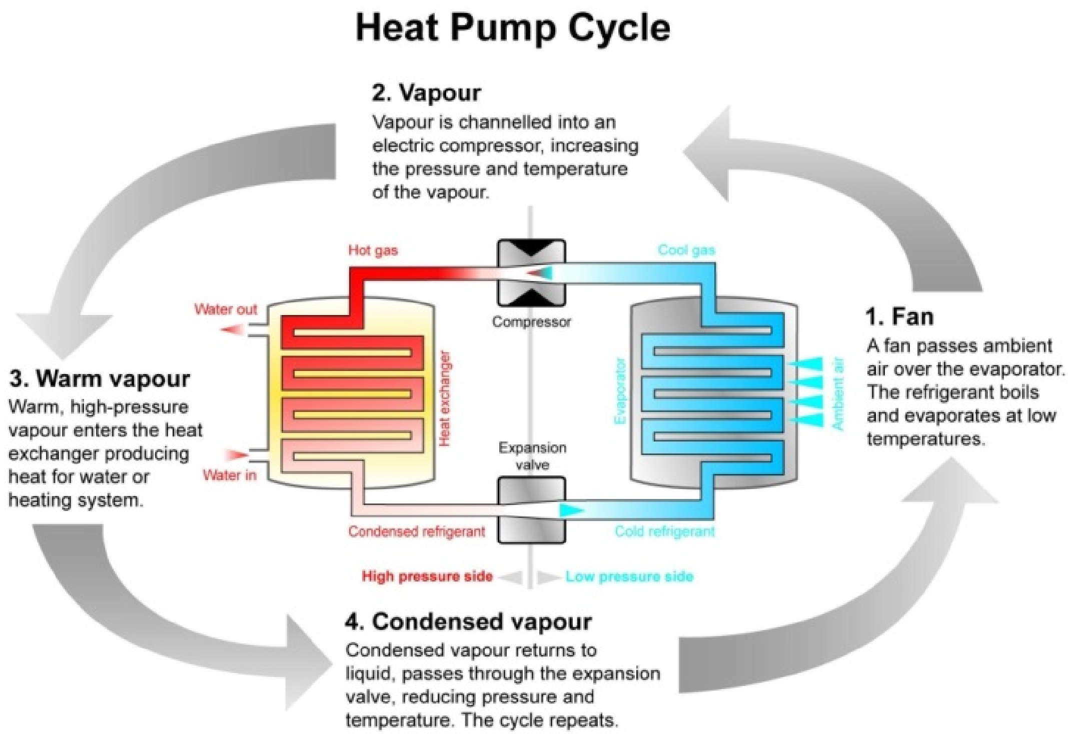

Figure 4-2: Heat Pump Cycle

Electrically driven heat pumps absorb low grade heat from a source such as the air, ground or river and upgrade it via an electrically driven vapor compression circuit to provide space heating and hot water. Figure 4-2 describes the vapor compression circuit that operates within an air source heat pump.

Where there is capacity in the ground or an available pond or river heat source, a water source heat pump will be possible. Otherwise, an air source heat pump will be used. Each residential customer or property will require a heat pump with integrated controls and a domestic hot water (DHW) hot water storage cylinder, which will require an electric emersion heater, to ensure water safety standards are met. Heat pumps operate most efficiently at lower output temperatures. Therefore, in most properties, internal modification may be required, which consist of upgrading radiators, installing a new heat pump compatible hot water cylinder and increased insulation measures. Older properties may also require upgrades to the electrical installation.

For older properties which cannot benefit from increased energy efficiency measures high temperature heat pump options are available. A hot water storage tank with an electric emersion heater will also be required, to ensure water safety standards are met. Heat pumps also contain a fan unit and will thus emit some noise, so location of the equipment may need to be carefully considered. There are no chemical air emissions in normal operation.

In the case of blocks of apartments and larger non-residential units it is envisaged that they would be supplied by a centralized heat pump system which will feed individual Energy Transfer Stations (ETS). Customers will have full control over there heating and hot water via an integrated timer and programmer. Some customers that require higher temperatures, such as hospitals and Research and Development (R&D) facilities, may opt for temperature boosting using electric boilers.

The increased electrical load associated with the introduction of electrically driven heat pumps will require additional capacity or even new substations within the area to meet the increased demand. Reinforcement of the electrical grid will also be a requirement with the widespread introduction of electrically driven heat pump solutions within the area. The transformation away from natural gas will also leave the existing gas network redundant.

The consideration on whether to increase the electrification instead of a community based solution is mainly that the capital costs for the power network reinforcement are expected to be lower than laying out piping in a district heating network. The costs for the additional generation required under an electrification scenario should also be considered.

Individual heat pumps are expensive but also very efficient. The cons are that they will need supplemental heat sources (air, water, ground), which should be included in the capital costs. The investment costs for electric boilers are much lower, but the efficiency is much lower compared to heat pumps.

The viability of a heat pump solution is very much dependent on the availability of abundant low cost electricity. The price of electricity consists of different components e.g. the costs from the power exchange, transportation costs (transmission and distribution), capacity cost, any fees etc. An individual solution will most probably pay quite high prices for the electricity since a smaller heat pump will be connected at a lower voltage level with higher distribution costs. With a heat pump connected centrally it could be connected at a higher voltage level with lower distribution costs. Furthermore, storage options will be limited with individual solutions. Therefore, it will be necessary to have the heat pump in operation even during times of high electricity pricing from the power exchange if there is a demand for heat, and this can often coincide with energy supplied at the highest carbon intensity.

An electrified solution provides limited resiliency for Cambridge and exposes residents to the potential for losing both heat and power in extreme weather events. Battery storage is a very expensive solution to overcome this issue at the moment and the technology is far from achieving the economic level required to compete with power plants.

Heat pump technology on an individual building basis has limited potential for storage to take account of fluctuating electricity supply from renewable energy sources , which result in the need for demand side management on a city wide scale. For this to work, electrification of the energy system will need to be combined with a wide scale roll out of “smart” appliances. Still, the economic benefit of flexible operation from individual heat pumps is much higher for the system than for each consumer. Therefore, an incentive tariff for flexible operation is required to encourage individual consumers.[2]

[2] Absorption heat pumps are also an option, but not considered since they do not use excess electricity production from renewables

4.2 Evaluation of Scenario 1

The scenario is evaluated based on the evaluation criterion described in section 1.1.

4.2.1 Energy Supply

The percentage production distribution for scenario 1 is displayed in Table 4-1.

Table 4-1: Energy Supply Scenario 1

	Heating %	Cooling %	Electric System %
Individual Heat Pump	90	20	---
Individual Electric Boiler	10	---	---
Individual Chillers	---	80	---
Solar PV	---	---	10
Electricity Grid	---	---	90

4.2.2 City Goals

The evaluation of scenario 1 is displayed in Table 4-2. The reasoning is described in bullet points.

Table 4-2: Scenario 1 Classification

Goals	Meeting the City Goals?
Clean	
Reliable	
Affordable	
Predictable	
Transparent	
Local Control	
Wealth Creating	
Innovative	
Just	

- **Clean:** Dependent on the city securing “green” electricity. However, unless the individual heat pumps are fully flexible, which several scientific projects show they are not, when considering technical constraints, the revenue from acting flexibly will be too low for the owners. The heat pumps can be operated in clusters responding to electricity prices. This scenario is not “clean” compared to the DH&C scenarios.
- **Reliable:** The reliability of technology is good, reliability of the electricity grid would not be sufficient unless the grid is strengthened. There would be no resiliency during power outages
- **Affordable:** Electricity prices are expected to increase in the future, even with the high efficiencies of the heat pumps, costs are still likely to be high.
- **Predictable:** Subject to the pricing of electricity though the high efficiencies of heat pumps levels this out
- **Transparent:** Up to the developer of the plant and energy network – city can exercise some control through permitting and planning
- **Local Control:** Partially – dependent on the greening of NEPOOL and investment in external renewable electricity.
- **Wealth Creating:** Not for Cambridge, yes for Eversource, the electricity supplier, and heat pump companies. Could create local maintenance jobs.
- **Innovative:** Yes as this would be the first full electrification of a city that we are aware of due to the scale.
- **Just:** Yes, in that everyone would be impacted in a similar way by grid issues.

5. SCENARIO 2 – DISTRICT ENERGY ELECTRIFICATION

5.1 Technologies

This scenario is a further development of scenario 1. However, in this scenario, the buildings in zone 1 and eventually zone 3 and zone 4 will be supplied by a district heating and cooling (DH&C) system supplied by heat pumps, electric boilers and chillers – all with thermal storages included. The production technologies for each zone are displayed in Table 5-1.

Table 5-1: Production Technologies for Scenario 2

	Zone 1	Zone 2	Zone 3	Zone 4
DH&C system	X		X	X
Block heating		X		
Heat Pump	X		X	X
Electric Boiler	X		X	X
Chillers	X	X	X	X
ATES	X		X	X
Thermal Storages	X		X	X
Individual Heat Pump		X		
Solar PV	X	X	X	X
Small gas boiler		X		

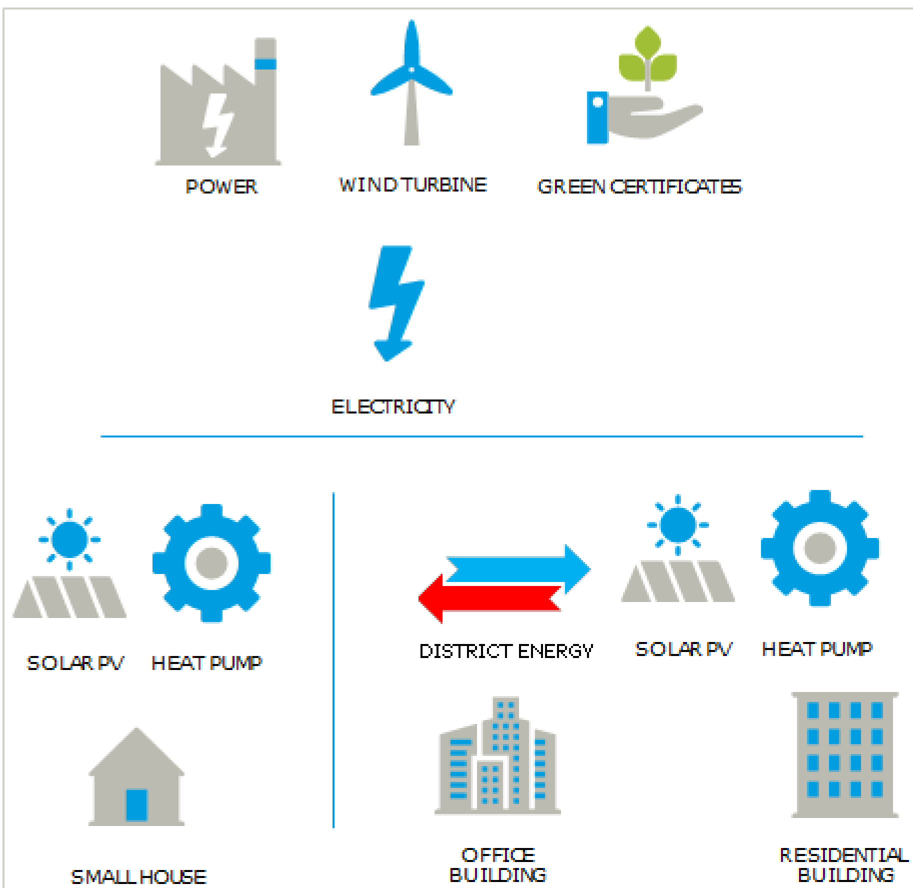

Figure 5-1: Scenario 2 District Energy Electrification

The city will still be dependent on external supply from the external electricity grid. The greening of New England Power Pool (NEPOOL), RECs and/or investments in renewable installations outside the city border is required. Maximum deployment of solar PV within the city boundary is assumed. Figure 5-1 displays the overall structure of scenario 2. Electricity is supplied by the external electricity grid with production from both conventional- and renewable power stations. Electrical consumption will increase with the introduction of electrically driven heat pumps and chillers as a replacement for gas furnaces. Cambridge city can invest in wind turbines located outside the city, buy green certificates or invest in solar PV mounted on rooftops inside the city. Whilst NEPOOL is expected to increase the proportion of renewable and sustainable power generation it is not expected to achieve 100 percent zero carbon over the timeframe of the study. The scale of the increase in electricity demand will likely reduce the potential for achieving full de-carbonization, especially in the medium term due to limited renewable energy capacity. The smaller buildings will still be supplied by individual heat pumps, but the larger buildings with a higher heat density will be supplied from centralized DH&C systems.

5.2 Evaluation of Scenario 2

The scenario is evaluated based on the evaluation criterion described in section 1.1.

5.2.1 Energy Supply

The percentage production distribution for scenario 2 is displayed in Table 5-2.

Table 5-2: Energy Supply Scenario 2

	Heating %	Cooling %	Electric System %
Individual Heat Pump	40	5	---
Individual Electric Boiler	2.5	---	---
Individual Chillers	---	40	---
DH&C Heat Pump	52.5	20	---
DH&C Electric Boiler	5	---	---
DH&C Chiller	---	35	---
Solar PV	---	---	10
Electricity Grid	---	---	90

5.2.2 City Goals

The evaluation of scenario 2 is displayed in Table 5-3. The reasoning is described in bullet points.

Table 5-3: Scenario 2 Classification

Goals	Meeting the City Goals?
Clean	
Reliable	
Affordable	
Predictable	
Transparent	
Local Control	
Wealth Creating	
Innovative	
Just	

- **Clean:** Same as scenario 1
- **Reliable:** Same as scenario 1
- **Affordable:** DH&C systems are only constructed, when more profitable than individual solutions, so naturally yes
- **Predictable:** Subject to the pricing of electricity though the high efficiencies of heat pumps and thermal storages can reduce vulnerability
- **Transparent:** Joint ownership of DH&C systems by consumers can provide a transparent operation and prices through open access data. Still, the company is exposed to the electricity price fluctuations and electricity market gaming
- **Local Control:** Same as scenario 1
- **Wealth Creating:** Same as scenario 1
- **Innovative:** Yes, in the sense that a DH&C network is constructed. New production units can later be added to system for reduced costs and higher flexibility
- **Just:** Same as scenario 1

6. SCENARIO 3 – ELECTRIFICATION IN CLUSTERS

6.1 Technologies

The production units in this scenario are similar to scenario 2. However, instead of a centralized production with a large thermal network, this scenario has decentralized production of DH&C in clusters. The heat source for the heat pump production is circulated in a low temperature network, which can have an inlet temperature of 20 ^{o}C and outlet temperature of 10 ^{o}C. The temperature may be boosted centrally by a large heat pump using heat from the river, pond, air, sewers, ATES or the district cooling system.

Table 6-1: Production Technologies for Scenario 3

	Zone 1	Zone 2	Zone 3	Zone 4
Heat source dis. system	X		X	X
Block heating	X	X	X	X
Heat Pump	X		X	X
Electric Boiler	X		X	X
Chillers	X	X	X	X
ATES	X		X	X
Thermal Storages	X		X	X
Individual Heat Pump		X		
Solar PV	X	X	X	X
Small gas boiler		X		

Table 6-1 shows the production technologies considered in scenario 3. Notice that a heat source distribution system is used to provide a heat source to the heat pumps located in clusters (block heating). Similar to scenario 1 and 2, the electricity supply must be converted to renewable energy for this scenario to be sustainable. Solar PV located on the rooftops within the city can also be a potential solution. The principle is sketched on Figure 6-1. A centrally located heat pump will supply a 20 ^{o}C heat source to the heat pump located in clusters, which allow these to operate with a higher efficiency. The solution will not differ much from scenario 2, only difference being the size and type of distribution network and the size and location of heat pumps. The same buildings supplied by DH&C in scenario 2 will also be supplied in this scenario.

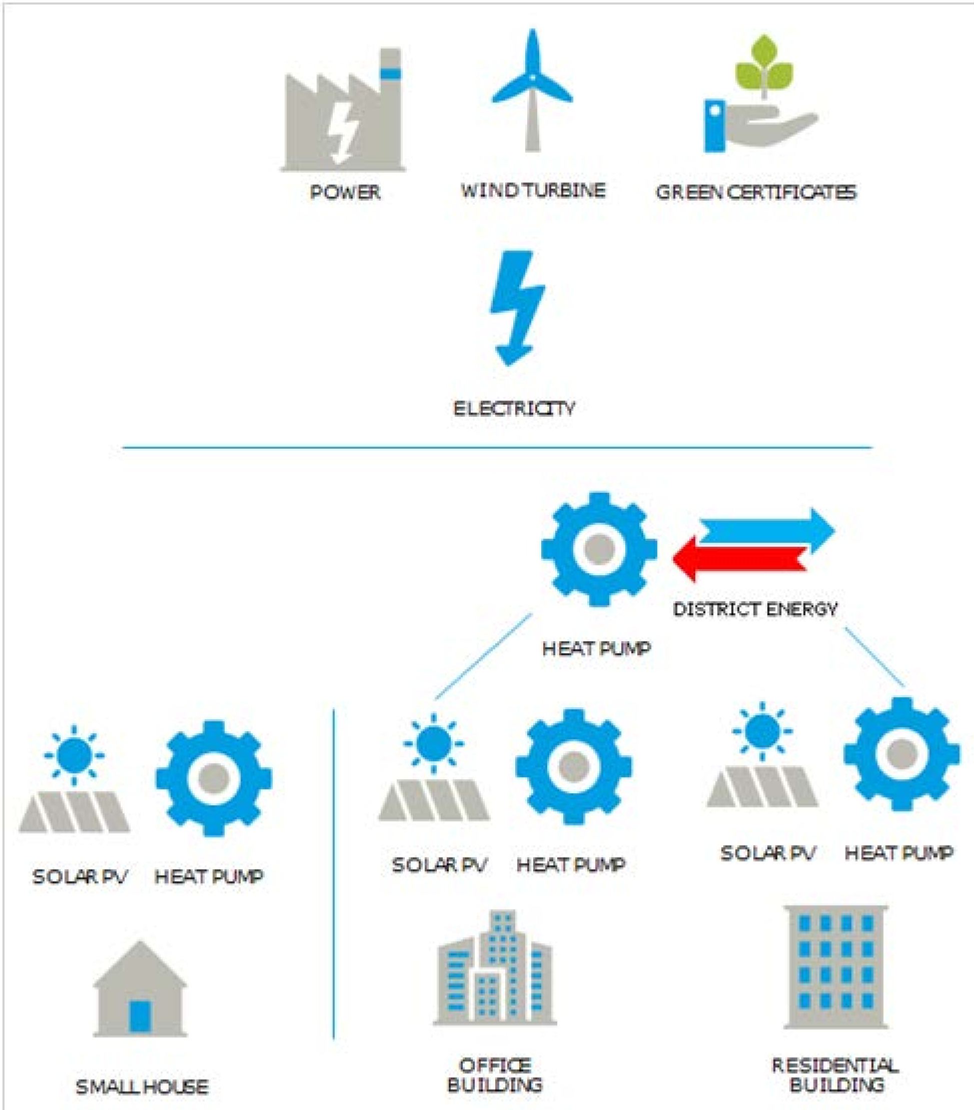

Figure 6-1: Scenario 3 Electrification in Clusters

6.2 Evaluation of Scenario 3

The scenario is evaluated based on the evaluation criterion described in section 1.1. The result is exactly the same as in scenario 2, which can be seen in Table 6-2. The reasoning behind the score can be seen in the evaluation of scenario 2, under section 5.2.2.

Table 6-2: Scenario 3 Classification

Goals	Meeting the City Goals?
Clean	
Reliable	
Affordable	
Predictable	
Transparent	
Local Control	
Wealth Creating	
Innovative	
Just	

7. SCENARIO 4 – DH&C SYSTEMS

7.1 Technologies

These scenarios consist of providing district heating and cooling to most of the city. Heat pumps, biomass plants and waste-to-energy plants are being considered for delivery of district heating. The heat pumps will furthermore in cooperation with chillers provide district cooling. Thermal storage for both heating and cooling is included. The structures of these four scenarios are displayed in Table 7-1, with their central technologies[3]. Basically, only the heat production technologies are changed.

Heat pumps and chillers are central, when constructing a district cooling system. Thermal storages will be used for both district heating and cooling scenarios. An ATES (Aquifer Thermal Energy Storage) system is also included in all scenarios to utilize the synergies between district heating and cooling systems. The electric boiler is a cheap solution for producing heat based on excess renewable electricity production.

Table 7-1: Production Technologies for Scenario 4

	Zone 1	Zone 2	Zone 3	Zone 4
District heating	X X X		X X X	X X X
District cooling	X X X X		X X X X	X X X X
Small scale community heating	X		X	X
Block heating		X X X X		
Heat pumps	X X X X		X X X X	X X X X
Chillers	X X X X	X X X X	X X X X	X X X X
Electric boilers	X X X X		X X X X	X X X X
Biomass CHP	X		X	X
Biomass Boiler	X		X	X
WtE	X		X	X
Geothermal	X		X	X
Thermal storage	X X X X		X X X X	X X X X
ATES	X X X X		X X X X	X X X X
Individual HP		X X X X		
Solar PV	X X X X	X X X X	X X X X	X X X X
Anaerobic digestion				X
Small gas boiler		X X X X		

Scenarios 4a, 4c and 4d all have a central district heating system established.

In scenario 4b, it is assumed that lengthy network connections are not viable. Therefore, district heating is only established in clusters of high heat density supplied by biomass boilers.

The district cooling system will in all scenarios be constructed in clusters of high cooling density supplied by heat pumps using an ATES system and chillers. Thermal storage will likely be profitable in all scenarios. The electricity consumption can be supplied as outlined under Scenario 1, supplemented by biomass and waste-to-energy plants which will also produce electricity in a combined heat and power (CHP) production. Solar PV mounted on each building is still an option for

[3] **Blue cross:** Scenario 4a, **Red cross:** Scenario 4b, **Green cross:** Scenario 4c, **Black cross:** Scenario 4d

increased local electricity production. The expansion of district heating and cooling (DH&C) into the zones displayed on Figure 2-1 is divided as stated below. Scenario 4b is an exemption, where district heating is only established in clusters instead of central systems. The structural difference between scenarios 4a, 4c and 4d compared to 4b is illustrated on Figure 7-1 and 7-2. Notice the difference between a central and decentral district heating system.

- **Zone 1**: DH&C network supplied by a mix of centralized heat pumps and chillers, biomass CHP or waste to energy CHP or geothermal with thermal storage. Electric boilers can also serve to provide peak production in the district heating system, when renewable energy production is high and electricity prices equally low. The thermal storage can consist of storage tanks or an ATES system. It is estimated that approximately 70-80 % of the consumers in the zone can profitably be supplied by DH&C.
- **Zone 2:** All consumers are supplied by individual heat pumps or by block heating systems, when profitable. The heat- and cold density is not immediately high enough to establish a district heating network and district cooling network respectively.
- **Zone 3:** Ultimately to be supplied like zone 1 with a DH&C system.
- **Zone 4:** Ultimately to be supplied like zone 1 with a DH&C system.

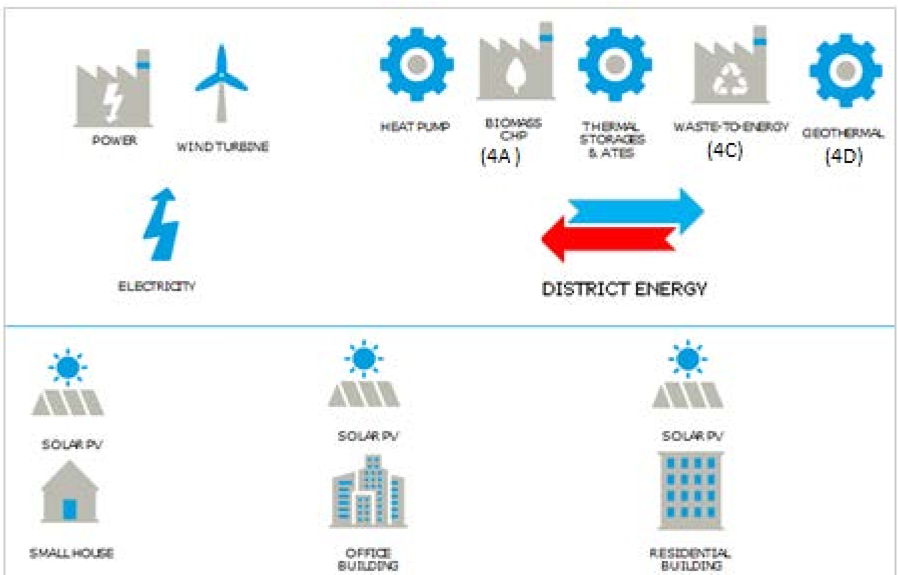

Figure 7-1: Scenario 4a, 4c and 4d

- Biomass CHP: Scenario 4a
- Biomass Boiler: Scenario 4b
- Waste-to-Energy: Scenario 4c
- Geothermal: Scenario 4d

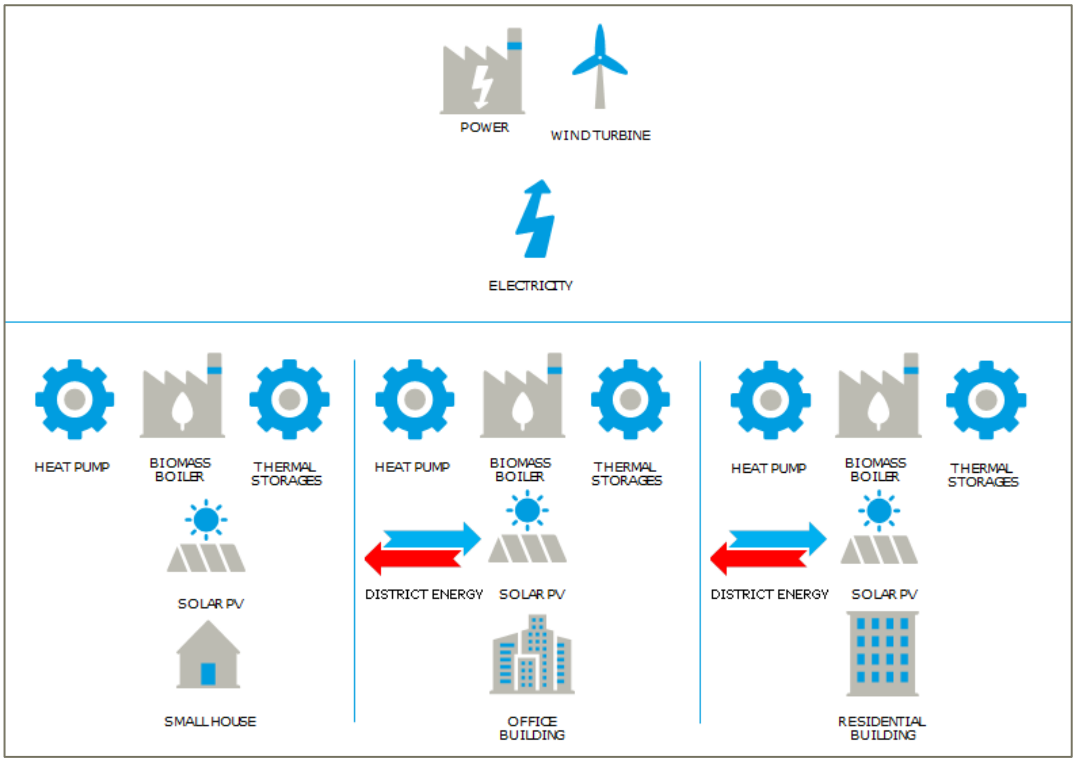

Figure 7-2: Scenario 4b

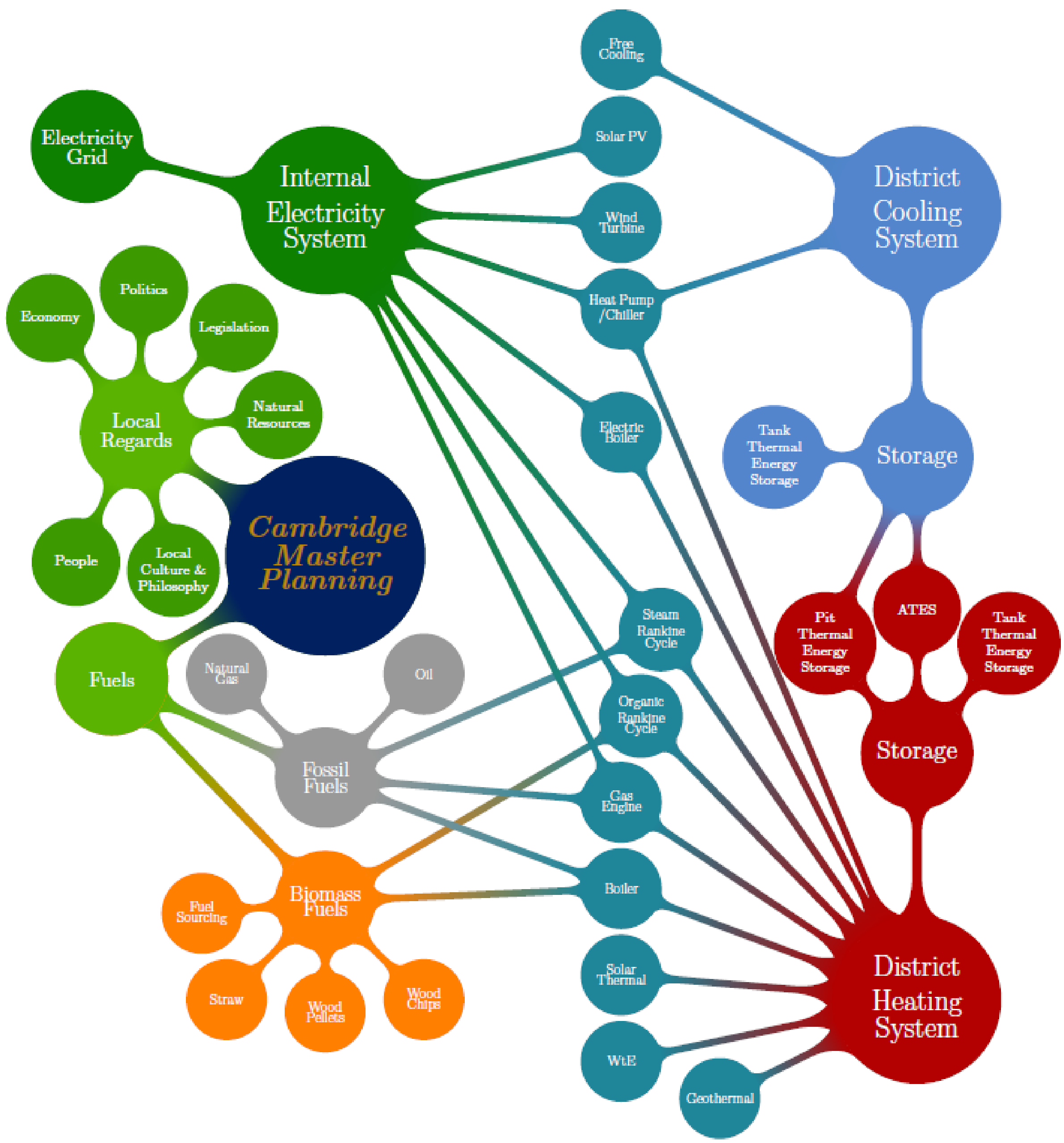

Figure 7-3: Master Planning a DH&C System in Cambridge

Local solar PV production mounted on rooftops is included in all scenarios. The electrical network may need strengthening and the socioeconomic costs may be too high, but the idea is not excluded. The different heat production technologies displayed on Figure 7-1 and Figure 7-2 must be compared to the division on scenario, as seen in Table 7-1. The concept of master planning the DH&C system in Cambridge City is displayed on Figure 7-3. The considered technologies for a combined DH&C system and their relation to the respective energy systems can also be seen. The considered fuels consist of biomass and fossil fuels. However, if a Waste to Energy (WtE) plant is found profitable – required waste must be available – the waste itself will be a fuel source. Keep in mind that the WtE plant can be designed to produce electricity. The relation between thermal energy storage used for both district heating and cooling is displayed in the form of tank thermal energy storage, pit energy storage and an ATES system. All plausible technologies for production of electricity, district heating and district cooling are displayed. One can with certainty argue that wind turbines are not relevant inside Cambridge City. However, wind turbines can be located outside the city producing electricity to the electricity grid, which can possibly be reimbursed in the energy accounts of the city. Each time a DH&C system is proposed in any scenario, the user can return to Figure 7-3 to investigate the possible production units and their system links.

7.2 Evaluation of Scenario 4

Each underlying scenario is evaluated based on the evaluation criterion described in section 1.1. For scenario 4a, 4c and 4d several of the answers to the evaluation criterion are the same. Therefore, if the answer is the same, it will just be stated as "*same as in …*"

7.2.1 Evaluation of Scenario 4a

7.2.1.1 Energy Supply

The percentage production distribution for scenario 4a is displayed in Table 7-2.

Table 7-2: Energy Supply Scenario 4a

	Heating %	Cooling %	Electric System %
Biomass CHP	50	---	25
Heat Pump	15	5	---
Individual Heat Pump	30	---	---
Electric Boiler	5	---	---
Chillers	---	95	---
Solar PV	---	---	10
Electricity Grid	---	---	65

7.2.1.2 City Goals

The evaluation of scenario 4a is displayed in Table 7-3. The reasoning is described in bullet points.

Table 7-3: Scenario 4a Classification

Goals	Meeting the City Goals?
Clean	
Reliable	
Affordable	
Predictable	
Transparent	
Local Control	
Wealth Creating	
Innovative	
Just	

- **Clean:** The system will reduce the carbon emission and toxic pollutants, by utilizing BAT for energy production. Furthermore, the use of primary fuel will be reduced. Still, public regulation to ensure flue gas treatment and energy efficiency is required.
- **Reliable:** The planning of the energy system can be undertaken to ensure a wanted resilience (security of supply). Installing more peak capacity into a DH&C system is a small expenditure compared to the total expenditures. Peaking units can furthermore be placed locally at hospitals and schools. The delivery of power can also be strengthened by a local biomass CHP plant.
- **Affordable:** DH&C systems will only be introduced in districts where it will be more profitable than individual heating. Therefore, obviously it will be affordable and competitive.

- **Predictable:** DH&C systems have the clear advantage compared to individual heating that it is more robust against changes in fuel prices. The DH&C system can switch between several production units or build new production units to hedge against high fuel prices. The rate volatility is therefore expected to decrease.
- **Transparent:** The cost of energy for consumers will presumably still be complex. However, local (joint) ownership of the energy companies can increase transparency and reduce the complexity by public access to data.
- **Local Control:** Only by enforcing local (joint) ownership of the energy companies can local control be increased. This is a keystone in renewable energy systems.
- **Wealth Creating:** The wealth creation will stem from local ownership and knowledge increase. The two universities can benefit from research in renewable energy systems. However, most likely, it will be expensive to have higher ambitions than the rest of the state and USA in general.
- **Innovative:** Enhancing local influence by including local universities, companies and citizens, innovative ideas will emerge. The city can work as example for other cities.
- **Just:** Yes, but local ownership and influence are required. Furthermore, many people owning one large company tends to be more robust than each person owning their own small heat/cold production facility.

7.2.2 Evaluation of Scenario 4b

7.2.2.1 Energy Supply

The percentage production distribution for scenario 4b is displayed in Table 7-4.

Table 7-4: Energy Supply Scenario 4b

	Heating %	Cooling %	Electric System %
Biomass Boiler	50	---	---
Heat Pump	15	5	---
Individual Heat Pump	30	---	---
Electric Boiler	5	---	---
Chillers	---	40	---
Solar PV	---	---	10
Electricity Grid	---	---	90

7.2.2.2 City Goals

The evaluation of scenario 4b is displayed in Table 7-5. The reasoning is described in bullet points.

Table 7-5: Scenario 4b Classification

Goals	Meeting the City Goals?
Clean	
Reliable	
Affordable	
Predictable	
Transparent	
Local Control	
Wealth Creating	
Innovative	
Just	

- **Clean:** The system will reduce the carbon emission by using biomass. Toxic pollutants need a strong regulation to be reduced. Public regulation to ensure flue gas treatment and energy efficiency is required. The use of primary fuel will be reduced compared to individual solutions. However, it will be higher than a central solution.

- **Reliable:** Same as 4a
- **Affordable:** Same as 4a
- **Predictable:** Compared to a central DH&C system, the decentralized solution will have a reduced ability to change between production facilities. The consumers will therefore be more exposed to changes in fuel prices.
- **Transparent:** Same as 4a
- **Local Control:** Same as 4a
- **Wealth Creating:** Same as 4a
- **Innovative:** Same as 4a
- **Just:** Same as 4a

7.2.3 Evaluation of Scenario 4c

7.2.3.1 Energy Supply

The percentage production distribution for scenario 4c is displayed in Table 7-6.

Table 7-6: Energy Supply Scenario 4c

	Heating %	Cooling %	Electric System %
WtE	50	---	10
Heat Pump	15	5	---
Individual Heat Pump	30	---	---
Electric Boiler	5	---	---
Chillers	---	40	---
Solar PV	---	---	10
Electricity Grid	---	---	80

7.2.3.2 City Goals

The evaluation of scenario 4c is displayed in Table 7-7. The reasoning is described in bullet points.

Table 7-7: Scenario 4c Classification

Goals	Meeting the City Goals?
Clean	
Reliable	
Affordable	
Predictable	
Transparent	
Local Control	
Wealth Creating	
Innovative	
Just	

- **Clean:** The WtE technology must be treated with care due to toxic pollutants. However, if treated correctly, the technology poses no highly environmental harmful pollutants. The fossil carbon contents in the waste will emit carbon dioxide when burned.
- **Reliable:** Same as 4a
- **Affordable:** Same as 4a
- **Predictable:** Same as 4a
- **Transparent:** Same as 4a
- **Local Control:** Same as 4a
- **Wealth Creating:** Same as 4a

- **Innovative:** Same as 4a
- **Just:** Same as 4a

7.2.4 Evaluation of Scenario 4d

7.2.4.1 Energy Supply

The percentage production distribution for scenario 4d is displayed in Table 7-8.

Table 7-8: Energy Supply Scenario 4d

	Heating %	Cooling %	Electric System %
Geothermal	50	---	---
Heat Pump	15	5	---
Individual Heat Pump	30	---	---
Electric Boiler	5	---	---
Chillers	---	40	---
Solar PV	---	---	10
Electricity Grid	---	---	90

7.2.4.2 City Goals

The evaluation of scenario 4d is displayed in Table 7-9. The reasoning is described in bullet points.

Table 7-9: Scenario 4d Classification

Goals	Meeting the City Goals?
Clean	
Reliable	
Affordable	
Predictable	
Transparent	
Local Control	
Wealth Creating	
Innovative	
Just	

- **Clean:** Same as 4a
- **Reliable:** Same as 4a
- **Affordable:** The investment costs of geothermal energy can be very high, if some drill holes prove unusable for district heating. This possess is a major challenge, as the investment costs of geothermal energy are high as standard.
- **Predictable:** Same as 4a
- **Transparent:** Same as 4a
- **Local Control:** Same as 4a
- **Wealth Creating:** Same as 4a
- **Innovative:** Same as 4a
- **Just:** Same as 4a

8. SCENARIO 5 – HYDROGEN CITY

8.1 Technologies

This scenario consists of a complete restructuring of Cambridge to be a hydrogen city. It must be stated that the technologies required are immature and still in a development phase. Furthermore, the conversion of electricity to hydrogen and back to electricity has a significant loss of energy. The solution will require significant expense, but remove all emissions. The principle of the solution is sketched in Table 8-2. Solar PV and wind turbines located outside the city produce hydrogen through an electrolyzer, which is converted back to electricity by a fuel cell located in the city to supply the electricity network and DH&C production facilities as seen in Table 8-1.

Table 8-1: Production Technologies for Scenario 5

	Zone 1	Zone 2	Zone 3	Zone 4
District heating	X		X	X
District cooling	X		X	X
Block heating		X		
Fuel Cell Power Plant	X		X	X
Solar PV	X	X	X	X
Heat Pump	X		X	X
Electric Boiler	X		X	X
Individual Heat Pump		X		
Chillers	X	X	X	X

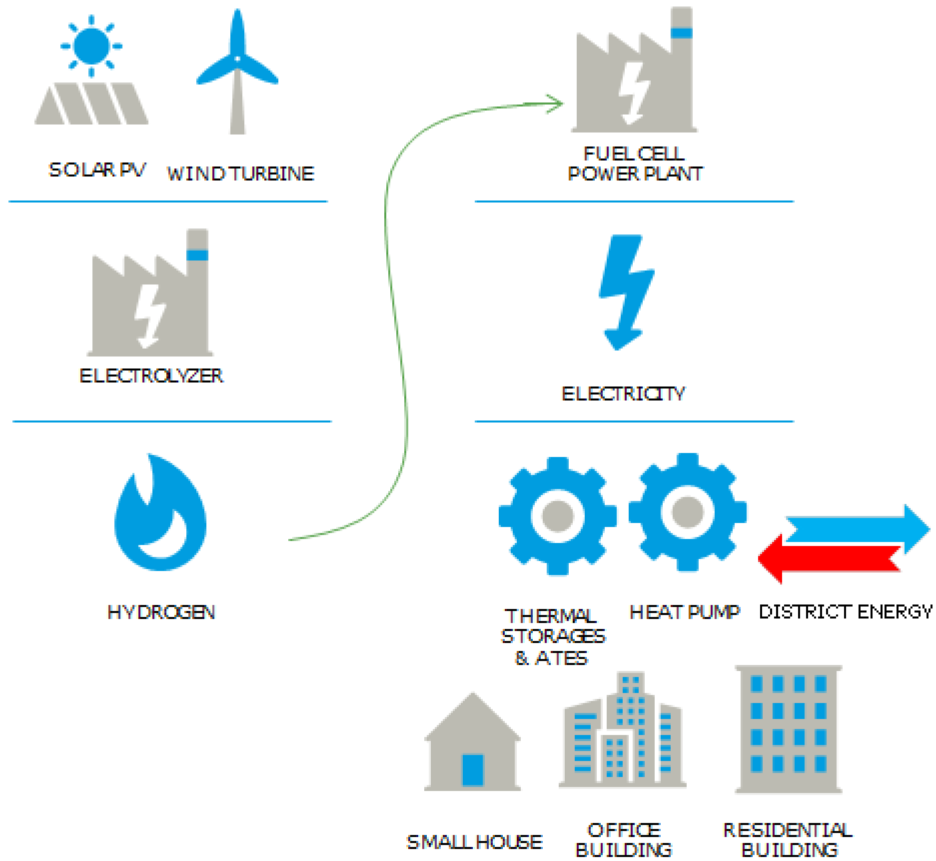

Figure 8-1: Scenario 5 Hydrogen City

8.2 Evaluation of Scenario 5

8.2.1 Energy Supply

The percentage production distribution for scenario 4a is displayed in Table 8-2.

Table 8-2: Energy Supply Scenario 5

	Heating %	Cooling %	Electric System %
Fuel Cell Power Plant	10	---	90
Heat Pump	30	70	---
Individual Heat Pump	35	---	---
Electric Boiler	15	---	---
Solar PV	---	---	10
Chillers	---	30	---

8.2.2 City Goals

The evaluation of scenario 4a is displayed in Table 8-3. The reasoning is described in bullet points.

Table 8-3: Scenario 5 Classification

Goals	Meeting the City Goals?
Clean	
Reliable	
Affordable	
Predictable	
Transparent	
Local Control	
Wealth Creating	
Innovative	
Just	

- **Clean:** The system will reduce the emissions and toxic pollutants to almost zero.
- **Reliable:** The planning of the energy system can be undertaken to ensure a wanted resilience (security of supply). The task will only be to install sufficient capacity of each technology to meet the supply. A large hydrogen storage facility and a large thermal storage facility are required.
- **Affordable:** The entire system will be extremely expensive to both invest in and operate, due to high energy losses. However, it can be argued that the DH&C system required will already be established reducing investment costs.
- **Predictable:** The system will be robust against variations in fuel prices, as it is self-sufficient. However, any longer outages on facilities will lead to production on alternative production units.
- **Transparent:** The cost of energy for consumers will presumably still be complex. However, local (joint) ownership of the energy companies can increase transparency and reduce the complexity by public access to data.
- **Local Control:** Yes, but joint ownership is required.
- **Wealth Creating:** The two universities can benefit from research in renewable energy systems.
- **Innovative:** Enhancing local influence by including local universities, companies and citizens, innovative ideas will emerge. The city can work as example for other cities.
- **Just:** Yes, but local ownership and influence are required. Furthermore, many people owning one large company tends to be more robust than each person owning their own small heat/cold production facility.

9. SCENARIO 6 – DH&C HYDROGEN CITY

9.1 Technologies

This scenario can be seen as the sum of all above scenarios and is much related to scenario 5, as hydrogen is still partially used for electricity production. However, in this scenario other technologies are used to produce electricity and DH&C, as seen in Table 9-1. The fuel cell production is only used to supply electricity demand, when other technologies are insufficient. The city can be fully renewable utilizing a variety of energy sources, but the costs are very high.

Table 9-1: Production Technologies for Scenario 6

	Zone 1	Zone 2	Zone 3	Zone 4
District heating	X		X	X
District cooling	X		X	X
Block heating		X		
Fuel Cell Power Plant	X		X	X
Solar PV	X	X	X	X
Heat Pump	X		X	X
Electric Boiler	X		X	X
Individual Heat Pump		X		
Chillers	X	X	X	X
Biomass CHP	X		X	X
Biomass Boiler		X		
Energy from Waste	X		X	X
Geothermal	X		X	X
Thermal Storage	X		X	X
ATES	X		X	X

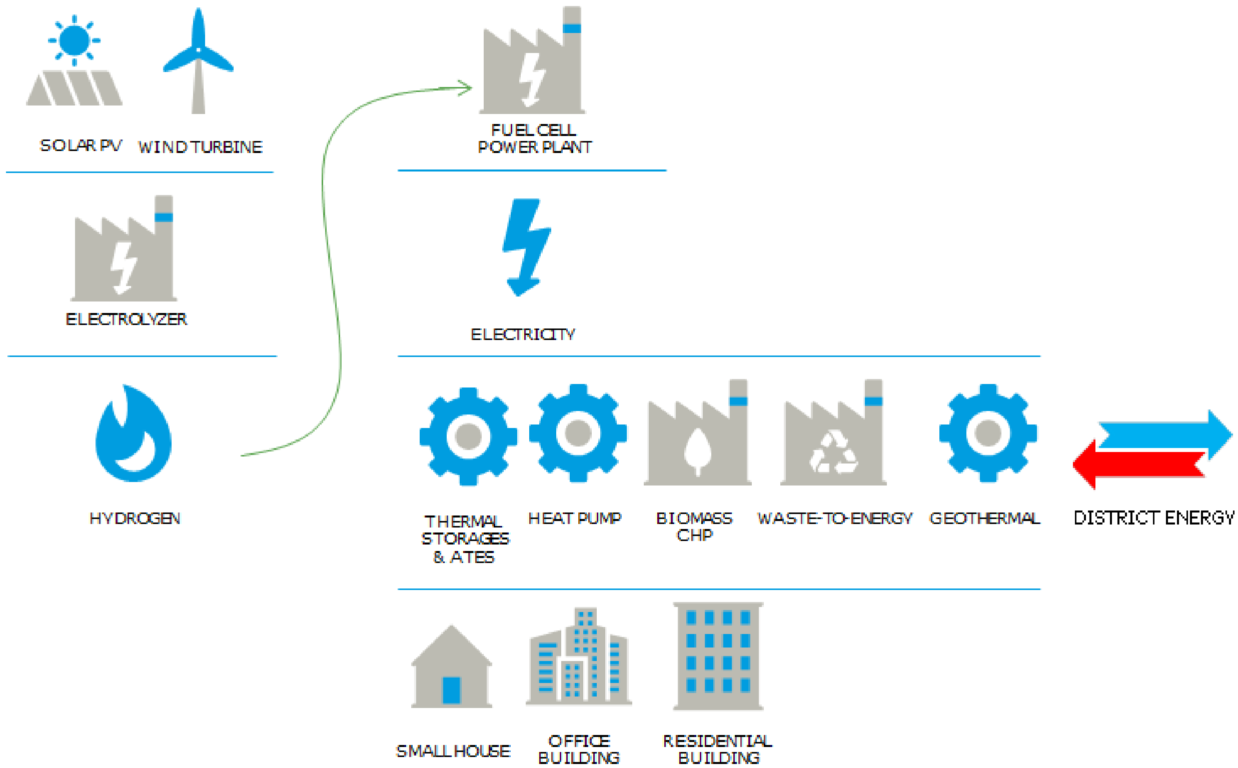

Figure 9-1: Scenario 6 DH&C Hydrogen City

9.2 Evaluation of Scenario 6

9.2.1 Energy Supply

The percentage production distribution for scenario 6 is displayed in Table 9-2.

Table 9-2: Energy Supply Scenario 6

	Heating %	Cooling %	Electric System %
Fuel Cell Power Plant	5	---	60
Heat Pump	20	70	---
Individual Heat Pump	20	---	---
Electric Boiler	5	---	---
Solar PV	---	---	10
Chillers	---	30	---
Biomass CHP	25	---	25
Biomass Boiler	5	---	---
Energy from Waste	10	---	5
Geothermal	10	---	---

9.2.2 City Goals

The evaluation of scenario 4a is displayed in Table 9-3. The reasoning is described in bullet points.

Table 9-3: Scenario 6 Classification

Goals	Meeting the City Goals?
Clean	
Reliable	
Affordable	
Predictable	
Transparent	
Local Control	
Wealth Creating	
Innovative	
Just	

- **Clean:** Same as scenario 5
- **Reliable:** The system will be very reliably as the production is based on several units and energy storages are included.
- **Affordable:** A gradual development to DH&C with hydrogen production as a final opportunity will ensure investments are undertaken in a profitable way
- **Predictable:** The system will be highly reliable with many production units and little reliance on an external electricity grid and fuels. Internal grid reinforcement still required.
- **Transparent:** Same as scenario 5
- **Local Control:** Same as scenario 5
- **Wealth Creating:** Same as scenario 5
- **Innovative:** Same as scenario 5
- **Just:** Same as scenario 5

APPENDIX 1
MEMO MARCH 3RD: WP2 PROCESS

MEMO

Job	**LCESS**
Client	**CCDD**
Date	**02/03/2017**
To	**Seth Federspiel, Susanne Rasmussen**
From	**Isidore Mc Cormack**
Copy to	**Mairead Kennedy**

1. INTRODUCTION

In accordance with the workshop held on February 14th in Cambridge's offices, outlined below is the agreed process for progression of the scenario development and how we propose to shortlist the developed Scenarios to progress towards Work Package 4.

2. WORK PACKAGE 2 PROCESS

Process	No. Scenarios	Input
Ramboll team establish a long list of opportunities through internal workshops – ideas will be derived using the detailed GIS maps prepared under WP1. **Output** Summary memo outlining scenarios: Description of the various technologies proposed, the proposed percentage energy supply split for each technology for that scenario, and whether it meets City goals. Technology descriptions should take account of the City goal/criteria which will be considered when rating.	9-12	Ramboll
Ramboll will present the longlist of scenarios in the summary memo submitted to CCDD and walk through them. CCDD will have one-two weeks to read and consider scenarios. CCDD and Ramboll then meet to score the scenarios together, receive feedback on any idea omissions. **Output** Reduced number of scenarios.	9-12	Ramboll & CCDD
Ramboll will prepare a more detailed summary memo on the selected scenarios for agreement for progression to WP4 assessment. No IRR, NPV – still qualitative level. **Output**	<9-12	Ramboll

Summary memo outlining remaining scenarios in more detail.		
CCDD and Ramboll meet again to score the scenarios together. 4-5 criteria used for shortlisting. Scenario's to be graded 1-5, bad to best. Initially will grade Business As Usual case for each zone. **Output** Reduced number of scenarios.		Ramboll & CCDD
Agreed shortlist presented to AC.	2-3	Presented to AC
Agree WP4 assessment criteria for final scenario assessment.		Ramboll & CCDD

3. PROGRAM

Outlined on the following page is the program for implementation of this WP2 with important client input dates highlighted in the table below. The vertical red line indicates our current position in the program, and the horizontal line indicates the tasks complete. The program is relatively tight due to delays in information gathering to date and completion of WP1. As a result program slack is limited and the highlighted dates need to be adhered to.

Client Input Required	Key Date
Scenario presentation to CCDD	Friday April 7th
CCDD to review and consider Scenarios	7-24th April
CCDD and Ramboll to score scenarios together	Monday April 24th
Scenario Development approach agreement with CCDD	Monday April 24th
CCDD to review and consider Scenarios	5-12th May
CCDD and Ramboll to score scenarios together	Friday May 12th
2-3 Scenarios Agreed for presentation to AC	Friday May 12th
AC Presentation of Scenarios	Likely week of 22-26th May

APPENDIX 2
OVERVIEW OF TECHNOLOGIES PROPOSED FOR EACH ZONE

Zone 1

	Scenario 1	Scenario 2	Scenario 3	Scenario 4a	Scenario 4b	Scenario 4c	Scenario 4d	Scenario 5	Scenario 6
District Heating		X	X	X		X	X	X	X
District Cooling		X	X	X	X	X	X	X	X
Small Scale Community Heating					X				
Block heating			X						
Heat Pump (large)	X	X	X	X	X	X	X	X	X
Electric Boiler	X	X	X	X	X	X	X	X	X
Chillers	X	X	X	X	X	X	X	X	X
Aquifer Thermal Energy Storage		X	X	X	X	X	X		X
Thermal Storage		X	X	X	X	X	X		X
Individual Heat Pump	X		X						
Solar PV		X	X	X	X	X	X	X	X
Small gas boiler									
Biomass CHP				X					X
Biomass boiler					X				X
Waste to Energy						X			X
Geothermal							X		X
Anaerobic digestion									
Fuel Cell Power Plant								X	X

Zone 2

	Scenario 1	Scenario 2	Scenario 3	Scenario 4a	Scenario 4b	Scenario 4c	Scenario 4d	Scenario 5	Scenario 6
District Heating									
District Cooling		X	X	X	X				
Small Scale Community Heating									
Block heating		X	X	X	X	X	X	X	X
Heat Pump (large)									
Electric Boiler	X								
Chillers	X								
Aquifer Thermal Energy Storage									
Thermal Storage									
Individual Heat Pump	X	X	X	X	X	X	X	X	X
Solar PV		X	X	X	X	X	X	X	X
Small gas boiler		X	X	X	X	X	X		
Biomass CHP					X				
Biomass boiler									X
Waste to Energy									
Geothermal									
Anaerobic digestion									
Fuel Cell Power Plant									

Zone 3

	Scenario 1	Scenario 2	Scenario 3	Scenario 4a	Scenario 4b	Scenario 4c	Scenario 4d	Scenario 5	Scenario 6
District Heating		X	X	X		X	X	X	X
District Cooling		X	X	X	X	X	X	X	X
Small Scale Community Heating					X				
Block heating			X						
Heat Pump (large)	X	X	X	X	X	X	X	X	X
Electric Boiler	X	X	X	X	X	X	X	X	X
Chillers	X	X	X	X	X	X	X	X	X
Aquifer Thermal Energy Storage		X	X	X	X	X	X		X
Thermal Storage		X	X	X	X	X	X		X
Individual Heat Pump	X								
Solar PV		X	X	X	X	X	X	X	X
Small gas boiler									
Biomass CHP				X					X
Biomass boiler					X				X
Waste to Energy						X			X
Geothermal							X		X
Anaerobic digestion									
Fuel Cell Power Plant								X	X

Zone 4

	Scenario 1	Scenario 2	Scenario 3	Scenario 4a	Scenario 4b	Scenario 4c	Scenario 4d	Scenario 5	Scenario 6
District Heating		X	X	X		X	X	X	X
District Cooling		X	X	X	X	X	X	X	X
Small Scale Community Heating					X				
Block heating			X						
Heat Pump (large)	X	X	X	X	X	X	X	X	X
Electric Boiler	X	X	X	X	X	X	X	X	X
Chillers	X	X	X	X	X	X	X	X	X
Aquifer Thermal Energy Storage		X	X	X	X	X	X		X
Thermal Storage		X	X	X	X	X	X		X
Individual Heat Pump	X								
Solar PV		X	X	X	X	X	X	X	X
Small gas boiler									
Biomass CHP				X					X
Biomass boiler					X				X
Waste to Energy						X			X
Geothermal							X		X
Anaerobic digestion					X				
Fuel Cell Power Plant								X	X

APPENDIX 5

LCESS AC MEETING MINUTES MAY 16TH

ENERGY

MINUTES OF MEETING

Project	**Low Carbon Energy Supply Strategy for Cambridge**
Subject	**AC Meeting WP2**
Date	**05/16/2017**
Location	**City of Cambridge**
Meeting no.	**3**
Taken by	**Mairead Kennedy, Ramboll**
Participants	**Susanne Rasmussen, City of Cambridge; Seth Federspiel, City of Cambridge; Bronwyn Cooke, City of Cambridge; John Bolduc, City of Cambridge; Meghan Shaw, City of Cambridge; James Cater, Eversource; Emma Corbalan, MIT; Mary Smith, Harvard; Melissa Chan, Climate Protection Action Committee; Patrick Haswell, Veolia, Ellen Katz, DPW, Cambridge; Isidore McCormack, Ramboll; John Flørning, Ramboll; Daniel Kelley, Ramboll.**

Agenda

1. **Introduction**
2. **Advisory Committee Agenda**
3. **Summary Notes**

Date 2017-05-1916

1. Introduction

We would like to extend our thanks to the advisory committee for their questions and feedback at this meeting. This fostered some very interesting conversations and ideas and all input was greatly appreciated. Comments from the AC meeting will be incorporated into the assessment of the high level scenarios developed under Work Package 2 (WP2) and the longlist of scenarios presented will now be reduced to a shortlist for more detailed assessment going forward under Work Packages 3 and 4.

Ramboll
Hannemanns Allé 53
DK-2300 Copenhagen S
Denmark

T +45 5161 1000
F +45 5161 1001
www.ramboll.com

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Version 1a

2. Advisory Committee Agenda

0. Introductions
1. Current status of project
2. Overview of work completed to date
3. Presentation of Scenarios developed under Work Package 2 (WP2)
4. Questions and Feedback
5. Discussion of scenario "fit" with City goals

3. Summary Notes

Introductions provided by Seth Federspiel, followed by presentation of WP2 Scenario development by Isidore McCormack (Ramboll), with support from John Flørning (Ramboll).

Participants were encouraged to ask questions to further their understanding of the general scenarios proposed. These are summarized below.

Scenario 2 Electrification with Centralized District Heating and Cooling

Q: Why are MIT and Harvard shown as the same zone?

A: They are shown in the same zone as these areas have similar characteristics.

Q: Why is just a single technology being considered?

A: A number of sources are under consideration as the heat source, the reason heat pumps predominate is that they enable the city to utilize a variety of heat sources under a fully electrified scenario, other technologies are considered in other scenarios.

Electrical boilers are also considered in Scenario 2.

Q: Where does the electricity come from to fuel this scenario?

A: Full solar build out is assumed within Cambridge, however this will only supply a very small proportion of the overall electricity requirement. The remainder will have to come from purchased green credits or from locally owned renewable energy installations in external locations.

Q: What is the back-up solution for the electrification scenario?

A: There is limited back up in the electrification scenario as it stands. This can be made more robust by utilizing oil backup generation as the gas utility would be redundant in this scenario. Full back up would however require numerous and large emergency generators.

Q: What happens to the existing infrastructure such as MIT, Harvard and Veolia?

A: This will be addressed in more detail in WP4 the purpose of WP2 is to establish the general principles and technology pathway to decarbonization with more specific implications for various stakeholders explored further in WP4.

Q: What is the difference in retrofits required when comparing this scenario to others?

A: The level of changes to building energy systems will be approximately the same.

Comments on the ability to meet Cambridge's goals

Concern was raised regarding the fact that this scenario largely depends on the decarbonization of the New England grid (NEPOOL) and purchasing either a renewable energy facility or green credits from elsewhere.

This is not a local supply solution and depends heavily in external conditions.

It was noted that this seems to be a distribution solution as opposed to a supply solution, more thought is required for the supply of the electricity.
The ability to store energy in this scenario is limited, though it was noted that battery storage in the future could be a viable alternative though not feasible at this scale now.

Less reliance on more controversial supply technologies , this could be a more easily accepted solution to residents and business in Cambridge.

The role of microgrids in improving resilience was raised as a possible measure.

It was noted that some participants felt that this scenario requires much less changes to local infrastructure than others: this can only be confirmed through further investigation. It is noted that external infrastructure requirements for this scenario are likely to be far greater than for other scenarios.

Scenario 4a District Heating and Cooling with biomass combined heat and power (CHP) and biomass boilers

Q: What is the source of biomass?

A: The exact supply needs to be determined through further study, wood chips are the most likely fuel type. This would need to be a certified green source to ensure that Cambridge's low carbon aspirations are protected. It was noted that Cambridge are still considering their position on the renewable credentials of biomass.

Q: Who will own and operate the plant?

A: This is to be determined. Local control or oversight of the plant will be important to ensure that emissions control requirements and transparency goals can be met.

Q: Is waste heat considered in all scenarios?

A: Waste heat will be considered where there is a suitable opportunity. Heat recovery from the sewers appears to be one of the biggest opportunities for waste heat recovery, with potential for other sources such as recovering excess heat from cooling process to also be used. For waste or low grade heat to be utilized a low temperature hot water district energy system would be necessary, as opposed to a steam network.

Q: Has a cost-benefit analysis been carried out for the hot water versus steam network?

A: This is based on our experience of the improved efficiencies achievable in hot water versus steam where up to 30 to 50 % saving in heat losses and subsequent fuel costs.

Q: Would Cambridge act as the utility?

A: This is to be determined.

Comments on the ability to meet Cambridge's goals

Harvard has already investigated biomass and the challenges around fuel transport and storage proved too difficult to overcome.

In general there was considerable concern regarding biomass transportation and storage, particularly for areas where delivery would be by truck.

It is understood that the supply chain in New England is still at an early development stage. A biomass scheme of this scale could help to catalyze the biomass supply chain industry in the area. This could contribute towards wealth creation in Cambridge / MA.

This option has a greater potential for utilizing thermal energy storage.

Scenario 4b District Heating and Cooling with Waste to Energy

As this includes a large element of biomass many of the questions and answers are the same, the waste energy issues are addressed here.

Q: What about the emissions – previous assessment by AC members have demonstrated significant issues with emissions from waste to energy plants.

A: The WtE in Europe plants have very tight environmental controls and are commonly located in dense urban areas with few issues. Emission controls will need to be employed and add cost to a plant. Emissions concerns should be balanced against the impact of other forms of disposal, for example in the community inventory - landfill accounts for the disposal of 20% of the waste but 80% of emissions.

Q: Is the small scale of the project worth the pain of installing waste to energy?

A: Perhaps not - this will be considered in the analysis, however the benefit of local disposal of waste must also be considered.

Q: The plant is sized for available waste, what are the implications of sizing for the entire heat load?

A: Waste would need to be imported from outside of Cambridge and sizing for full heat load would not be recommended. Plants are very expensive and most of the heat would have to be rejected. If sufficient volumes of waste could be secured it would be recommended to design for a maximum of 40-60 % of the annual energy demand to enable many annual full load hours for the plant in operation

Comments on the ability to meet Cambridge's goals

A comment was raised about the fairness of utilizing waste from other cities and removing this as a possible resource from those cities.

Fuel storage was raised as a concern.

Potential to repurpose existing plants and infrastructure.

Scenario 5a Hydrogen City with Heat Pumps

Q: What are the space requirements for a fuel cell?

A: Approximately the same size as three large scale grocery stores

Q: What is the benefit of hydrogen?

A: As a means to store excess renewable electricity generation and utilize at a later date, increases the total amount of renewable electricity that can be used.

Q: Where does the renewable electricity come from?

A: External to the city – the same issues as for Scenario 2a.

Q: Is this economically viable?

A: Not at the moment but may be an option in the future, it is an innovative technology that is growing.

Q: What are the safety concerns?

A: This is a consideration; hydrogen is more explosive that natural gas, however the technology to mitigate this is available. If existing HDPE gas piping is re-used fittings will need to be replaced.

Scenario 5b Hydrogen City with Hydrogen Boilers

This scenario is largely similar to Scenario 5a, instead of a single large scale fuel cell and heat pump individual block and building level units are utilized.

General Comments

Q: What role could demand side reduction measures play in the overall decarbonization?

A: This is a consideration; demand side reduction measures could be appropriate in helping to reduce the load on the grid during peak times by utilizing various methods of smart storage and peak shifting.

Q: Do decisions made now preclude other technologies from being implemented in the future?

A: For the hot water district energy systems, the distribution infrastructure is a way in which changing technologies can be quickly and easily switched into the system. For a fully electrified building level scenario there are many more restrictions on the system development.

APPENDIX 6

LCESS WORKSHOP 3 AC PRESENTAITON MAY 16TH

LOW CARBON ENERGY SUPPLY STRATEGY STUDY, CAMBRIDGE, MA

ADVISORY COMMITTEE MEETING WORKSHOP 3

RAMBOLL

AGENDA

MEETING OBJECTIVE: Agree scenarios for progression to Work Package 4 analysis

PURPOSE:

- Build consensus on future energy supply for City of Cambridge
- Advise City on stakeholders opinions on scenarios and their perspectives

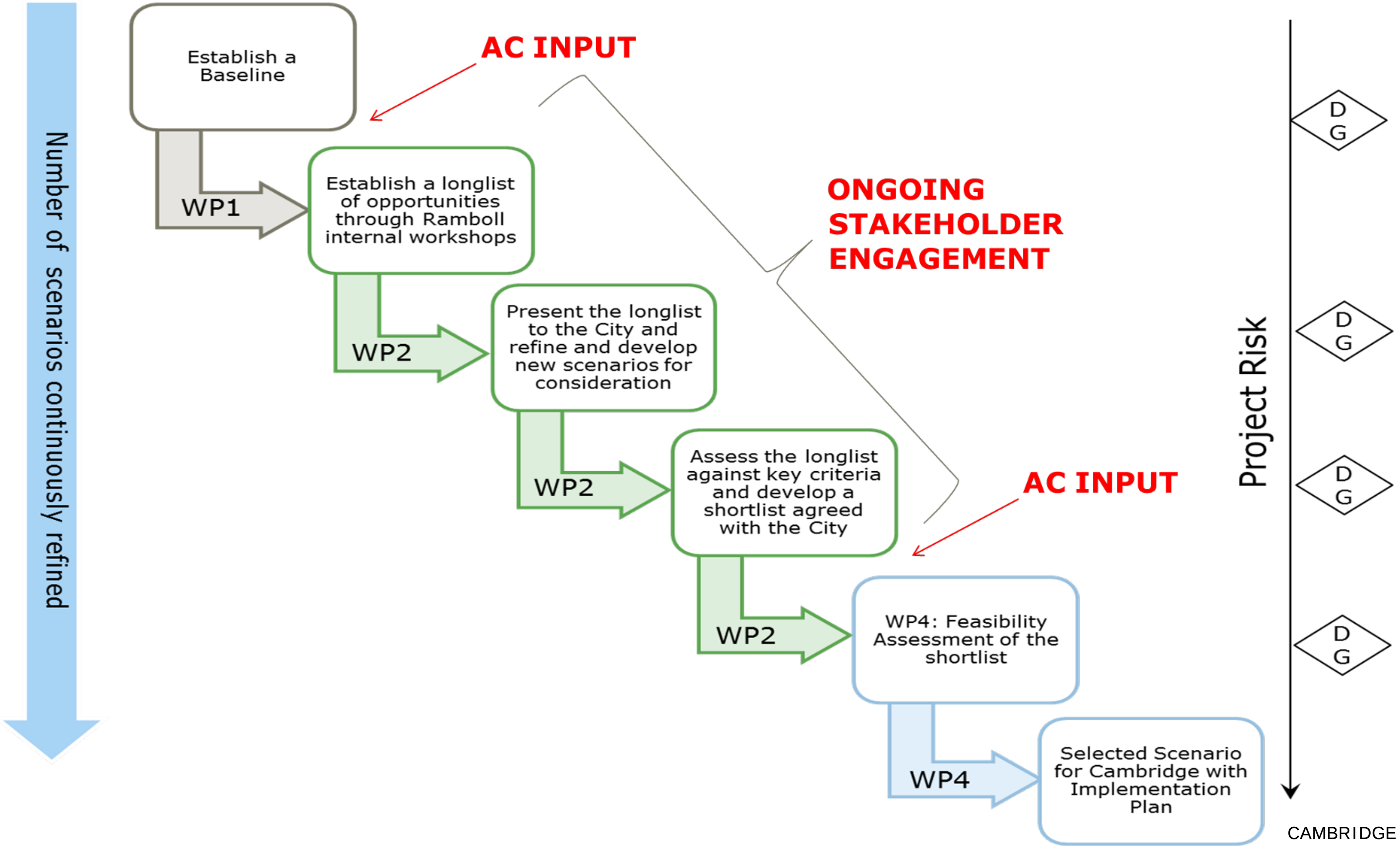
PROCESS:

- Review the scenario selection process and discuss scores provided by AC of 5 Scenarios presented in *Scenario Discussion Report*
- Understand differences of opinions on scenarios and address questions to ensure clear understanding of each scenario
- Agree 1-2 scenarios for progression to WP4

PROJECT COMPONENTS AND CURRENT STATUS

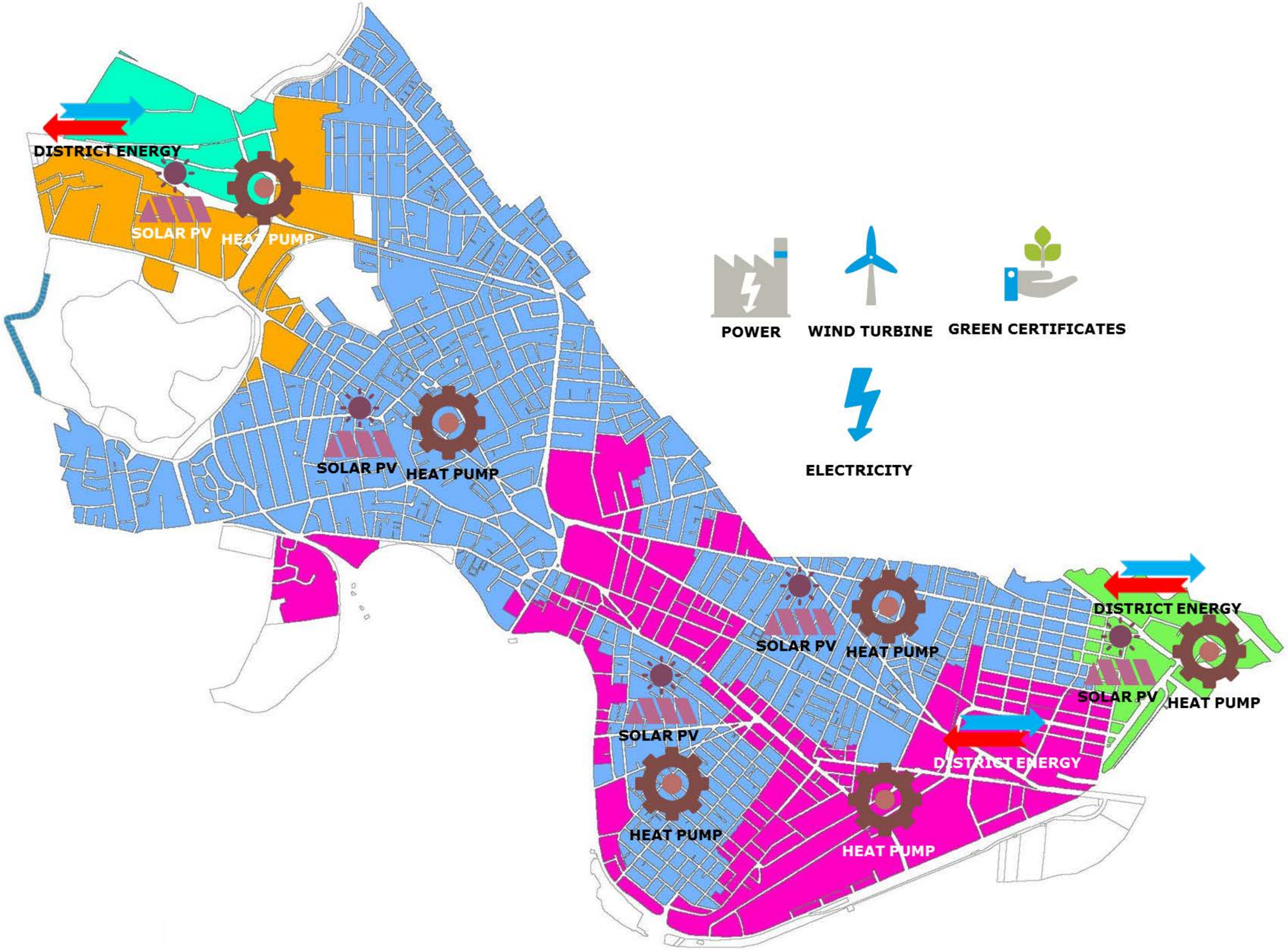
- Work package 1: Baseline situation assessment of City's current energy supply and barriers to low carbon
- Work Package 2: Low Carbon Scenarios Development
- Work Pacakge 3: Change and Benefit Management
- Work Package 4: Technical and economic viability assessment

SCENARIO DEVELOPMENT PROCESS – ITERATIVE ENGAGEMENT AND EVOLVEMENT OF SCENARIOS



RAMBOLL

SC2 – ELECTRIFICATION WITH CENTRALISED DHC



RAMBØLL

SC.2 RELEVANT TABLES

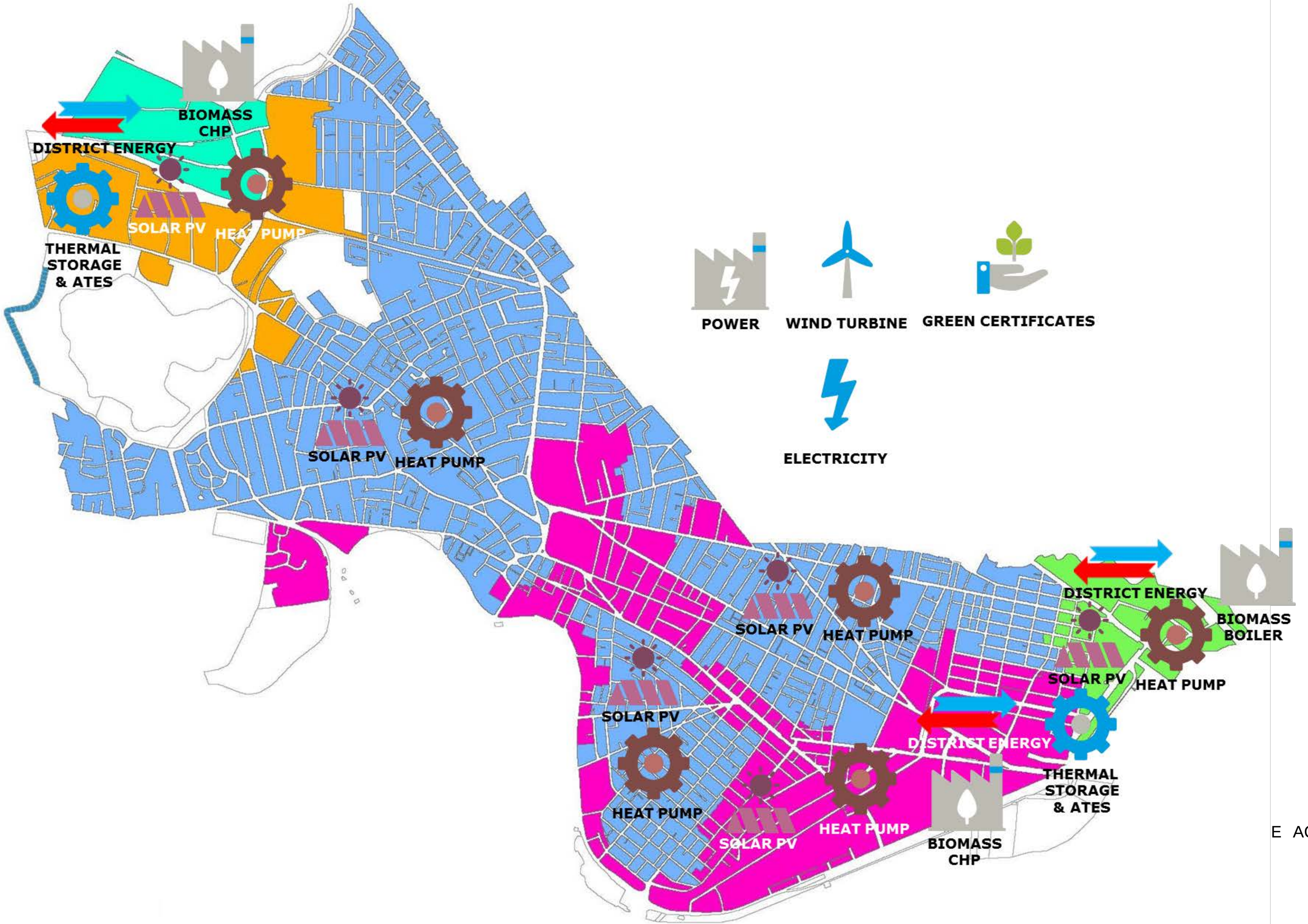
Table 5-2 Scenario component generation capacity, physical size and cost estimate

	Capacity	Required space (ft2)	Rough estimate ($ million)
Heat pumps	150 MW	330,000	100 - 150 $
Electric boilers	150 MW	<50,000	10 – 20 $
Back-up on oil, storage	300 MW	40,000	10 – 20 $
Pit Thermal Energy Storage (PTES)	> 260 million gallons	700,000	40 – 60 $
DH network			100 - 150 $
TTES	13,000,000 gallons	8,600	8 – 12 $
TOTAL Costs			250 – 400 $

Table 5-3: Energy Supply Scenario 2

	Heating %	Cooling %	Electric System %
Individual Heat Pump	40	5	---
Individual Electric Boiler	2.5	---	---
Individual Chillers	---	40	---
DH&C Heat Pump	52.5	20	---
DH&C Electric Boiler	5	---	---
DH&C Chiller	---	35	---
Solar PV	---	---	10
Electricity Grid	---	---	90

SC4A DHC WITHOUT WTE / AD



SC.4A RELEVANT TABLES

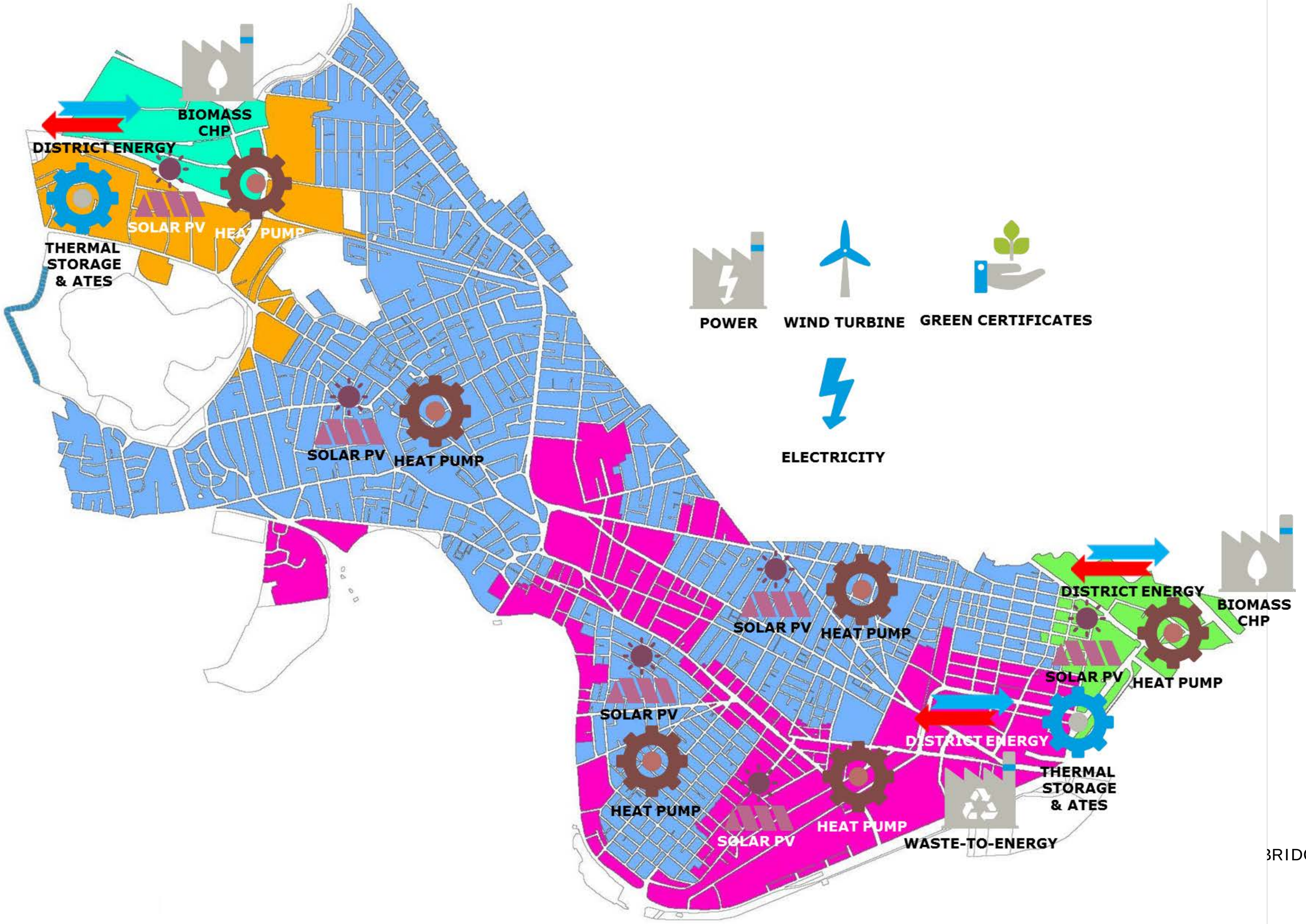
Table 6-2 Scenario component generation capacity, physical size and cost estimate

	Capacity	Required space (ft2)	Rough estimate ($ million)
Biomass CHP	85 MW heat	500,000	100 - 150 $
Heat pumps	50 MW heat	150,000	30 - 50 $
Biomass heat only	30 MW heat	50,000	10 – 20 $
Heat only boilers - oil + storage	300 MW	40,000	10 - 20 $
DH network	NA	NA	100 - 150 $
Tank Thermal Energy Storage (TTES)	50,000 m3	800	8 – 12 $
TOTAL Costs	-	-	250 – 400 $

Table 6-3: Energy Supply Scenario 4a

	Heating %	Cooling %	Electric System %
Biomass CHP	35	---	25
Biomass	15		
Heat Pump	15	5	---
Individual Heat Pump	30	---	---
Electric Boiler	5	---	---
Chillers	---	95	---
Solar PV	---	---	10
Electricity Grid	---	---	65

SC4B DHC WITH WTE / AD



SC.4B RELEVANT TABLES

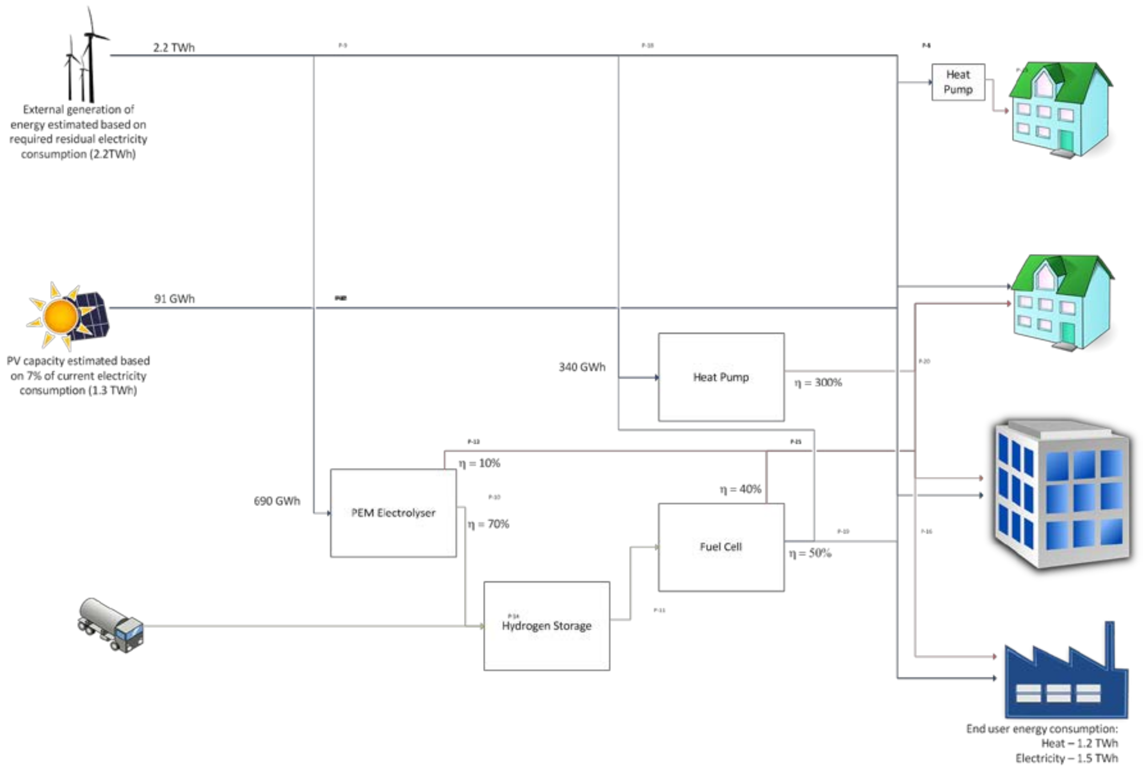
Table 6-5 Scenario component generation capacity, physical size and cost estimate

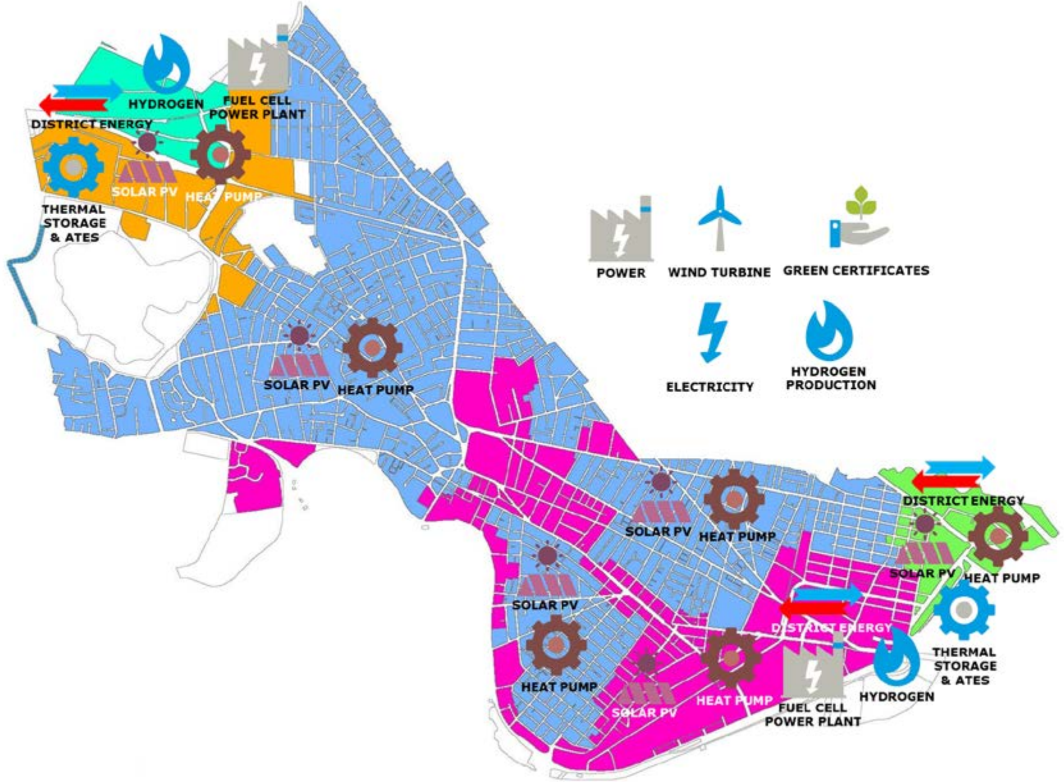
	Capacity	Required space (ft2)	Rough estimate ($ million)
Waste to energy, CHP	10 MW	500,000	40 - 60 $
Biomass CHP	85 MW heat	500,000	100 - 150 $
Heat pumps	50 MW heat	150,000	30 - 50 $
Biomass heat only	30 MW heat	50,000	10 – 20 $
Heat only boilers - oil + storage	300 MW	40,000	10 - 20 $
DH network			M 100 - 150 $
Tank Thermal Energy Storage (TTES)	50,000 m3	800	M 8 – 12 $
TOTAL Costs			M 250 – 400 $

Table 6-6: Energy Supply Scenario 4b

	Heating %	Cooling %	Electric System %
WtE	8	---	2
Biomass, Biomass CHP	42		8
Heat Pump	15	5	---
Individual Heat Pump	30	---	---
Electric Boiler	5	---	---
Chillers	---	40	---
Solar PV	---	---	10
Electricity Grid	---	---	80

SC.5A HYDROGEN





SC.5A RELEVANT TABLES

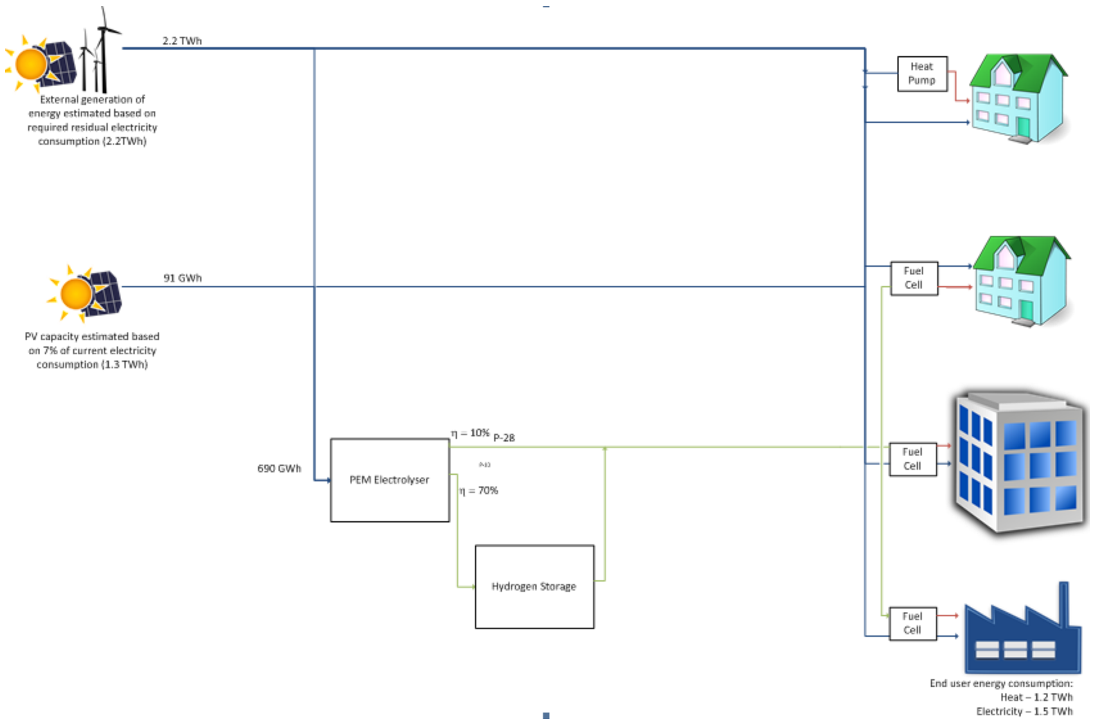
Table 7-2 Hydrogen component requirement costs and capacities

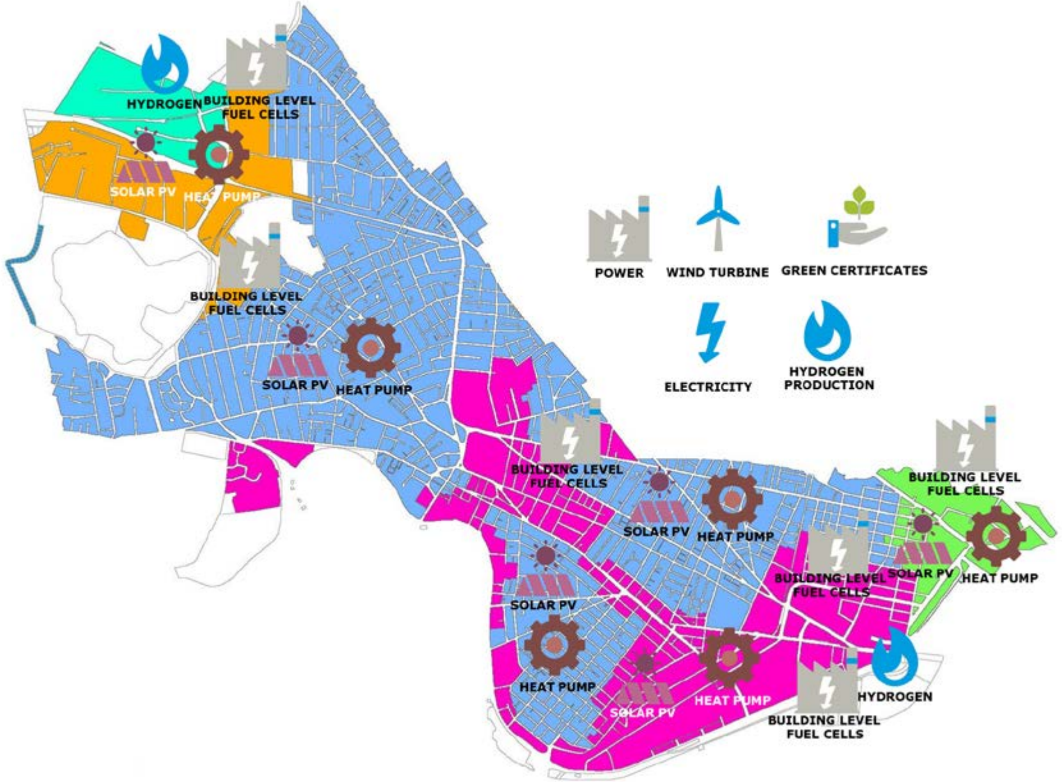
Element	Approximate capital cost ($ million)	Notes
Water electrolysis plant	$71	Indicative cost based on a cost per kg H2 of $900/kW.
Hydrogen compressor	$4.7	Budgetary capex figure for plant needed to compress hydrogen into the buffer store
Hydrogen storage	$11.4	Buffer based on store size for 8.7t H_2. Full plant capacity for 6 hours.
Stationary fuel cell	$1,104	Approx. capex $6,000/kW, fuel cell for regeneration of electricity from hydrogen
Centralized Heat Pump	$150	Heat pump capacity of >250 MW output
District heating network	$100– $150	As other scenarios
Total	$1,500	

Table 7-3: Energy Supply

	Heating %	Cooling %	Electric System %
Fuel Cell Power Plant/Local Fuel Cells	10	---	19
Heat Pump	30	50	---
Individual Heat Pump	35	20	---
Electric Boiler	15	---	---
Solar PV	---	---	10
Chillers	---	30	---
External Renewable Energy source			71%

SC.5B HYDROGEN WITH HYDROGEN BOILERS





SC.5B RELEVANT TABLES – SAME AS 5A

Table 7-2 Hydrogen component requirement costs and capacities

Element	Approximate capital cost ($ million)	Notes
Water electrolysis plant	$71	Indicative cost based on a cost per kg H2 of $900/kW.
Hydrogen compressor	$4.7	Budgetary capex figure for plant needed to compress hydrogen into the buffer store
Hydrogen storage	$11.4	Buffer based on store size for 8.7t H_2. Full plant capacity for 6 hours.
Stationary fuel cell	$1,104	Approx. capex $6,000/kW, fuel cell for regeneration of electricity from hydrogen
Centralized Heat Pump	$150	Heat pump capacity of >250 MW output
District heating network	$100– $150	As other scenarios
Total	$1,500	

Table 7-3: Energy Supply

	Heating %	Cooling %	Electric System %
Fuel Cell Power Plant/Local Fuel Cells	10	---	19
Heat Pump	30	50	---
Individual Heat Pump	35	20	---
Electric Boiler	15	---	---
Solar PV	---	---	10
Chillers	---	30	---
External Renewable Energy source			71%

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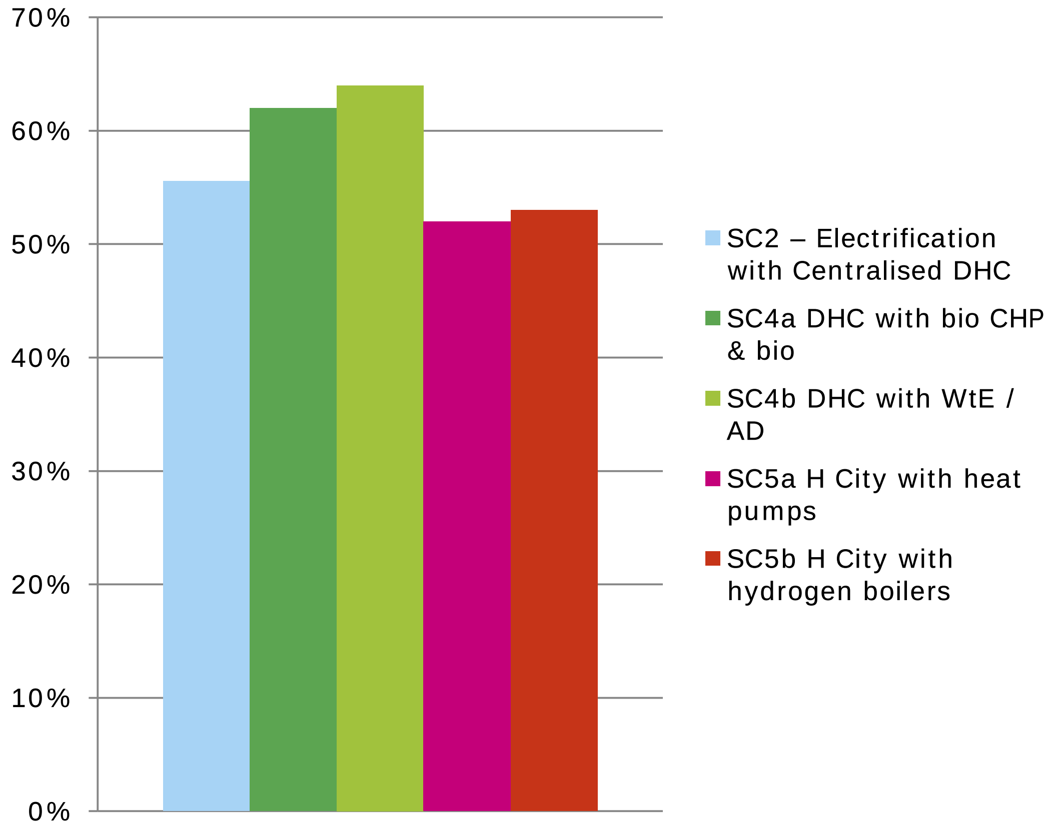
AVERAGE TOTAL % SCORES PER SCENARIO

- Scenario 4 options with DHC receive highest total scores when considering all goals city has



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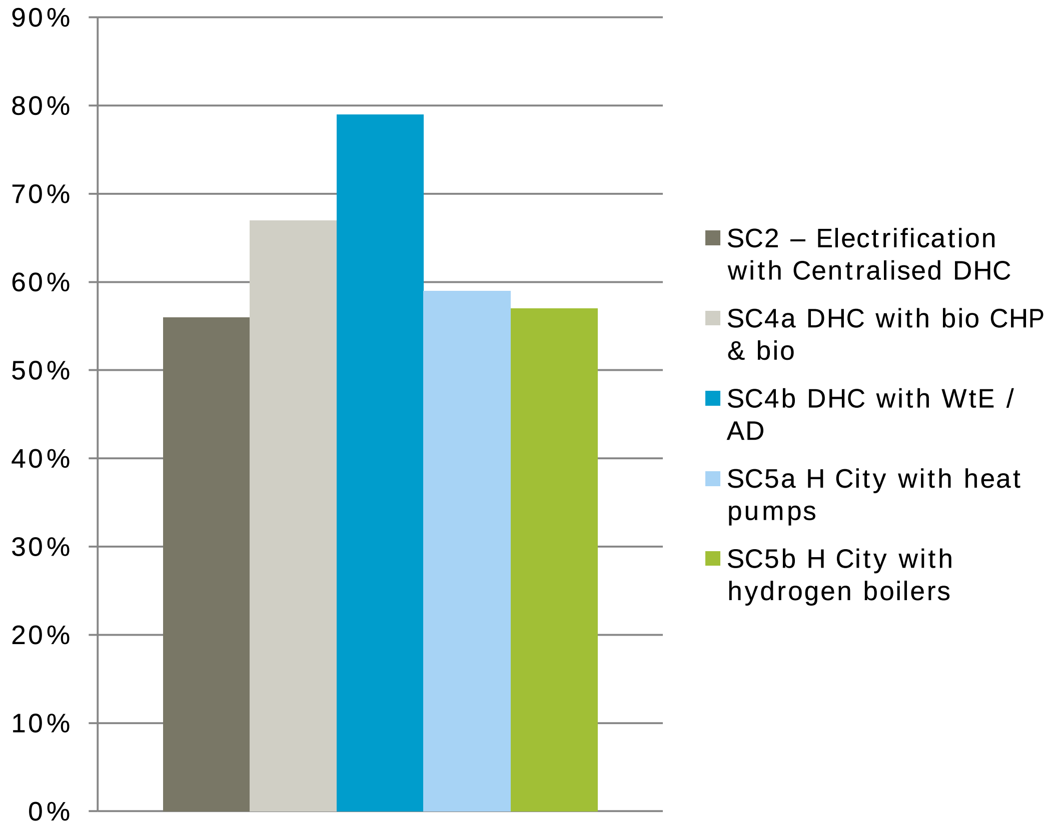
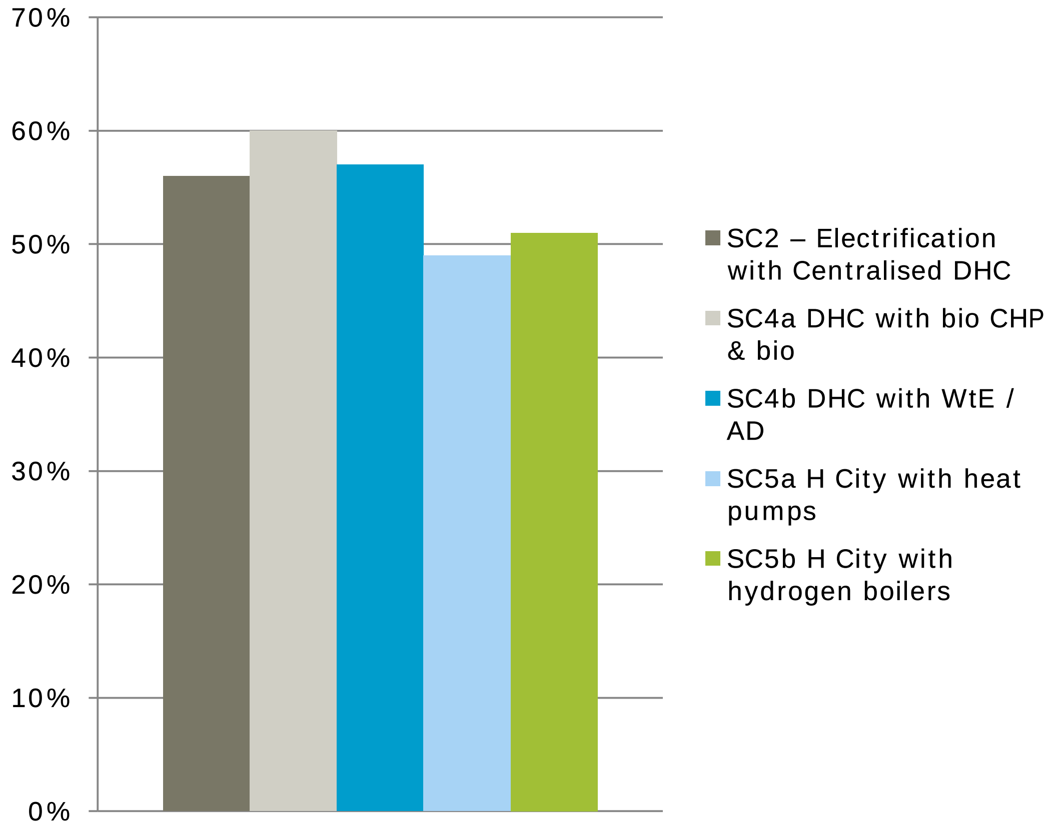
AVERAGE TOTAL % SCORES FOR CLEAN, RELIABLE AND AFFORDABLE PER SCENARIO

- Scenario 4a DHC with WtE/AD receives highest score when only considering the goals of Clean, Reliable and Affordable



AVERAGE TOTAL % SCORES FOR PREDICTABLE, TRANSPARENT, LOCAL CONTROL, WEALTH CREATING, INNOVATIVE AND JUST PER SCENARIO

- Sc.4b DHC with biomass CHP has highest score
- Very close scoring between Sc. 2, 4a and 4b when considering the other City goals of Predictable, Transparent, Local Control, Wealth Creating, Innovative



PROJECT COMPONENTS AND NEXT STEPS

- Work package 1: Baseline situation assessment of City's current energy supply and barriers to low carbon
- Work Package 2: Low Carbon Scenarios Development
- Work Pacakge 3: Change and Benefit Management
- Work Package 4: Technical and economic viability assessment

THANK YOU

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CITY GOALS

- Clean: Reduce carbon emissions and toxic pollutants created by the system.
- Reliable*: Minimize system downtime from outages and ensure high quality of power delivered.
- Affordable*: Keep rates as low as possible and maintain competitiveness.
- Predictable: Minimize rate volatility.
- Transparent: Consumers can understand their power costs and what drives changes in costs.
- Local Control: Give residents greater control over their energy resources and energy choices.
- Wealth Creating: Keep more energy revenue in the local economy instead of exporting it to outside suppliers — to help drive local economic development, create new businesses and jobs.
- Innovative: The system spawns innovation, intellectual property creation, and entrepreneurship.
- Just: The system promotes "energy equity," protecting vulnerable populations from undue hardship, and promotes energy literacy.

APPENDIX 7

LCESS AC MEETING MINUTES FEBRUARY 15TH

RAMBOLL

ENERGY

MINUTES OF MEETING

Project	**Low Carbon Energy Supply Strategy for Cambridge**
Subject	**AC Meeting WP1**
Date	**02/15/2017**
Location	**City of Cambridge**
Meeting no.	**2**
Taken by	**Mairead Kennedy, Ramboll**
Participants	**Steve Lanou, MIT; Melissa Peters, City of Cambridge; Seth Federspiel, City of Cambridge; Charles Hopkins, Vanderweil; Susanne Rasmussen, City of Cambridge; Adam Jacobs, City of Boston; James Cater, Eversource; Mary Smith, Harvard Tina Miller, Cambridge Housing Authority Ben Myers, Compact for a Sustainable Future; Oliver Sellers-Garcia, City of Somerville; Ellen Katz, DPW, Cambridge; Isidore McCormack, Ramboll.**

Agenda

1. **Introduction**
2. **Advisory Committee Agenda**
3. **Summary Notes**
4. **Other Notes**

Date 22/02/2017

Ramboll
Hannemanns Allé 53
DK-2300 Copenhagen S
Denmark

T +45 5161 1000
F +45 5161 1001
www.ramboll.com

1. Introduction

We would like to extend our thanks to the advisory committee for their enthusiastic and valued input at this meeting. This fostered some very interesting conversations and ideas and all input was greatly appreciated. Comments from the AC meeting will be incorporated into the Work Package 1 (WP1) report once formal comments have been received on the draft document, due to be issued this week.

2. Advisory Committee Agenda

0. Introductions
1. Current status of project
2. Demand data collection process
3. Demand maps produced
4. Supply map and options outline
5. Working Groups, Session 1
6. Working Groups, Session 2
7. Constraints and opportunities
8. Regulatory framework
9. City capability
10. Goal comparison
11. Next steps of implementation

3. Summary Notes

Introductions provided by Seth Federspiel, followed by presentation of WP1 methodology and outcomes by Isidore McCormack (Ramboll), with support from Mairead Kennedy (Ramboll) and Charles Hopkins (Vanderweil Engineers).

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Outlined below is the feedback received from the respective teams for each workshop.

Team A - Kilojoules
Steve Lanou, MIT
Melissa Peters, City of Cambridge
Seth Federspiel, City of Cambridge
Charles Hopkins, Vanderweil

Workshop 1

Comments on the supply map produced for WP1:

- Consider routes into the city for biomass and biofuels - transportation and storage - routes of established biomass sources
- Is biomass low carbon?
- Solar is missing from the map
- Consideration of larger scale solar PV arrays
- Consider demarcating geothermal areas - are there some areas of the city that have better or lesser potential - where is geothermal better or worse
- Wind studies - wind in the river?
- Marking up significant municipal infrastructure opportunities

Barriers:

- Implied that there is an imbalance of production / demand
- How to share resources
- Regulatory changes
- Campuses becoming net exporters
- Biomass storage
- Biogas utilization

Workshop 2

Potential Supply Strategy:

- Utilization of green electricity coming into the city
- Understand potential for collaboration and existing agreements
- Regulatory issues impacting solar technology within Cambridge
- Consider district energy for major development centres
- Local wind potential is low
- Onshore and offshore wind is not a direct advantage for the city of Cambridge

Team B - Carbon Busters
Susanne Rasmussen, City of Cambridge
Adam Jacobs, City of Boston
James Cater, Eversource
Mary Smith, Harvard

Workshop 1

Comments on the supply map produced for WP1:

- Excess capacity at Kendall in summer - utilize heat in tri-gen?
- Data centres and ice rinks
- Veolia has exhaust coming out on some cold days
- Wastewater recovery
- Having microgrids to serve these areas - more efficient
- Large scale turbine on Danehy Park - penetrating landfill cap - flicker impact would be the limiting factor (previous study)

Workshop 2

Potential Supply Strategy:

- Ice rink
- District Energy at Alewife, Kendall Square
- Capped Landfill - explosive manholes
- Solar potential
- Collaboration with Boston, Somerville
- External options offshore and onshore wind

Team C - Team Thorium

Tina Miller, Cambridge Housing Authority
Ben Myers, Compact for a Sustainable Future
Oliver Sellers-Garcia, City of Somerville
Ellen Katz, DPW, Cambridge

Workshop 1

Comments on the supply map produced for WP1:

- Mystic power plant
- More detail required around the economic potential
- Thorium molten salts nuclear option – make use of Cambridge's brainpower
- Solar resources not on the mapping
- Utilizing the water treatment facility
- Server rooms
- Sewer pumping station
- Anaerobic digestion - Who owns the waste in Cambridge?

Workshop 2

Potential Supply Strategy:

- Carbon offsets for some developments - used locally
- Waste to Energy at Danehy Park (using landfill gas or a new Anaerobic Digestion facility)
- District Energy potential high in Kendall

- Solar PV on the lake and throughout the city
- Small hydro project -=water department - been revived recently - upstream pumping facilities - turbines in the water - pump up to a facility in Bellwood and insert turbines.

4. Other Notes

It was noted that the majority of utility grade electricity in Cambridge is from regional power plants, if these convert to low carbon there would be less barriers to a low carbon solution in Cambridge. The question posed is: how can the city influence low carbon electricity? Engaging and lobbying state representatives was identified as an important step.

Identified barrier to low carbon electricity in power procurement with the timescales involved, recommendation was to consider products of wholesale electricity buyers.

Suggestion that consideration be given to electrifying the heat supply in Cambridge- this will be considered as the project moves forward.

The importance of technology flexibility for carbon reduction and bridge or enabling transition technologies was also highlighted – this will be a major consideration of the project given the long timeframes.

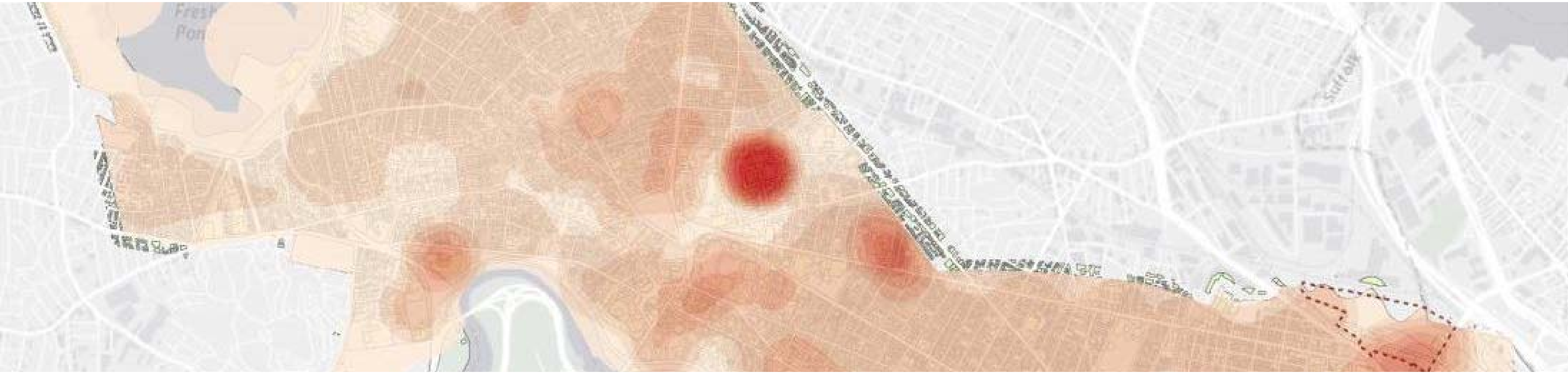
Resiliency was also noted as a key issue, as was ensuring comfort for building occupants.

Suggestion was made that while a wholescale steam to hot water conversion would be difficult and prohibitively expensive this should be considered and encouraged on an incremental basis.

Concerns around public engagement are noted, specifically the need to be careful around terminology and giving the impression that there is a “plan” in place already. The City of Cambridge noted that they are carful to refer to this as a strategy, not a plan, and that the primary function of public engagement is for education.

APPENDIX 8

LCESS WORKSHOP 2 AC PRESENTATION FEBRUARY 15TH



LCESS CAMBRIDGE: 2ND AC MEETING

WP1: EXISTING FACTORS AND BARRIERS REPORT SUMMARY AND WORKSHOP

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AGENDA

1. Current status of project
2. Demand data collection process
3. Demand maps produced
4. Supply map and options outline
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RAMBOLL

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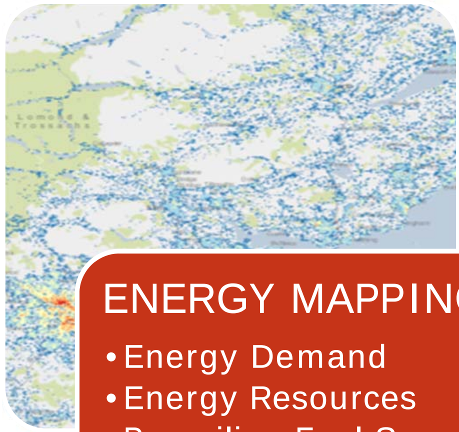
FS1

ACTIVITY FOCUS

Work Package 1: Existing Factors and Barriers

- **Objective:** To develop *the basis* for making scenarios (opportunities) work package through data collection and analysis.
- **Tasks:** To collect all needed data (technical, stakeholders, economical, barriers, current set-up, power structure, regulatory, City capabilities, risks, etc.). To analyze current and future situations.



ENERGY MAPPING

- Energy Demand
- Energy Resources
- Prevailing Fuel Sources
- Existing and Planned Developments, Networks

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FS1 Explain AC role for each of these WPs
Federspiel, Seth; 01-11-2016

Figure 1: Proposed Workplan – Low Carbon Energy Supply Strategy Study

	Month																								
	SEP	OCT				NOV				DEC				JAN				FEB				MAR			
		We																							
	1a	1b	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Advisory Committee Meeting						X										X								X	
Client team meetings	X					X				X						X								X	
Project Start-Up																									
Work Package 1: Existing Factors and Barriers																									
Data Collection																									
Desktop Review																									
Energy Demand Mapping																									
Establish database framework and protocols																									
Establish background mapping																									
Sort, Filter and Clean Data																									
Agree benchmarking assumptions for new developments and existing building archetypes																									
Apply benchmarking for existing building archetypes																									
Apply benchmarking for new developments																									
Agree Energy Demand Baseline with City																									
Energy Demand Mapping _ GIS																									
Energy Supply Mapping																									
Establish protocols for recording supply data																									
Assess and characterize identified existing supply assets																									
Assess and characterize identified planned supply assets																									
Identify, characterize and map potential new supplies																									
Agree Energy Supply Baseline with City																									
Collate and map_GIS																									
Map Opportunities and Constraints																									
Data Analysis																									
Barriers and Risk																									
Reporting																									
Baseline Report - Draft																									
Collate and Produce Energy Demand and Supply Maps																									
Client Review																									
Baseline Report - Final																									
Decision Gate Meeting 1																									
Presentation findings regarding factors and barriers etc.																									
Presentation of Energy Mapping																									
Agree Report for WP1																X									

AGENDA

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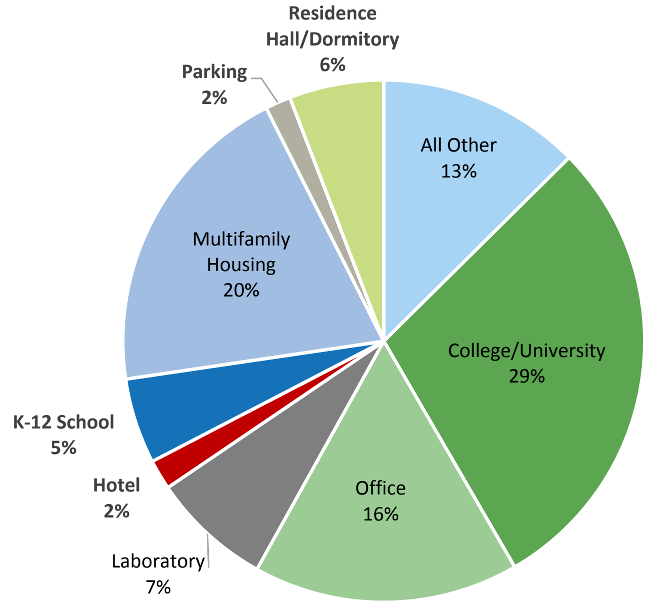
ENERGY DEMAND – DATA COLLECTION PROCESS

- What we know:
  - **Energy consumption** for 780 major properties in Cambridge;
  - **Building use types** for Cambridge properties;
  - **Energy benchmarks** from regional and national studies.
- How we can use this information:
  - **Establish energy demand profiles** for Cambridge properties and Cambridge as a whole.



Nine overarching property types identified within City of Cambridge: 2015 Building Energy Use Disclosure Ordinance

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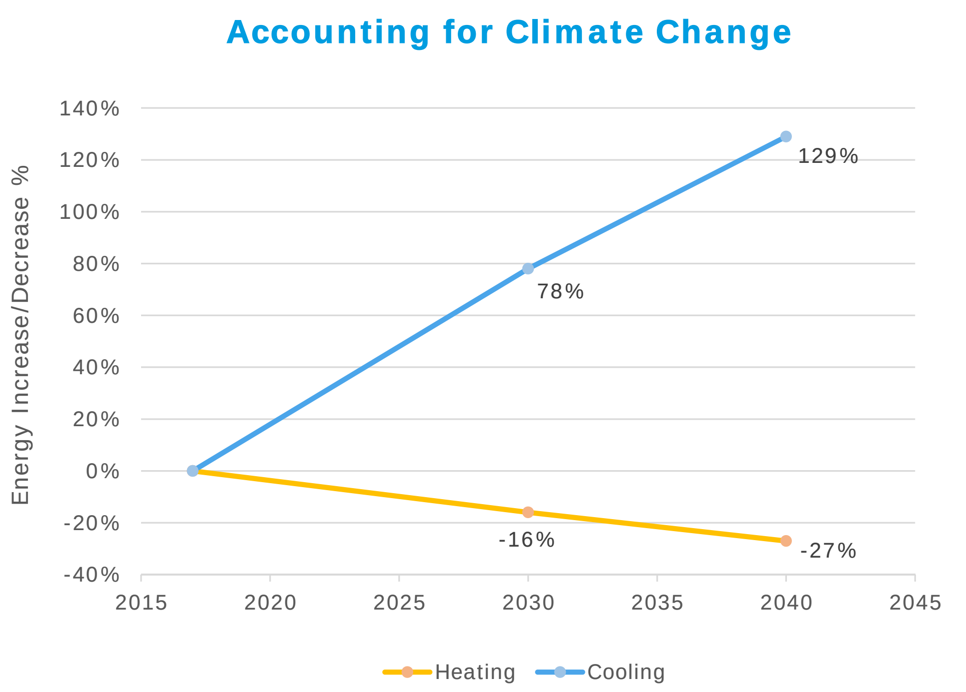
ENERGY DEMAND – PLANNING FOR THE FUTURE

- Accounting for climate change:
  - **Heating** energy;
  - **Cooling** energy.
- Improvements to existing buildings:
  - **Envelope** upgrades (insulation, glazing systems);
  - **Building code** for major renovations
  - **Lighting** upgrades



Anticipated changes to heating and cooling energy due to climate change.

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AGENDA

1. Current status of project
2. Demand data collection process
3. Demand maps produced
4. Supply map and options outline
5. Working Groups, Session 1
6. Working Groups, Session 2
7. Constraints and opportunities
8. Regulatory framework
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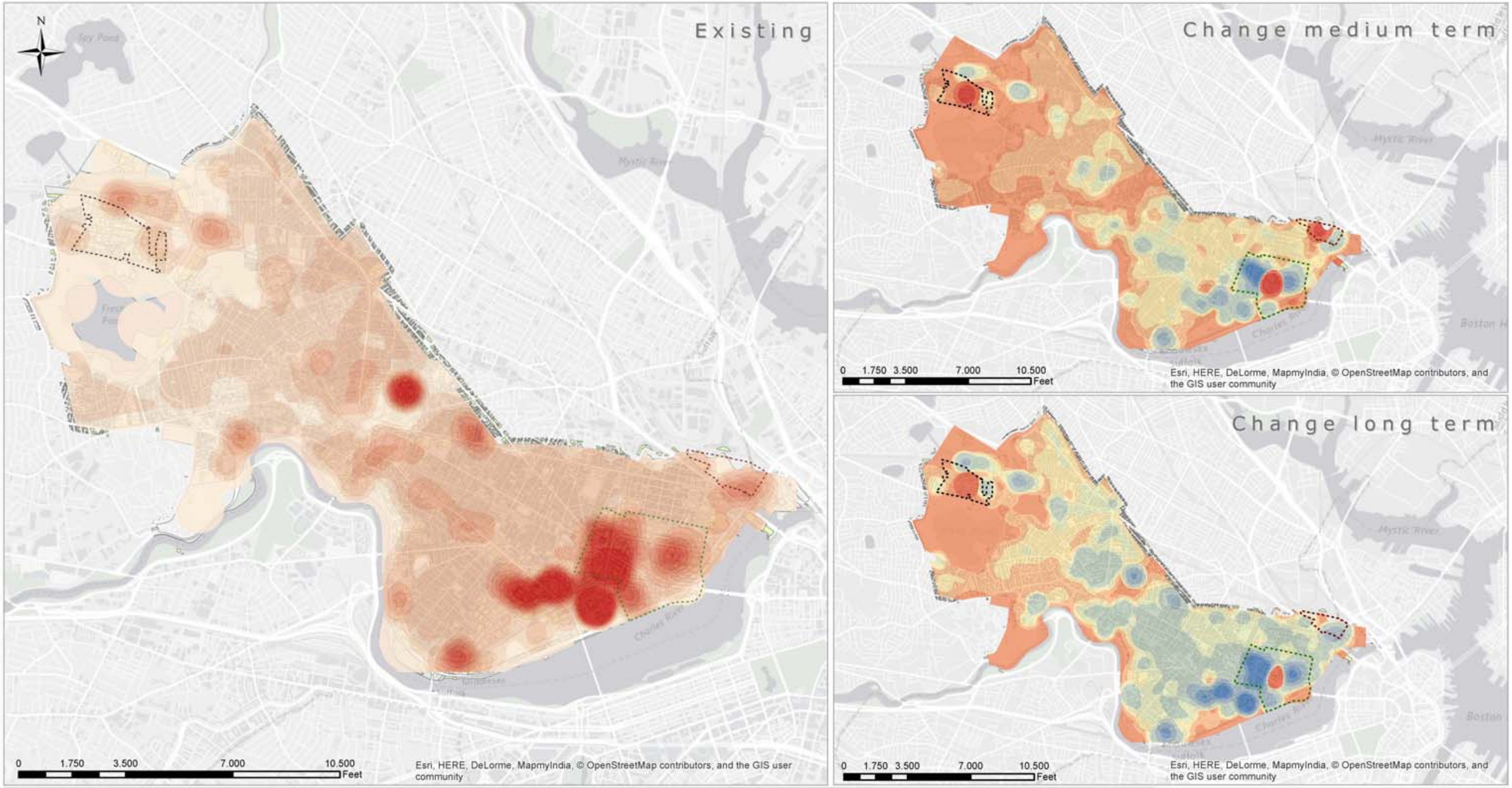

Legend
Landuse parcels
Buildings
AleWife
Kendall_Square
Northpoint

Thermal Demand by kBTU/sq.ft
2 - 10
11 - 20
21 - 40
41 - 60
61 - 80
81 - 100
101 - 125
126 - 150
151 - 200
201 - 621

Change by kBTU/sq.ft
-130.8 - -75.0
-74.9 - -50.0
-49.9 - -25.0
-24.9 - -10.0
-9.9 - -7.5
-7.4 - -5.0
-4.9 - -2.5
-2.4 - 2.5
2.6 - 100.0
100.1 - 451.8

Rev.	Date	Signature	Checked	Approved
1	03/02/2017	SDJ	MK	IMC

Project no. 1100025630

CITY OF CAMBRIDGE ENERGY MASTERPLANNING

Heat demand (current, medium and long term)

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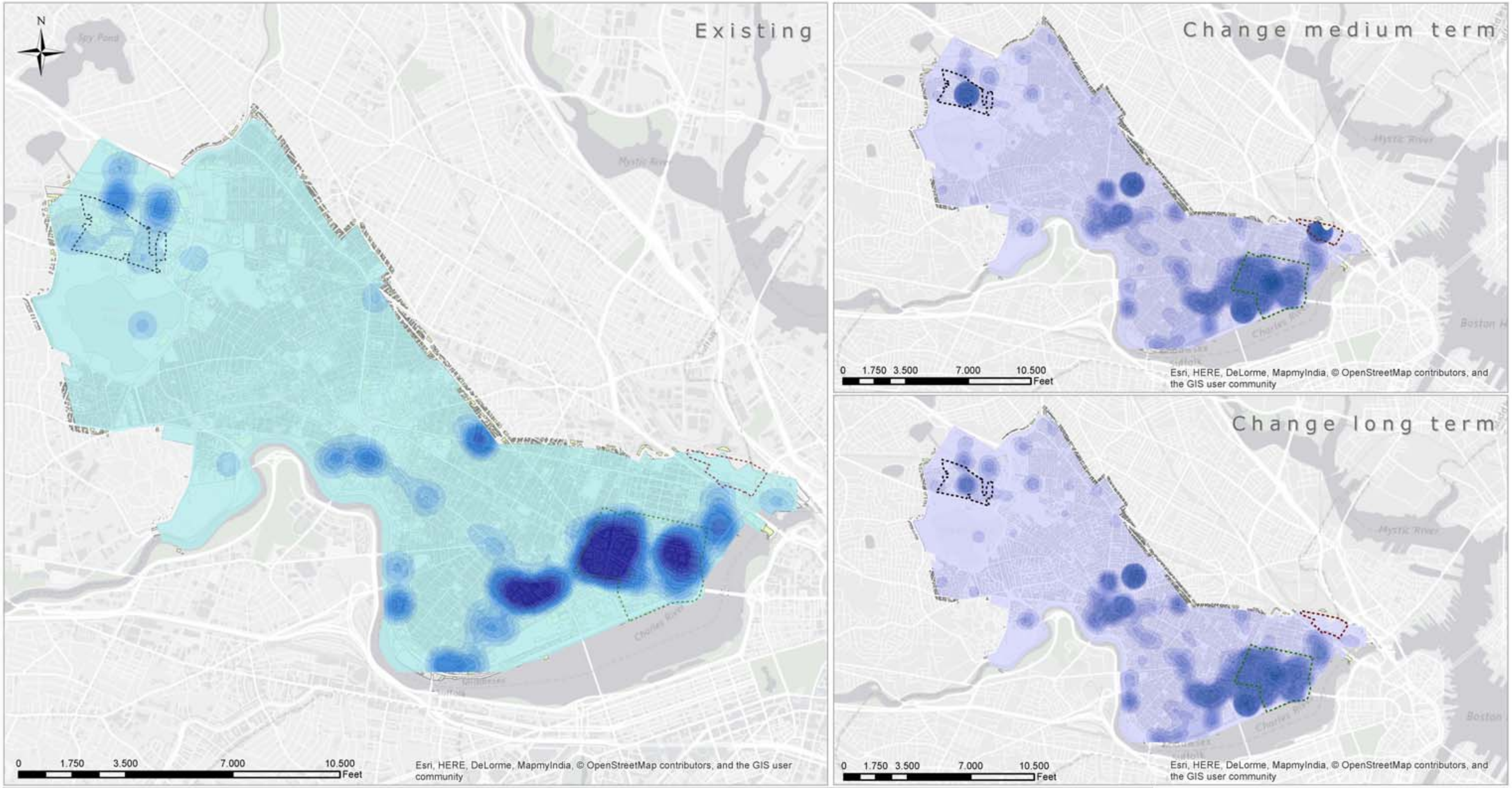
Cambridgema.gov



- Landuse parcels
- Buildings
- AleWife
- Kendall_Square
- Northpoint

Cooling Demand by kBTU/sq.ft

- 0 - 2
- 3 - 4
- 5 - 6
- 7 - 8
- 9 - 10
- 11 - 15
- 16 - 20
- 21 - 25
- 26 - 30
- 31 - 57

Change by kBTU/sq.ft

- 0 - 2
- 3 - 4
- 5 - 6
- 7 - 8
- 9 - 10
- 11 - 20
- 21 - 50
- 51 - 100
- 101 - 150
- 151 - 220

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1	03/02/2017	SDJ	MK	IMC

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CITY OF CAMBRIDGE ENERGY MASTERPLANNING

Cooling demand (current, medium and long term)

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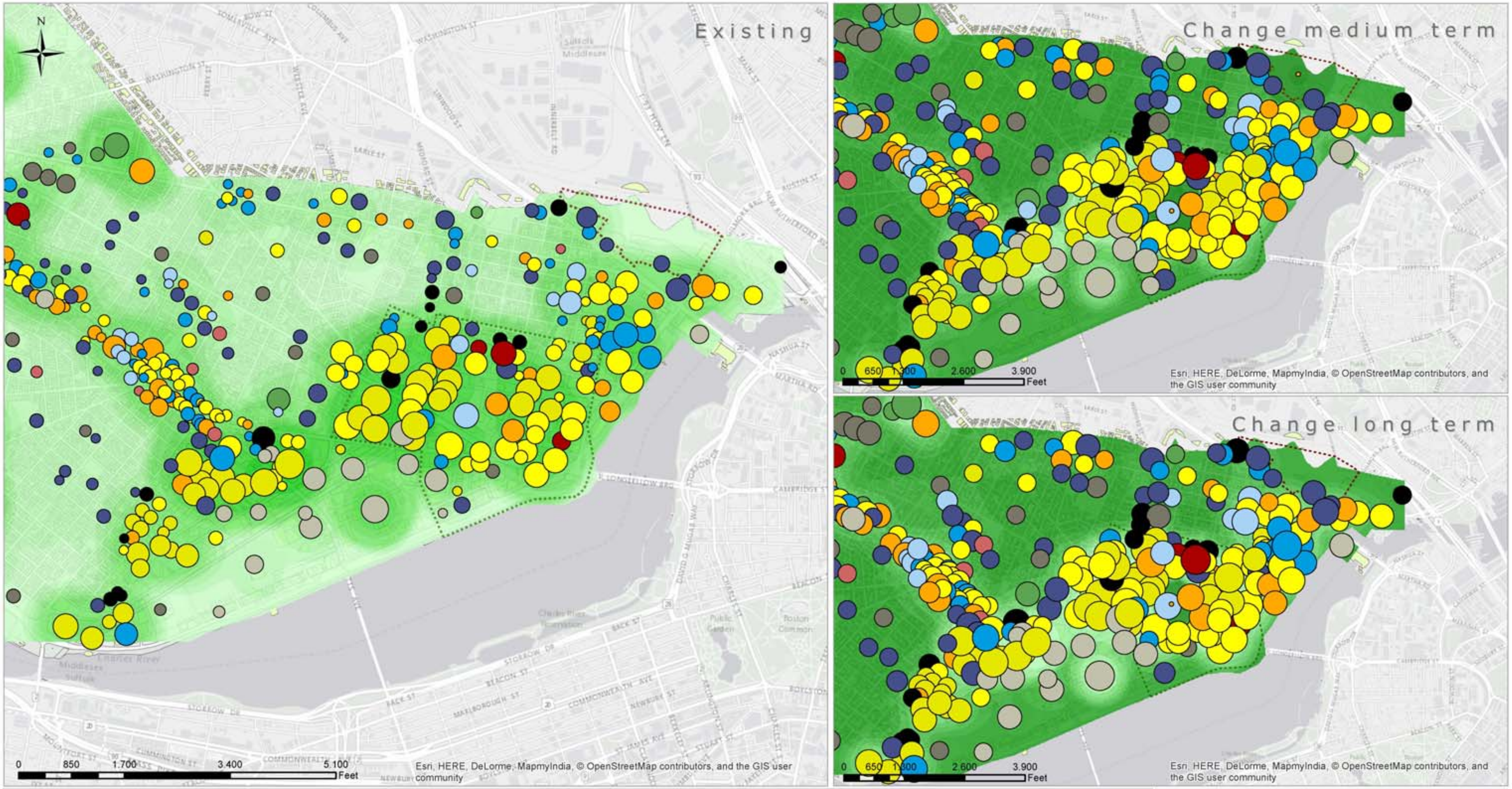

Landuse parcels
Buildings
Kendall_Square
Northpoint

Electricity Demand by kBTU/sq.ft
0 - 5
6 - 10
11 - 15
16 - 20
21 - 25
26 - 50
51 - 75
76 - 100
101 - 250
251 - 453

Building type
Assisted Living/Boarding House
Charitable/Religious
Commercial
Education
Government Operations
Health
Higher Education
Industrial
Mixed Use
Office
Office/R&D
Residential
Transportation
Utility

Electricity demand above 500,000 kBTU
500,000 - 750,000
750,001 - 1,000,000
1,000,001 - 2,500,000
2,500,001 - 5,000,000
5,000,001 - 7,500,000
7,500,001 - 10,000,000
10,000,001 - 25,000,000
25,000,001 - 50,000,000
50,000,001 - 100,000,000
> 100,000,001

Change by kBTU/sq.ft
-77 - -50
-49 - -20
-19 - -15
-14 - -10
-9 - -8
-7 - -5
-4 - -3
-2 - 0
1 - 100
101 - 315

Change by kBTU
< -10,000,000
-9,999,999 - -5,000,000
-4,999,999 - -1,000,000
-999,999 - -500,000
-499,999 - -100,000
-99,999 - -50,000
-49,999 - 0
1 - 1,000,000
1,000,001 - 25,000,000
> 25,000,001

Rev.	Date	Signature	Checked	Approved
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Project no. 1100025630

CITY OF CAMBRIDGE ENERGY MASTERPLANNING

Electricity demand (current, medium and long term)
South east city focus

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AGENDA

1. Current status of project
2. Demand data collection process
3. Demand maps produced
4. Supply map and options outline
5. Working Groups, Session 1
6. Working Groups, Session 2
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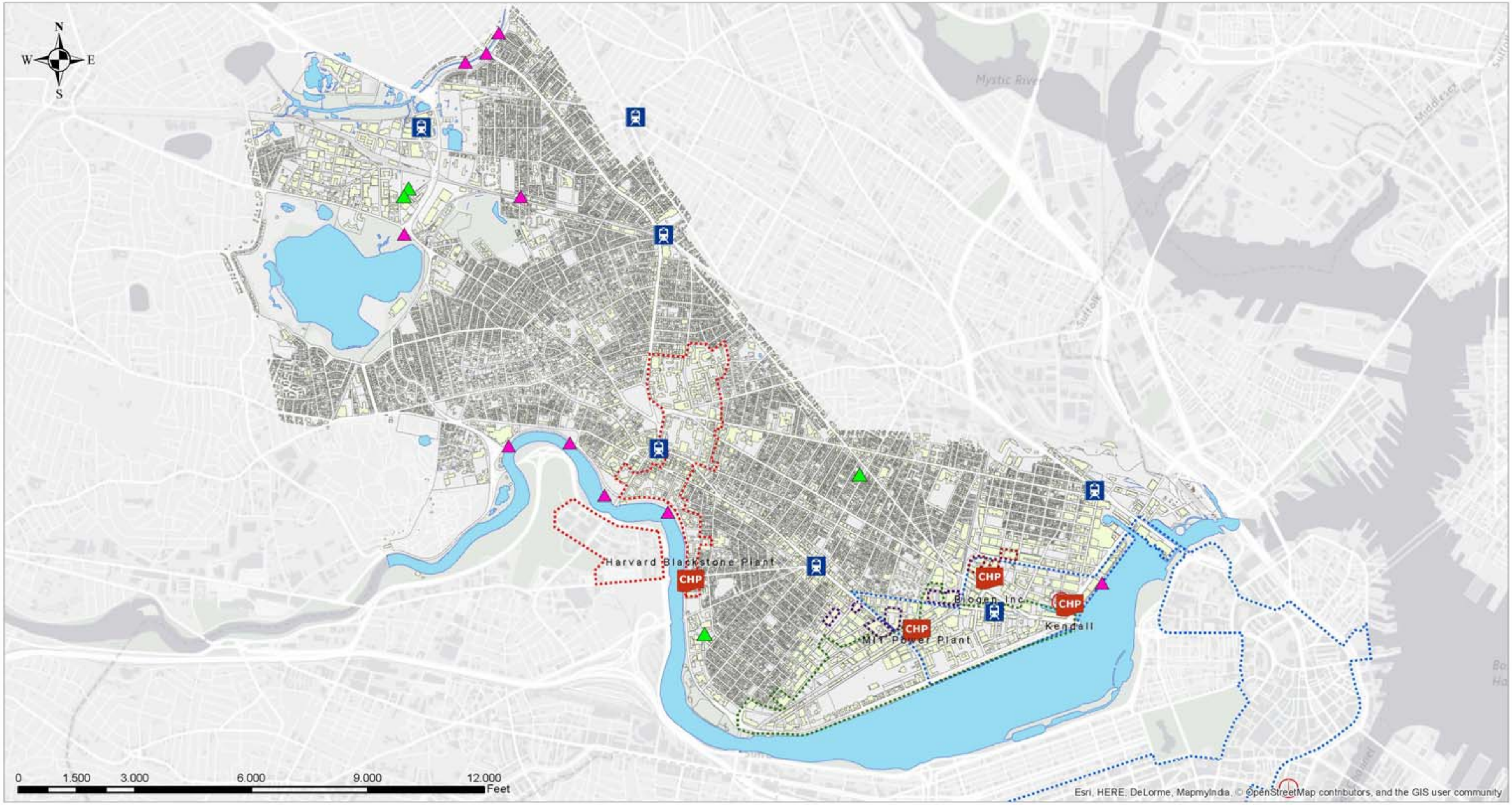

Legend				
Landuse parcels	Harvard Steam System Area	BIOGEN Steam System Area	Combined heat and power	MBTA Stations
Buildings	MIT	Novartis Steam System Area	Steam Generating Plant	Waste Water Storage Point
Water Bodies with cooling / heating potential	Veolia Service Territory		Tranformer Station	

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Project no. 1100025630 Scale: 1:74000

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CITY OF CAMBRIDGE ENERGY MASTERPLANNING

Alternative Supply sources

AGENDA

1. Current status of project
2. Demand data collection process
3. Demand maps produced
4. Supply map and options outline
5. Working Groups, Session 1
6. Working Groups, Session 2
7. Constraints and opportunities
8. Regulatory framework
9. City capability
10. Goal comparison
11. Next steps of implementation

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WORKING GROUP TEAMS

TEAM A

- Mary Smith, Harvard
- James Cater, Eversource
- Brad Swing, Adam Jacobs, Travis Sheehan, Boston
- Susanne Rasmussen, CCDD
- Steve Lenkauskas, Dept. of Electrical Cambridge

TEAM B

- Emma Corbalan, MIT
- Patrick Haswell, Veolia
- Melissa Peters, Community Planning
- Melissa Chan, Climate Protection Action Committee

TEAM C

- Ben Myers, Compact for a Sustainable Future
- Oliver Sellers-Garcia, City of Somerville
- Ellen Katz, Dept. of Public Works Cambridge
- Tina Miller, Cambridge Housing Authority

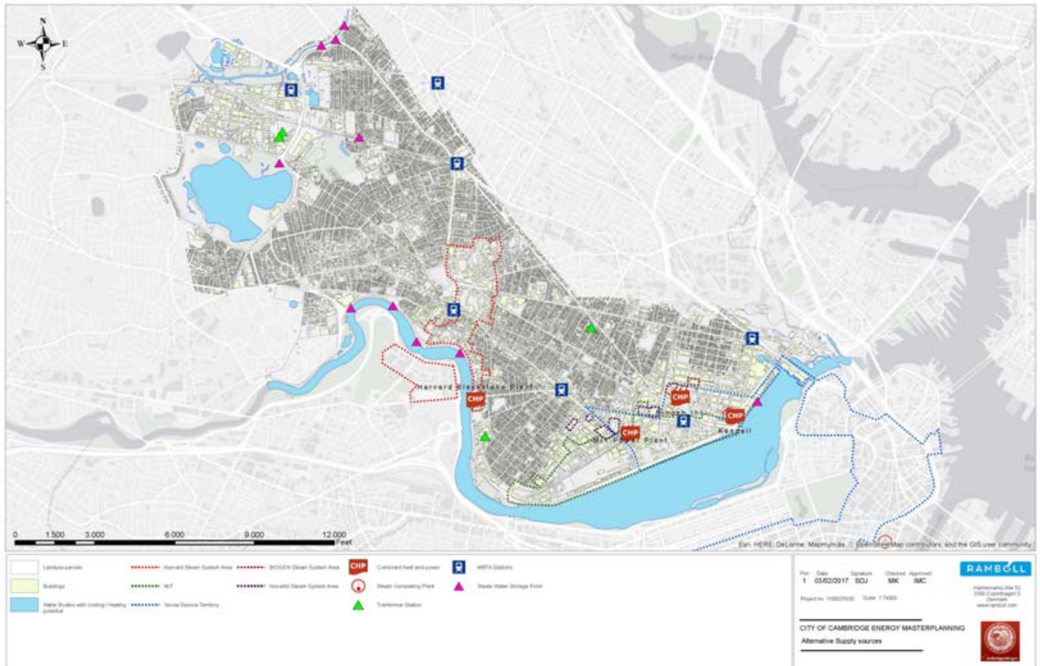
WORKING GROUPS, SESSION 1

Task 1: What is your low carbon team name?

Task 2: Please consider the Supply Map provided and list of current and potential supplies for Cambridge

- What is missing from supply map / list of supplies (highlighted in green)?
- What does the team foresee as being difficult / barriers to implementation in Cambridge?

Session 1 duration: 12 minutes
Present findings: 1 minute per team
Please use post-its and pens to mark up as needed



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AGENDA

1. Current status of project
2. Demand data collection process
3. Demand maps produced
4. Supply map and options outline
5. Working Groups, Session 1
6. Working Groups, Session 2
7. Constraints and opportunities
8. Regulatory framework
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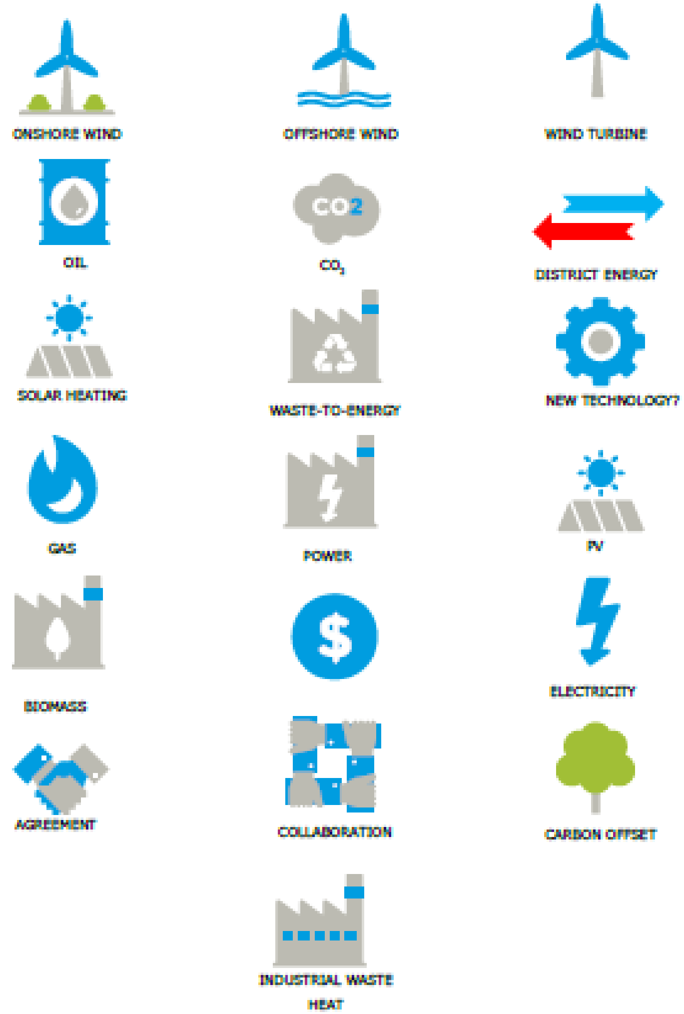
11. Next steps of implementation

WORKING GROUPS, SESSION 2: WHAT DO YOU SEE AS THE NET ZERO ENERGY SUPPLY FUTURE OF CAMBRIDGE?

BUILD YOUR OWN LOW CARBON ENERGY SUPPLY STRATEGY

- Info-graphics outline supply options
- Use pictogram stickers supplied to indicate on the maps provided what you think is required for low carbon energy supply for Cambridge – feel free to draw or write on maps to elaborate

Session 1 duration: 12 minutes
Present findings: 1 minute per team
Please use post-its and pens to mark up as needed



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AGENDA

1. Current status of project
2. Demand data collection process
3. Demand maps produced
4. Supply map and options outline
5. Working Groups, Session 1
6. Working Groups, Session 2
7. Constraints and opportunities
8. Regulatory framework
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10. Goal comparison
11. Next steps of implementation

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CONSTRAINTS AND OPPORTUNITIES: ENERGY NETWORKS (REFERS TO HEATING, COOLING AND ELECTRICITY NETWORKS)

Constraint

- Congested utility space in city
- Civil works costs: Any opportunity to de-risk network routing should be considered at the earliest possible stages of a project
- Lack of available data on exact locations of other existing and planned services
- Lack of data on planned works by stakeholders

Opportunity

- Coincide installation with planned road works
- Coincide works with new developments planned over the duration of the low carbon energy supply strategy
- Green Line Extension of the T is planned by 2021
- Timing the installation of energy networks with other disruptive construction could help to reduce costs and reduce disruption to the public

CONSTRAINTS AND OPPORTUNITIES: SUPPLY ASSETS

Constraint

- Cambridge is committed to considering non-fossil fuel alternatives for the city, but do not have direct control over any of the existing plants and the future plans that the operators of these facilities may have
- Not having direct control of energy supply may prove to be a constraint to meeting the goals of Cambridge.
- Lack of detailed data on supply situation of relevant stakeholders: RFI's outstanding

Opportunity

- Each of the three main plant operators (Veolia, Harvard, MIT) have plans for reducing their own GHG emissions
- Main plant operators with control over supply have engaged in a meaningful way with this strategy development process to ensure a workable cross stakeholder strategy solution is developed.

CONSTRAINTS AND OPPORTUNITIES: DEMAND SIDE

Constraint

- Changes due to Net Zero Actions and climate change will impact the energy demand on which energy networks are sized will change.
- Such changes may impact the business case of the network by reduced heat sales if new connections do not materialize
- Cooling network demands are predicted to increase, could mean networks would not be capable of supplying the full demand of customers

Opportunity

- Heating demand reduction may free up capacity in networks for new connections

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10. Goal comparison
11. Next steps of implementation

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REGULATORY FRAMEWORK

Electricity

- Massachusetts operates an unbundled electricity sector
- DPU Regulation 220 CMR 8.00 outlines the conditions for the sale of electricity
- Distributed Generation is possible through interconnection - approval from the local utility / distribution company (Eversource in Cambridge) needed
- Net metering allowed with caps
- Green Communities Act of 2008: goal for clean energy generation to serve 20% of customer load by 2020

Initiatives, obligations and incentives:

- Renewable Energy Portfolio Standard (RPS)
- RPS Solar Carve Out
- Alternative Energy Portfolio Standard (APS)
- Renewable Energy Certificates (RECs)
- Alternative Compliance Payments (ACPs)
- Database of State Incentives for Renewables and Efficiency (DSIRE) website lists 163 programs that offer incentives, policies or technical resources to promote distributed generation
- Integrated Resource Planning
- Grid Modernization Plans

REGULATORY FRAMEWORK

Heating and Cooling

- Supply of steam for heating is regulated in Massachusetts according to 220 CMR 20.00
- District energy systems supplied by hot or chilled water are not specifically regulated through the Department of Public Utilities in MA.
- Cooling and heating system allowances and limitations for the City of Cambridge are defined by the Massachusetts Building Code: 8th Edition Base Code (780 CMR)

Initiatives, obligations and incentives:

- DOER is preparing draft regulations to include Renewable Thermal in the APS
- Waste heat usage from Energy from Waste and Combined Heat and Power is incentivized through the APS
- DOER and MassCEC provides Renewable Heat Incentives for residential, business, commercial and industrial heat consumers

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REGULATORY FRAMEWORK

Natural Gas

- Regulation 220 CMR 14.00 outlines how the unbundled gas network in Massachusetts is to provide services related to the provision of natural gas.
- The DPU Gas Division ensures that gas companies provide their customers with the most reliable resource at the lowest possible cost.
- Gas Division is responsible for the regulation of the eight investor-owned gas distribution companies in Massachusetts
- Eversource is the gas supplier in Cambridge
- The Gas Division monitors the market at the regional and national level to ensure that the Massachusetts consumers continue to receive the economic and environmental benefits that natural gas has to offer
- 220 CMR 101.00 through 113.00 outline the Gas Distribution Code for Massachusetts and are designed to ensure safe operating practices for persons engaged in the storage, transportation and distribution of gas.

REGULATORY FRAMEWORK

Storage

- 05/2015, MA launched the Energy Storage Initiative – Goal: Advancing energy storage capability within the state
- Energy storage goals for state currently being set
- To date, energy storage in Massachusetts has been primarily concentrated on pumped hydro-storage.
- Massachusetts and the City of Cambridge currently offer a number of incentives for energy storage applications but incentives are primarily limited to fuel cells operating at the building level.

New Energy Facility Construction

- The Energy Facilities Siting Board ("Siting Board ") license the construction of major energy infrastructure in Massachusetts, including large power plants, electric transmission lines, natural gas pipelines and natural gas storage facilities.
- The Siting Board ensure a reliable energy supply for the Commonwealth with a minimum impact on the environment at the lowest possible cost.

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AGENDA

1. Current status of project
2. Demand data collection process
3. Demand maps produced
4. Supply map and options outline
5. Working Groups, Session 1
6. Working Groups, Session 2
7. Constraints and opportunities
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CITY CAPABILITY TO BECOME INVOLVED IN ADDRESSING THE FUTURE ENERGY SUPPLY OF CAMBRIDGE

Financial Capability

- City of Cambridge has a healthy financial status
- AAA rated bond issuing capability
- Precedence of the City issuing bonds to fund capital projects

Public Interest

- Strong interest of the community in its development and in its understanding of the need for alternatives to fossil fuel supplied energy (exemplified by the Participatory Budgetary process investment choices)

Drivers

- Net Zero Action Plan
  - Sets a trajectory to achieve continued GHG reductions until net zero has been achieved, while accommodating growth of the community and local economy
- Metro Boston Climate Preparedness Commitment
  - Develop and/or update a local climate mitigation plan and implement at least three climate mitigation actions by 2020.
  - Committed that the region will achieve net zero/carbon-neutral status by 2050.

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1. Current status of project
2. Demand data collection process
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5. Working Groups, Session 1
6. Working Groups, Session 2
7. Constraints and opportunities
8. Regulatory framework
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11. Next steps of implementation

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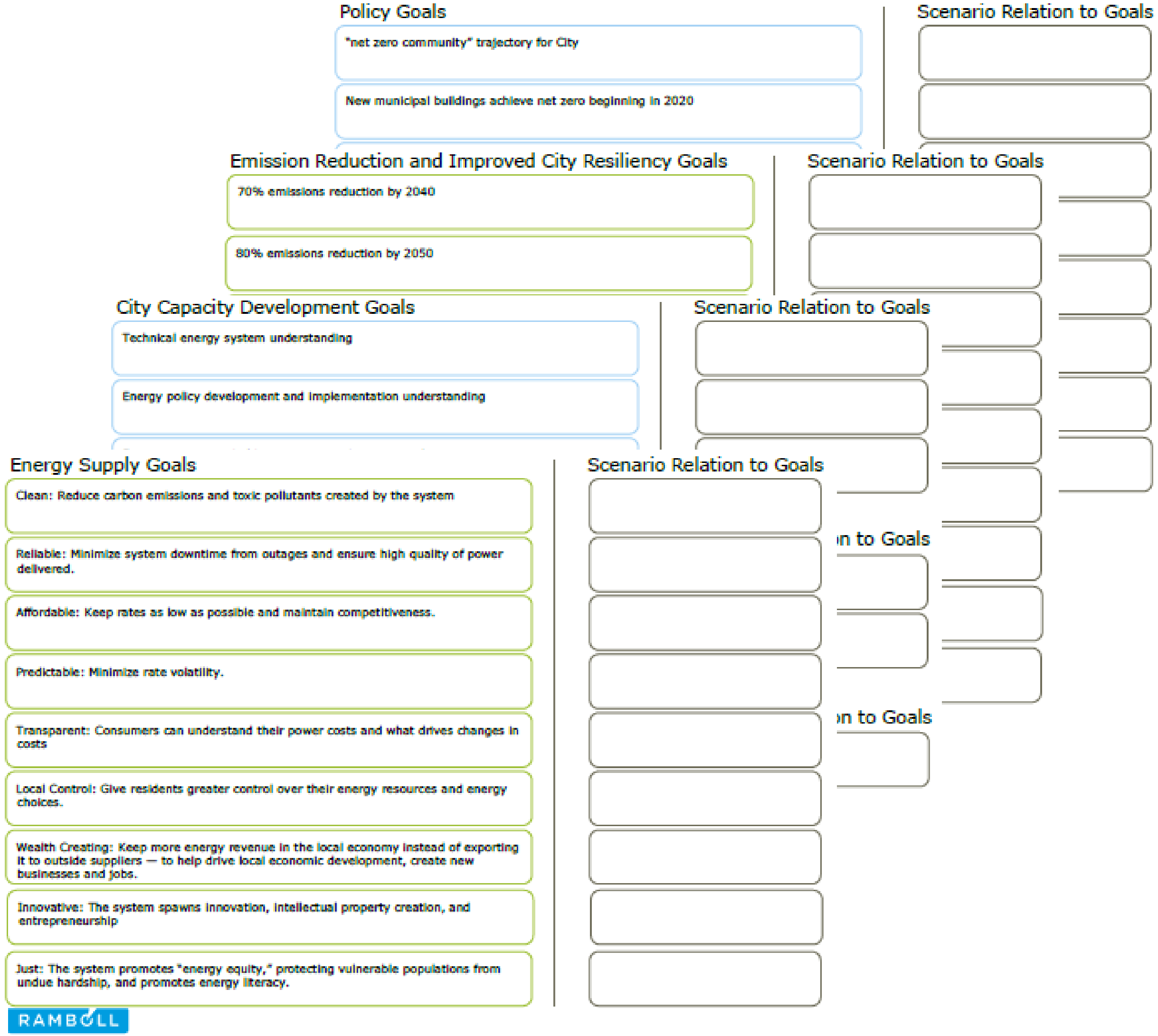
GOAL COMPARISON

- Goal Mapping tools will be used to facilitate relating the final scenario and action plan to the relevant goals and targets of the City.
- Purpose: To facilitate the City in its tracking of goal realization and how the selected scenario for implementation will assist in meeting these.



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AGENDA

1. Current status of project
2. Demand data collection process
3. Demand maps produced
4. Supply map and options outline
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6. Working Groups, Session 2
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10. Goal comparison
11. Next steps of implementation

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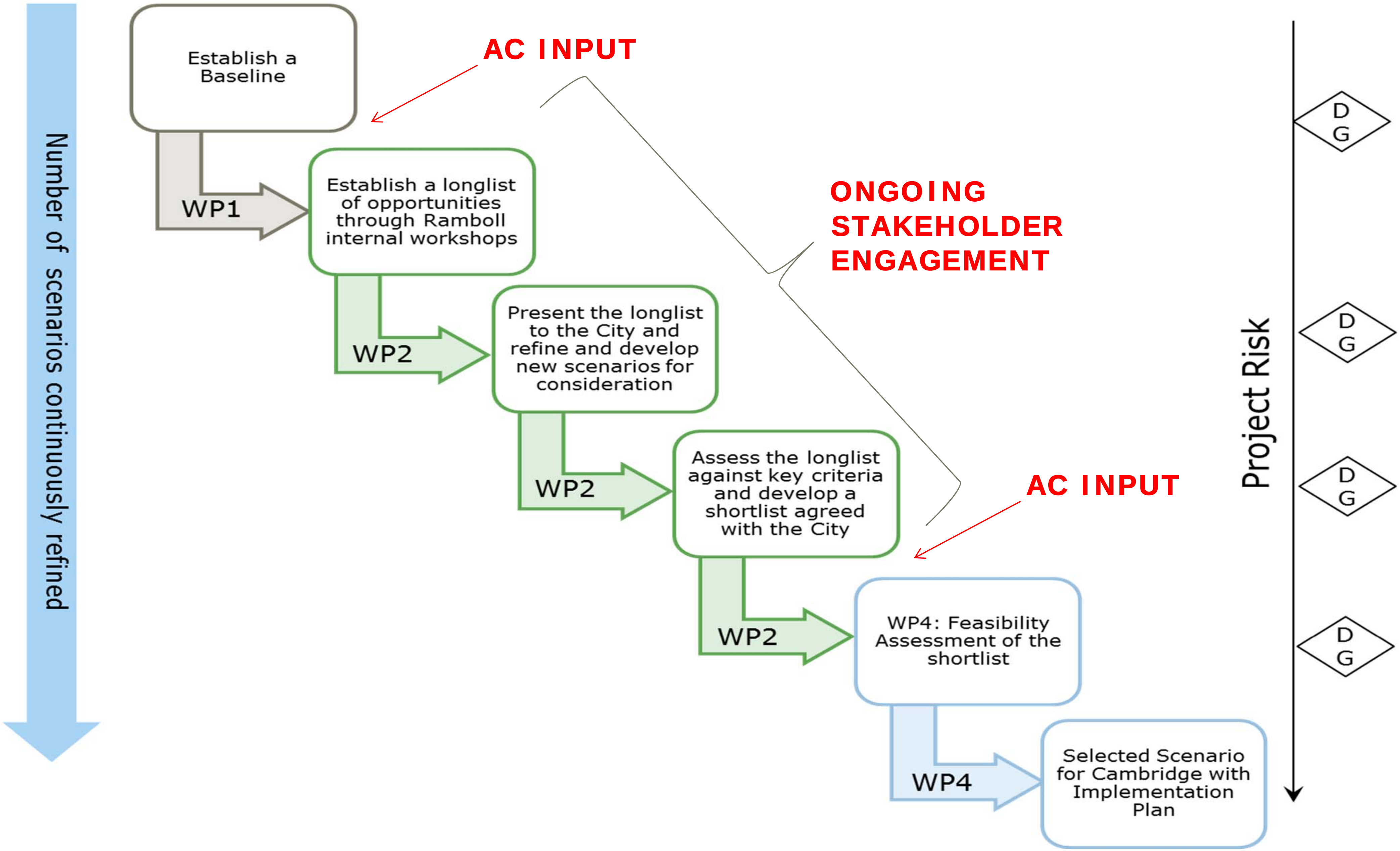

Number of scenarios continuously refined
Establish a Baseline
AC INPUT
WP1
Establish a longlist of opportunities through Ramboll internal workshops
ONGOING STAKEHOLDER ENGAGEMENT
WP2
Present the longlist to the City and refine and develop new scenarios for consideration
WP2
Assess the longlist against key criteria and develop a shortlist agreed with the City
AC INPUT
WP2
WP4: Feasibility Assessment of the shortlist
WP4
Selected Scenario for Cambridge with Implementation Plan
Project Risk
D G
D G
D G
D G

THANK YOU FOR YOUR TIME!

APPENDIX 9

SCENARIO SELECTION PROCESS DOCUMENT WP2 REV 1

MEMO

Job	**LCESS**
Client	**CCDD**
Memo	**Assessment Criteria Decision Document**
Date	**30/11/2016**
To	**Seth Federspiel, Susanne Rasmussen**
From	**Isidore McCormack**
Copy to	**Bronwyn Cooke, Christ Hastings, Charles Hopkins, Julia Rogers, Mairead Kennedy**

Document approved	**YES** ☐	**NO** ☐
By DG SC	**NAME:**	**NAME:**
Date		

1. Introduction

This memo is a decision gate document, to provide options and recommendations to the client for agreement regarding the assessment criteria which will be used to evaluate the scenarios developed by the Consultant in Work Package 2. Once the content of this document is agreed upon, this will provide the basis for project progression.

Additionally this document is to ascertain a percentage weighting which should be given to each of the three quantitative criteria outlined, as required by the client.

Outlined herein is the process for scenario development and the proposed scenario assessment criteria to be used for the project to identify the best scenario for progression.

2. Technology Screen

We propose initially to carry out a technology screen to determine which technologies are suitable for utilisation in Cambridge and should be considered for scenario development. This process is outlined in Table 1 below for your consideration, and results in a yes / no output.

3. Criteria Selection Discussion

To develop the selection criteria, we have worked with those outlined in the project brief by CCDD and as published in the Carbon Neutral Cities Alliance framework report.

Table 2 outlines the three quantitative criteria to assess the various scenarios developed. Each of these requires a percentage weighting to be agreed with CCDD and included under the "Relative Importance to Cambridge" column.

Table 3 outlines the qualitative criteria to assess the various scenarios developed.

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Wealth creating has been removed as a criterion. This is a difficult criterion to provide a useful output on for which to select a scenario. This is issue is also covered within the "economic viability" and "affordability" criterion.

Demand reduction has been removed as a criterion. This will not be addressed by the measures or scenario's proposed to alter the energy supply, and so will not assist in scenario selection. Therefore the Consultant recommends to address this criterion at the beginning of the scenario analysis, emphasising the need for demand reduction implementation measures, however that these are outside the scope of this supply study.

The policy and institutional barriers criterion will be evaluated in more detail under the barriers to implementation and how to address report sections. For the section evaluating the scenarios, we propose to indicate whether there is a barrier or not in existence to the scenario.

Following assessment of each scenario using the outlined criteria below, a priority of scenarios list will be developed under Work Package 2 for agreement to progress to the feasibility assessment part of the project (Work Package 4).

Table 1 Technology Screen

Technology	Environmental Impact , CO_2 Abatement Potential and cost of CO_2 abatement	Revenue Potential	Risk	Consider as Opportunity?
Gas Combined Heat and Power Plant (Open Cycle) (waste heat recovery)				
Biomass heating				
Biomass CHP				
Biogas CHP				
Organic Rankine Cycle				
Gas engine CHP				
Anaerobic Digestion with CHP				
Energy Recovery Facility				
Bio-liquid CHP				
Solar Thermal Panels				
Ground Source Heat Pumps				
Water source heat pumps				
Industrial heat recovery				
Deep geothermal borehole				
Air source heat pumps				
Wind Generation				
Photo Voltaic Solar				
Wave power				
Tidal power				
Hydro power				
Nuclear				

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Table 2 Quantitative criteria

	CCDD Goals	Criteria / Proxy	Units	Relative Importance to Cambridge (% / 100)
Quantitative				
	Clean	CO2 emission reductions. Use natural gas carbon value and carbon factor of grid to establish emissions saved, following calculation of how much gas and electricity is to be saved/supplied from a non-fossil fuel source.	tonnes CO2e	
	Affordable	Cost of supply to Customers Base case of gas ($/BTU) and electricity ($/kWh) costs today and how these are impacted => % increase or decrease.	Total % increase/decrease in cost of energy	
	Economic Viability	Global benefit expressed in Internal Rate of Return or Net Present Value. Will incorporate O&M, investment, fuel, revenue etc.	IRR %, NPV	

Table 3 Qualitative criteria

	CCDD Goals	Criteria / Proxy
Qualitative		
	Policy and Institutional barriers	1. No barrier exists to implementation 2. Moderate Barriers exist to implementation 3. Considerable Barriers exist to implementation
	Reliable / Resilience	1. Provides resilience in some case 2. Provides resilience in majority of cases 3. Provides resilience in all cases
	Predictable	1. Provides rate certainty over short period compared to BAU 2. Provides rate certainty over medium period compared to BAU 3. Provides rate certainty over long period compared to BAU

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	Transparent	1. Pricing structure is transparent and understandable 2. Pricing structure is somewhat transparent and understandable 3. Pricing structure is not transparent and understandable
	Local Control	1. Local Control (either as a cooperative, local business, CCDD) 2. Some local control (SPV/PPP etc.) 3. Minimal control (fully private, either a global or national firm)
	Innovative	1. Brings considerable “added value” to City as “Green City” 2. Brings some “added value” to City as “Green City” 3. No added value to City as “Green City”
	Just	1. Benefits will be equally available to all residents and businesses 2. Benefits will be available to approximately 50% of residents and businesses 3. Benefits will be concentrated in a small area only and not available to the majority of residents and businesses

APPENDIX 10

SCENARIO SELECTION PROCESS DOCUMENT WP2 REV 2

MEMO

Job	**LCESS Cambridge**
Client	**CCDD**
Memo no.	**Scenario Selection Process Outline**
Date	**09/02/2017**
To	**Susanne Rasmussen, Seth Federspiel**
From	**Isidore Mc Cormack**

1. Introduction

The purpose of this memo is to outline the objectives for a project scenario assessment workshop to be held with the City of Cambridge 14th February 2017.

It is important that as the Low Carbon Energy Supply Strategy moves forward to work packages 2, 3 and 4 that there is an agreed methodology in place to assess project opportunities. Given the scale of the task at hand it is vital that a robust, transparent methodology can be established to deliver an actionable plan for the City of Cambridge that meets the needs of the city moving forward.

It is critical that the City of Cambridge is involved and engaged in developing the details of this strategy at the earliest possible stages in order to ensure that ownership of the project outcomes can be fully transferred from the consultant to the City at project completion.

The purpose of developing a project prioritization methodology is not to restrict scenario development at the initial stages but rather to provide a framework for moving from an initial longlist of scenario ideas to a shortlist of scenarios that would then be considered in more detail. This shortlist of scenarios would be the output from WP2.

This shortlist of scenarios would then be assessed for feasibility in WP4. The aim of WP4 is to develop a proposal and implementation plan for the scenario determined to best meet the goals for the city of Cambridge.

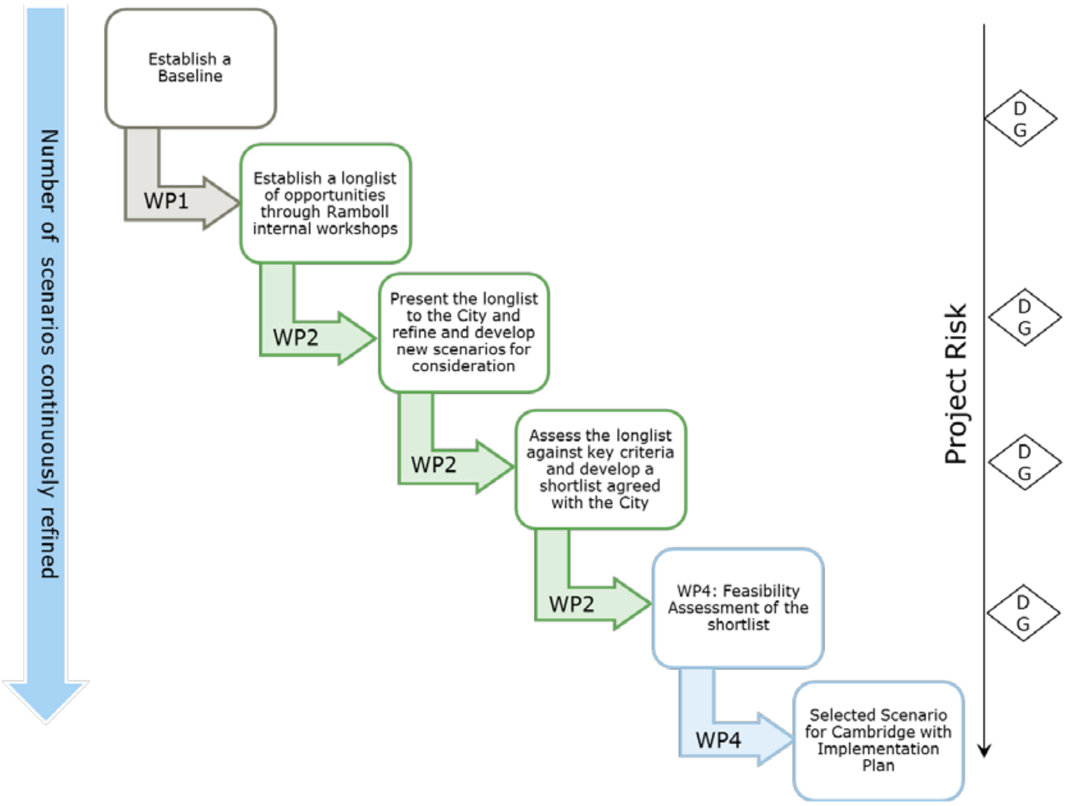
In Ramboll's experience it is of utmost importance that this framework is developed as a partnership between the client and consultant. For this project to deliver a truly actionable plan the key questions that must be addressed are:

1. What is the City's key driver – in this case the delivery of carbon reduction targets
2. **What information does the city need in order to make a decision**
3. What are the secondary considerations – the city's goals as defined in the RFP document

As things stand the item that now needs to be understood and incorporated into the project assessment is number 2, highlighted in bold above. This is central to the outcome of the entire project. Ramboll are committed to developing this low carbon supply strategy for Cambridge with a realistic implementation plan to meet the objectives of this study. To do so the outcomes of this study will need to be framed in such a way that it can be used as a tool to bring key stakeholders (both internal in the City and external) on board with the proposals. To do this Ramboll needs to understand from the City what are the key components that they need to make decisions for implementing policy changes.

To kick-start the conversation Ramboll produced an initial document aimed at providing some insight into our approach used in other areas for assessing project opportunities. Following our initial meeting on January 11th we have reassessed our methodology and set out hereunder an updated approach for project implementation with the process of both WP2 and WP4 clearly laid out and the timing defined.

The proposed project work packages are set out in the image below with decision gate points highlighted on the right hand side.



2. Work Package 2 Process

The key elements of WP2 will be:

1) Consultant internal review of data and workshops to develop a longlist of scenarios

2) Workshop with City of Cambridge to review initial scenarios and get feedback and incorporate ideas

3) Refine the long list of low carbon energy supply scenarios

4) Identify any gaps in the data collected under WP1

5) Re-engage with key stakeholders to gather data and discuss scenario specific issues such as the potential for interconnection

6) Develop maps and narratives for scenarios

7) Consultant reviews and assesses scenarios to ensure alignment with the City's goals

Options for Review and Assessment of Scenarios under WP2:

A. Carry out a qualitative assessment of each scenario against the project goals setting out the overall argument for and against consideration of each scenario as a shortlist for detailed feasibility; or

B. Develop a list of key headings and then score each technology option in different categories against a business as usual assessment. This approach can be subjective and a rigorous review and critique of initial scoring is recommended by the client in WP2, this approach is showcased from page 125 of the St. Paul project:

https://www.stpaul.gov/sites/default/files/Media%20Root/Planning%20%26%20Economic%20Development/Ford%20Site%20Energy%20Study%20Report%20-%20FINAL%20and%20Appendices%2012-4-15.pdf

The table below is an example of the approach for combustion technologies, other categories were: heat pumps, solar technology etc.

Combustion technologies

Table 1: Technology evaluations - Combustion

	Total	Net Zero	Resilience	Innovation	Energy efficient	Cost effective
Frying/vegetarian oil boiler	19	5	4	3	4	3
Biomass CHP	18	5	5	3	3	2
Natural gas CHP	18	3	4	2	5	4
Industrial waste boiler	18	5	3	3	4	3
Biomass boiler	16	5	4	2	2	3
Natural gas boiler	16	2	4	1	4	5

This has the benefit over the purely qualitative approach of providing easy to follow assessments, but is still a subjective assessment of technologies at this stage.

8) Second Workshop with the City of Cambridge to present the scenarios and develop a shortlist of scenarios for feasibility assessment

3. Work Package 4 Process

Work Package 4 will take the shortlist from WP2 and assess these scenarios in a detailed way resulting in a techno-economic model per scenario which will output the overall project carbon savings, capital cost, ongoing operational costs and IRR, including other key performance indicators as required by the City.

The models can be built to provide most outputs (such as NPV at various timescales, ROI, payback periods, carbon emissions reductions etc.). However it can be difficult and time consuming to retrofit these requirements once the models is complete, which is one of the key reasons why emphasis is being placed on the information needed by the city at this stage.

Ramboll have previously proposed (Memo issued 11.10.2016: Assessment Criteria Decision Document) that these projects be assessed based on a combined qualitative and quantitative matrix. This would allow for transparency and would provide a means to assess various projects based on standard metrics.

It was never the intention that these would be the only criteria considered, simply that they provide a readily understandable, robust means of demonstrating the various advantages and disadvantages of different scenarios and would outline the “critical criteria”.

These would be considered critical factors to be supported by deep dive narratives addressing the remaining goals of the city and other barriers and opportunities posed by the scenario which could impact on the overall suitability of a particular project.

It is Ramboll’s experience that too many quantitative criteria results in no clear answers and that the most successful projects are the ones where the most important goals of the City can be clearly defined and measured. (See example document sections referred below).

Ramboll have proposed the following, however these discussions and workshops are in place to provide a platform to discuss and agree a route forward that meet’s Cambridge’s needs.

The table below shows again Ramboll’s previous suggestions with Cambridge’s comments – we propose to discuss this methodology again. This has been used successfully on other projects, however what works in one location may not work for another and we need to make sure that this is reflective of local requirements.

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Table 1 Quantitative criteria

	CCDD Goals	Criteria / Proxy	Units	Relative Importance to Cambridge (% / 100)
Quantitative				
	Clean	CO2 emission reductions. Methane, N20,CFL etc.- and calculated in CO2 equivalents. Avoidance of S02, S04 etc. to be considered also – reduction of air pollution Consider life cycle of technologies Use natural gas carbon value and carbon factor of grid to establish emissions saved, following calculation of how much gas and electricity is to be saved/supplied from a non-fossil fuel source.	tonnes CO2e	
	~~Affordable~~Cost	Cost of supply to Customers Base case of gas ($/BTU) and electricity ($/kWh) costs today and how these are impacted => % increase or decrease.	Total % increase/decrease in cost of energy	
	Economic Viability	Global benefit expressed in Internal Rate of Return or Net Present Value. Will incorporate O&M, investment, fuel, revenue etc.	IRR %, NPV	

Example documents:

Unfortunately due to client confidentiality issues it has not been possible to provide the specific project examples to Cambridge that are the most directly relevant to this project. However similar approaches were taken on each of the following projects:

Refer to page 125:
https://www.stpaul.gov/sites/default/files/Media%20Root/Planning%20%26%20Economic%20Development/Ford%20Site%20Energy%20Study%20Report%20-%20FINAL%20and%20Appendices%2012-4-15.pdf

Refer to Section 4, page 38 onwards:

https://www.london.gov.uk/sites/default/files/energy_masterplan_for_london_riverside_-_havering.pdf

Refer to Section 5, page 43:

https://www.london.gov.uk/sites/default/files/energy_masterplan_for_colindale_-_brent.pdf

4. Stakeholder Engagement

As part of the scenario development key benefits for main stakeholders will begin to be identified through engagement and discussion. The City of Cambridge objective is to develop a roadmap to fundamentally change the supply of energy to their city. This will require a free and open discussion as to all possibilities and will need to engage all of Cambridge. In energy terms scale matters and one of the ways in which really transformative measures can be successful for all concerned is by understanding the interconnecting relationship possibilities between stakeholders.

This process will only be successful if real and meaningful engagement is achieved. The establishment of the AC and discussions with key stakeholders to date has been a great start to the project. One of the key considerations moving forward is how best to continue this collaborative effort to ensure a successful outcome for all concerned.

Once the project shortlist is completed, there will be a presentation to the AC committee for comments and WP2 will be concluded.

WP3 will then begin, which is a critical pathway in the project development where Change and Benefit Management will be undertaken. The objective is to develop a road map as to how to implement the required change outlined in the new energy supply strategy.

Key actions required will include addressing the most important topics/barriers of the scheme. A memo with interim results of these actions will be presented.

This study has already raised some interesting questions that need to be considered by the City of Cambridge at a high level once more detail has been developed, these include:

- Use of the Charles river as a future asset, whilst ensuring that environmental regulations (specifically temperatures) can be met at all times.
- Deployment of biomass in Cambridge, biomass is not without controversy but has also been deployed very successfully in other regions.
- How best to maintain interest and engagement in the project process and to achieve the best outcomes.

These issues and others will continue to be logged and incorporated into the project planning and discussion process to ensure that these conversations happen with the appropriate people during WP3.

Stakeholder engagement in WP1 has taken quite a light approach. As agreed with the City, the advisory committee meeting in February will highlight the role of stakeholders and the need for engagement.

Following this we propose to highlight stakeholders for immediate follow up with face to face meetings and then those stakeholders that will be engaged once projects are identified.

APPENDIX 11

SCENARIO SELECTION PROCESS DOCUMENT WP2 REV 3

MEMO

Job LCESS
Client CCDD
Date 02/03/2017
To Seth Federspiel, Susanne Rasmussen
From Isidore Mc Cormack
Copy to Mairead Kennedy

1. Introduction

In accordance with the workshop held on February 14th in Cambridge's offices, outlined below is the agreed process for progression of the scenario development and how we propose to shortlist the developed Scenarios to progress towards Work Package 4.

2. Work Package 2 Process

Process	No. Scenarios	Input
Ramboll team establish a long list of opportunities through internal workshops - ideas will be derived using the detailed GIS maps prepared under WP1. **Output** Summary memo outlining scenarios: Description of the various technologies proposed, the proposed percentage energy supply split for each technology for that scenario, and whether it meets City goals. Technology descriptions should take account of the City goal/criteria which will be considered when rating.	9-12	Ramboll
Ramboll will present the longlist of scenarios in the summary memo submitted to CCDD and walk through them. CCDD will have one-two weeks to read and consider scenarios. CCDD and Ramboll then meet to score the scenarios together, receive feedback on any idea omissions. **Output** Reduced number of scenarios.	9-12	Ramboll & CCDD
Ramboll will prepare a more detailed summary memo on the selected scenarios for agreement for progression to WP4 assessment. No IRR, NPV - still qualitative level.	<9-12	Ramboll

Output Summary memo outlining remaining scenarios in more detail.		
CCDD and Ramboll meet again to score the scenarios together. 4-5 criteria used for shortlisting. Scenario's to be graded 1-5, bad to best. Initially will grade Business As Usual case for each zone. **Output** Reduced number of scenarios.		Ramboll & CCDD
Agreed shortlist presented to AC.	2-3	Presented to AC
Agree WP4 assessment criteria for final scenario assessment.		Ramboll & CCDD

3. Program

Outlined on the following page is the program for implementation of this WP2 with important client input dates highlighted in the table below. The vertical red line indicates our current position in the program, and the horizontal line indicates the tasks complete. The program is relatively tight due to delays in information gathering to date and completion of WP1. As a result program slack is limited and the highlighted dates need to be adhered to.

Client Input Required	Key Date
Scenario presentation to CCDD	Friday April 7th
CCDD to review and consider Scenarios	7-24th April
CCDD and Ramboll to score scenarios together	Monday April 24th
Scenario Development approach agreement with CCDD	Monday April 24th
CCDD to review and consider Scenarios	5-12th May
CCDD and Ramboll to score scenarios together	Friday May 12th
2-3 Scenarios Agreed for presentation to AC	Friday May 12th
AC Presentation of Scenarios	Likely week of 22-26th May