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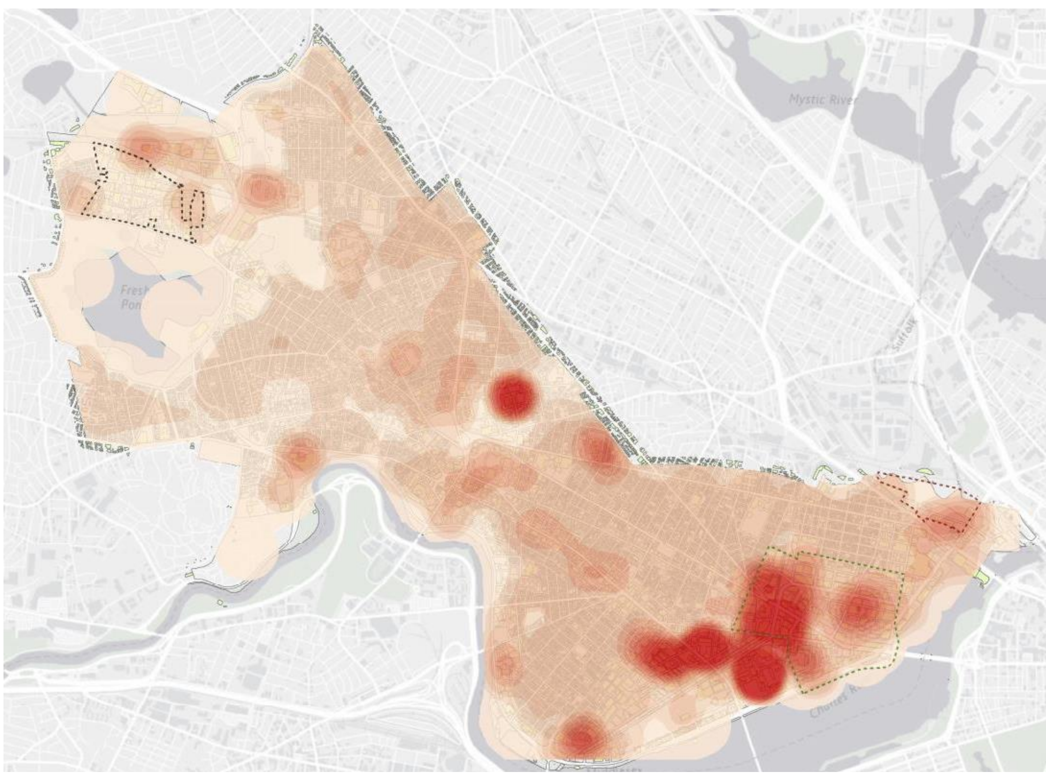
LOW CARBON ENERGY SUPPLY STRATEGY
WP1: EXISTING FACTORS AND BARRIERS



RAMBOLL VANDERWEIL

LOW CARBON ENERGY SUPPLY STRATEGY
WP1: EXISTING FACTORS AND BARRIERS

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Glossary of Terms

AC	Advisory Committee
ACP	Alternative Compliance Payment
BEUDO	Building Energy Use Disclosure Ordinance
CBECS	Commercial Building Energy Consumption Survey
CHP	Combined Heat and Power
CDPW	Cambridge Department of Public Works
CoP	Coefficients of Performance
DG	Distributed Energy
DHW	Domestic Hot Water
DOE	Department of Energy
EEAC	Energy Efficiency Advisory Council
EUI	energy use intensity
GHG	Green House Gas
HRSG	heat recovery steam generators
HVAC	Heating Ventilation Air Conditioning Unit
ISO	Independent system operator
Labs 21	International Institute for Sustainable Laboratories
kBTU/ft2	Thousand British Thermal Units per square foot
kWHs	Thousand watt hours
MassCEC	Massachusetts Clean Energy Center
MBTA	Massachusetts Bay Transportation Authority
MWRA	Massachusetts Water Resources Authority
MMBTU	Million British Thermal Unit
MW	Mega Watt
ORC	Organic Rankine Cycle
NPDES	National Pollutant Discharge Elimination System
REC	Renewable Energy Certificate
RTO	Regional transmission organization

EXECUTIVE SUMMARY

Ramboll was commissioned by the City of Cambridge to undertake a community-wide Low Carbon Energy Supply Strategy (LCESS) assessment.

The project is split into four work packages. This report is for the first of these: Work Package 1 (WP1).

The purpose of WP1 was to establish the project baseline for energy demand, supply and regulations in order to inform the development of low carbon energy supply scenarios for Cambridge.

Demand Assessment

The demand assessment for Cambridge is complete. This process involved utilizing building level energy information from Building Energy Use Disclosure Ordnance (BEUDO) to update the Cambridge property database with energy demand information. Benchmark energy data derived from BEUDO and Commercial Building Energy Consumption Survey (CBECS) was applied to buildings not included in the BEUDO to generate a master database of point demand data for the whole of Cambridge.

Supply Assessment

An assessment of the existing and potential energy supply sources in Cambridge was undertaken. For existing supply assets this involved engaging directly with asset owners such as Veolia, MIT and Harvard to gather information and further understand the existing plants. Not all requested information could be provided; information will continue to be gathered as the project moves forward to scenario development to ensure that critical information can be included in the assessment.

Potential supply sources have been summarized in the report. In general these are high level assessments of technology suitability and potential for Cambridge. More information is required before potential supply capacities can be calculated. Data collection continues for a number of technologies. The potential for utilization of some supply assets will be fully established in the scenario development and feasibility phases where concrete project plans can be developed.

Mapping

Energy demand maps for the city of Cambridge have been made in ArcGIS showing the existing energy demand patterns for heating, cooling and electricity. Change maps showing how energy demand is expected to develop in Cambridge over the long and medium term due to improvements to existing buildings, climate change and new developments, have also been produced.

A map showing the locations of the main supply assets across the city has been made and is included in Appendix 5a.

Regulatory Review

A comprehensive review of relevant regulations impacting energy supply in Cambridge was undertaken to identify key barriers to project development.

Next Steps

- On completion of WP1, Work Package 2 (WP 2) commenced and is now underway.

In WP2 scenarios for low carbon energy supply will be developed.

WP2 will be a collaborative effort involving the consultant, client and key stakeholders. It is important that this LCESS delivers real results and benefits for all concerned in order to meet the ambitious emission reduction targets set by the City of Cambridge and agreed upon by all stakeholders. WP2 is a critical step in this process.

Initially a longlist of projects will be developed by the consultant and then discussed and refined through workshops and one on one meetings with key stakeholders.

A shortlist of scenarios will be developed and agreed based on the city's key goals and objectives.
WP3 involves the development of a change and benefit management plan which will ensure that key decisions required by Cambridge can be facilitated.

WP4 will close out the project with a feasibility assessment of the shortlist opportunities and a selection of the preferred opportunity.

A detailed implementation plan and roadmap to a low carbon supply future for Cambridge will be the key outcome.

1. INTRODUCTION

1.1 Overview

Ramboll and Vanderweil Engineers have been appointed by the City of Cambridge to develop a Low Carbon Energy Supply Strategy study (“the study”).

The study forms part of the 25 year Net Zero Action Plan for setting Cambridge on a trajectory to becoming a net zero GHG community with improved community resilience.

Achieving the net zero objectives relies on a combination of energy efficiency improvements, renewable energy production and, where necessary, purchase of carbon offsets or, potentially, credits. To achieve these goals and address renewable energy production, a significant shift in the supply of energy to Cambridge buildings away from fossil fuel based sources and toward low- or zero-carbon sources will be required.

The aim of the study is to provide a better understanding to the City of the full potential and barriers to renewable energy and low carbon energy solutions in Cambridge.

1.2 Acknowledgements

The study is supported by a project advisory committee (“the AC”) who have generously provided their time and input to help steer and inform the project. The members of the AC are listed below and their input and time is very much appreciated by the Consultant and the City of Cambridge.

- Ben Myers, Boston Properties
- Brad Swing, Adam Jacobs, Travis Sheehan, City of Boston
- Ellen Katz, Dept. of Public Works Cambridge
- Emma Corbalan, MIT
- James Cater, Eversource
- Mary Smith, Harvard
- Melissa Chan, Climate Protection Action Committee Cambridge
- Melissa Peters, Community Planning Division Cambridge
- Oliver Sellers-Garcia, City of Somerville
- Patrick Haswell, Veolia
- Steve Lenkauskas, Dept. of Electricity Cambridge
- Tina Miller, Cambridge Housing Authority

1.3 Work Package 1 Objectives

The objective of this report is to outline the existing factors and barriers through data collection, and the options for deployment of renewable energy and low carbon district heating and cooling in the City of Cambridge. Work Package 1 (WP1) has involved an intensive data collection process, the results of which are outlined in this report. This report sets out the baseline for energy demand and supply in Cambridge and outlines the key regulatory issues impacting energy. Scenario development will occur in the next phase of the project, Work Package 2 (WP2).

1.4 Structure of Report

Sections 2 and 3 of this report outline the demand and supply situation in existence in Cambridge today. The Consultant will outline the approach taken to data gathering, the assumptions made and the overall findings.

Section 4 provides GIS mapping of the supply and demand situation in Cambridge today with analysis of same. Section 5 outlines the constraints and opportunities identified currently for the City of Cambridge. Sections 6-9 look at the regulatory framework, city capacity and goals of the city of Cambridge to give a policy, capability and ambition background to the study.

Section 9 outlines the Consultants recommendations and next steps based on the previous sections of the report.

2. ENERGY DEMAND IN CAMBRIDGE

2.1 Introduction

Energy consumption for the Cambridge community was evaluated at the building level, primarily via reporting completed by larger commercial, institutional, residential, and municipal buildings within Cambridge. Understanding current energy assumption trends at this level provides a quantifiable baseline which can be used to assess future energy reduction opportunities and impacts on the city's energy load profile.

The main objectives of establishing energy demand in Cambridge include:

- Assess the Cambridge Building Energy Use Disclosure Ordinance dataset to establish energy benchmarks by building type;
- Extrapolate Disclosure Ordinance results to Cambridge properties where energy information is not available/not known;
- Where needed, utilize established energy benchmarking studies (i.e. Kendall Square Eco-District Study, Commercial Energy Consumption Survey) to provide additional support for unsubstantiated or missing energy information.

The 2015 Cambridge Building Energy Use Disclosure Ordinance (BEUDO) provides the basis for establishing energy consumption benchmarks by building type. The 2015 BEUDO dataset includes energy information from the previous 2014 year. Each entry within the dataset reflects energy information for single building(s). Nine overarching building category types were identified (refer to Figure 1). These nine types were broken down into 39 building types identified within the 2015 BEUDO dataset (refer Figure 1) which includes 785 individual entries, each representing a single building.

Altogether, properties reporting through BEUDO make up only a portion of total Cambridge properties. Properties not included via BEUDO reporting were identified via the publically-available Cambridge Assessor Database, which includes approximately 28,800 properties.

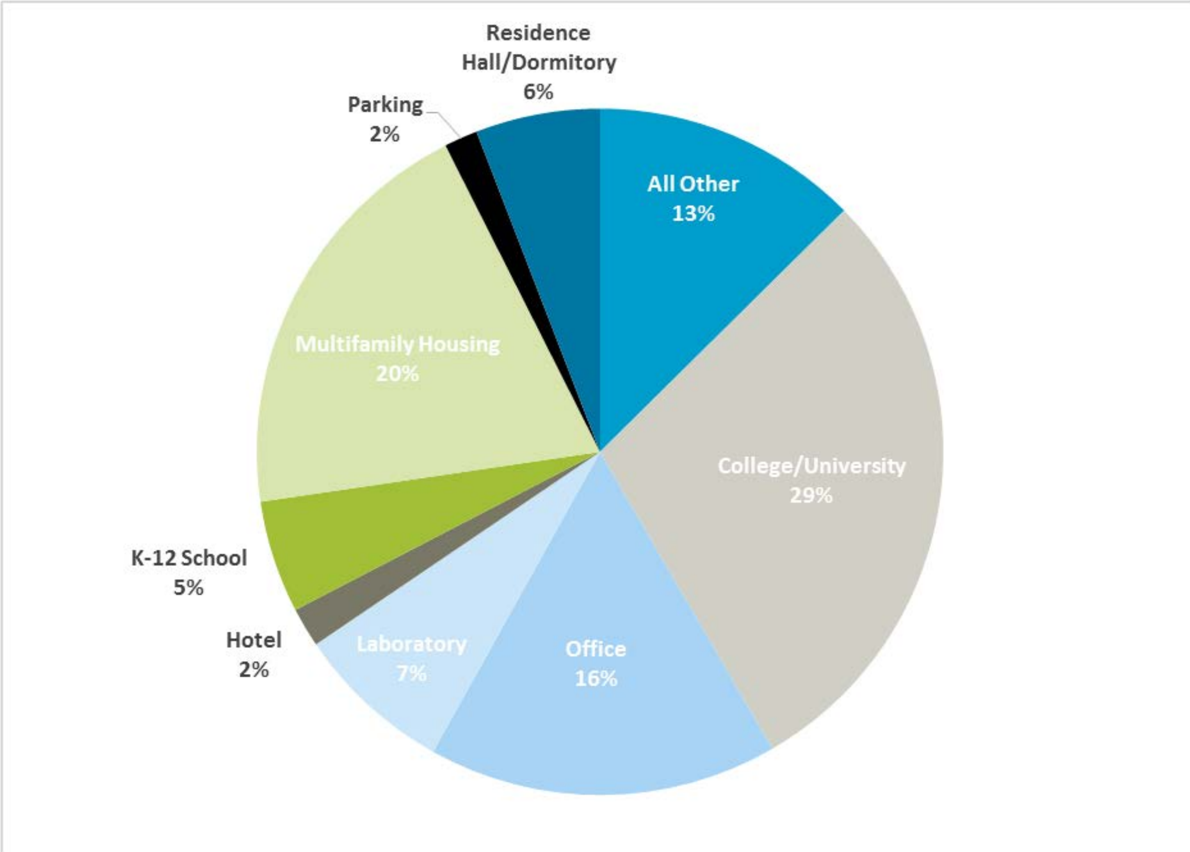

Figure 1 Percentage of building gross square foot represented by the nine overarching building category types of the BEUDO

2.2 Analysis and Methodology

The primary data-points evaluated within the BEUDO reporting data include:

- Property address
- Property owner
- Property type
- Property gross floor area (ft^2)
- Electricity consumption
- Thermal consumption (natural gas, fuel oil, steam)

Energy use information and property gross floor area allows for a whole-building energy benchmark metric to be calculated, also known as an energy use intensity value (EUI). EUI values are represented as a total energy per square foot ($kBTU/ft^2$). Figure 2 provides a summary of median EUI values for each building type. Additional details on data processing can be found in Appendix 1.

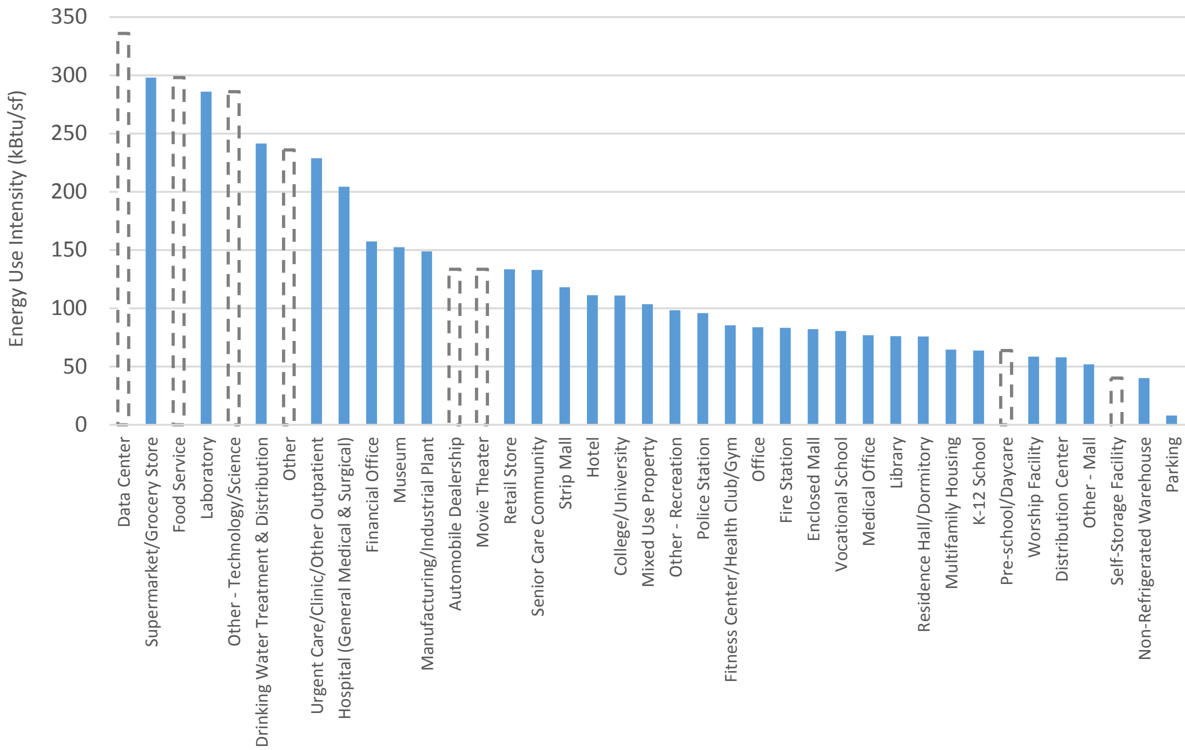

Figure 2 Summary of median EUI values for each building type (calculated from BEUDO data)

Property types with missing and/or misleading data are identified with dashed lines. These property types were allocated typical energy consumption values based on similar building types captured in the BEUDO dataset or through established benchmarking analyses such as the Commercial Building Energy Consumption Survey, Department of Energy and the International Institute for Sustainable Laboratories (Labs 21).

With benchmarking values allocated to property types with missing/misleading information, Figure 3 provides a comparison between national 2012 Commercial Building Energy Consumption Survey (CBECS) benchmarks and the 2015 BEUDO reporting benchmarks. CBECS data for 2015 is not yet available.

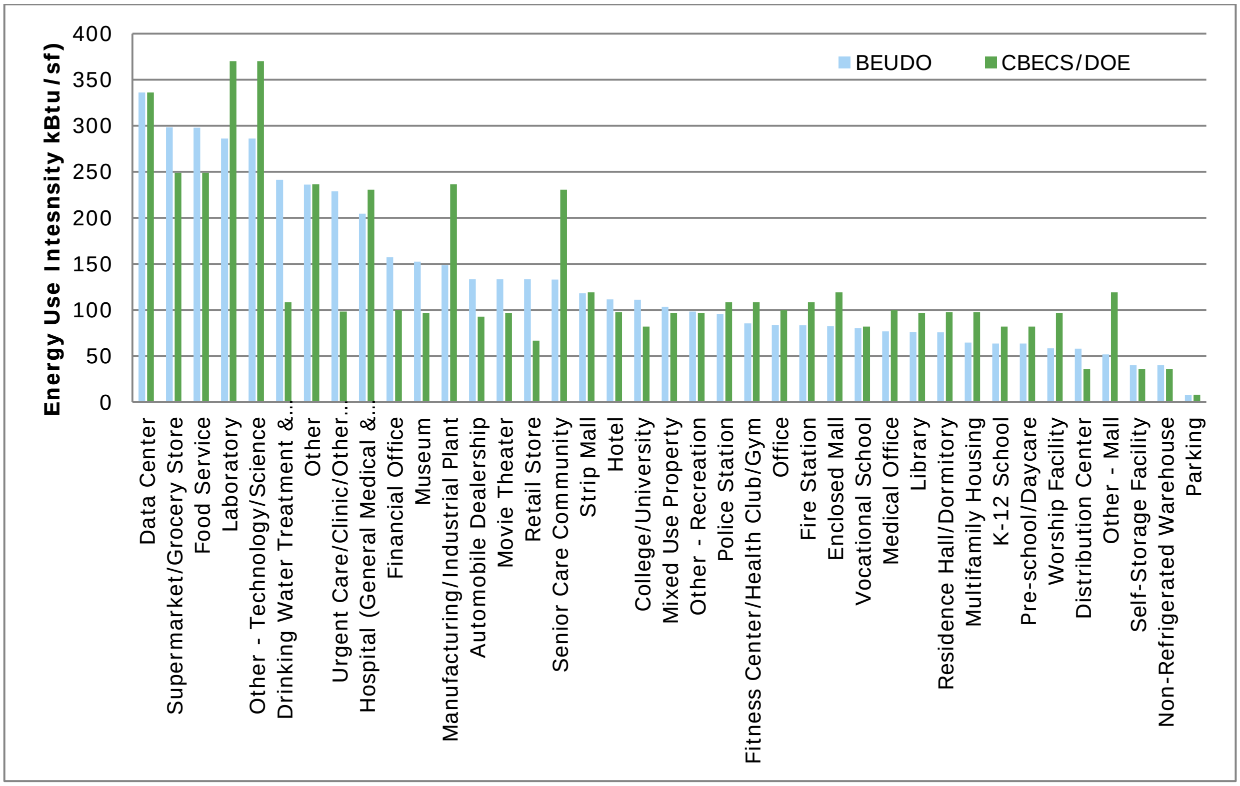

Figure 3 Comparison between national 2012 Commercial Building Energy Consumption Survey benchmarks and the 2015 BEUDO reporting benchmarks

2.3 Energy End-use

Understanding fuel mix and their respective uses is an integral part of establishing future low-carbon initiatives, as this will allow the City of Cambridge to achieve a greater understanding of how to focus on schemes at the community- and building-level.

CBECS tables were consulted to establish typical energy end-use estimates for electricity, heating, cooling and domestic hot water usage.

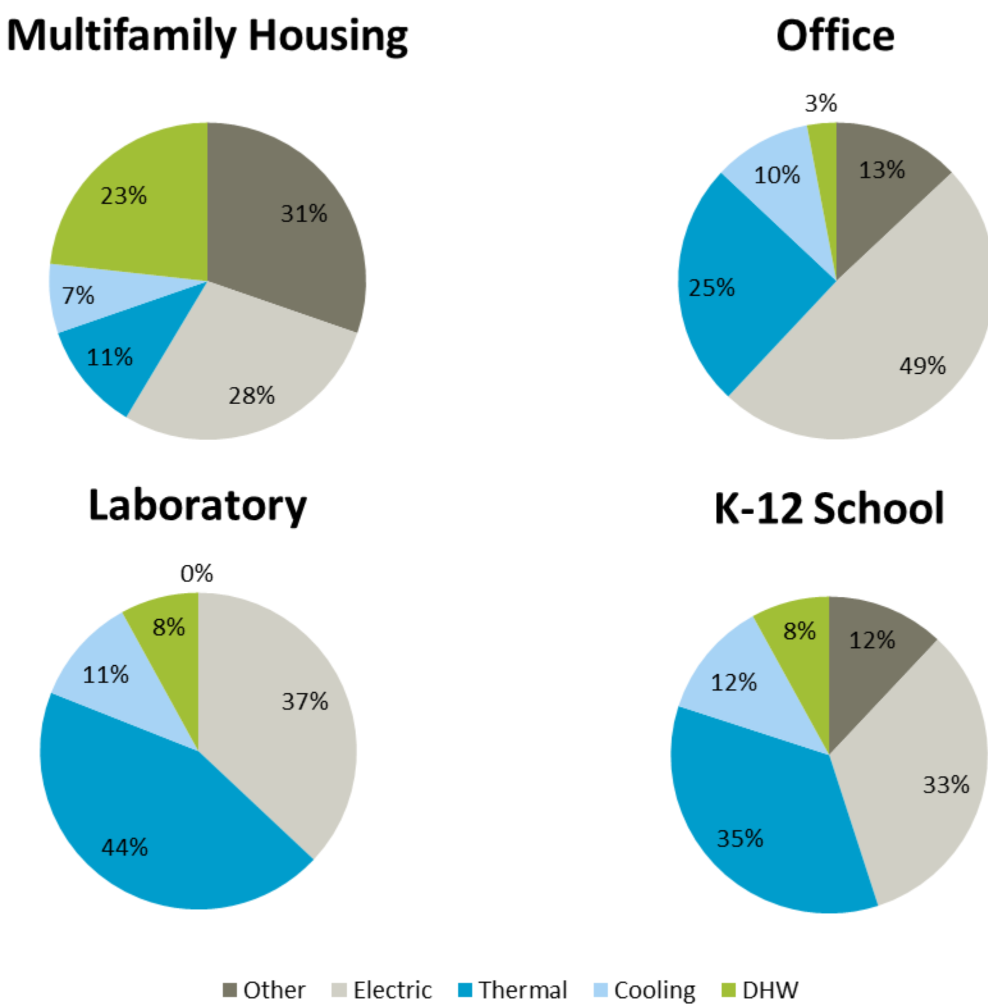

Figure 4 Typical energy use breakdown for a sampling of four major building types

2.4 Conclusions following data collection

As expected, Cambridge energy usage by building type generally coincides with national averages established by CBECS. In some instances, Cambridge properties show improved building performance when compared against national benchmarks.

The top three energy users by type included supermarket/grocery stores, laboratories and urgent-care medical facilities. The lowest three energy users by type included parking garages, warehouses, and worship facilities. These results are typical in an urban setting and did not significantly vary from usual understanding of energy consumptions for these building types.

In some instances, the analysis was constrained by the information available and additional assumptions were utilized in order to develop an accurate assessment of energy use. Major constraints included:

- Limited entries by building type;
- Limited and/or no energy information available;
- Efficiency and/or loss factors to establish building level heat-demand;
- Accurate energy end use breakdowns.

In these instances – for either individual buildings or the dataset as a whole – results were cross-referenced with CBECS, Labs 21 and DOE databases to ensure accurate representation of energy profiles, energy end use and efficiency factors.

The total energy demand at a building level for the city of Cambridge is as follows:

Demand Type	Energy Demand (MMBTU)
Heating	6,060,000
Cooling*	508,000
Electricity	4,230,000
Total	10,798,000

Table 1: Total Demand Values for Cambridge

*Note: Some cooling may be captured within the electricity demand for buildings, without building level breakdowns specific to cooling this cannot be extracted, every effort has been made to ensure that cooling demand has been captured through the BEUDO dataset.

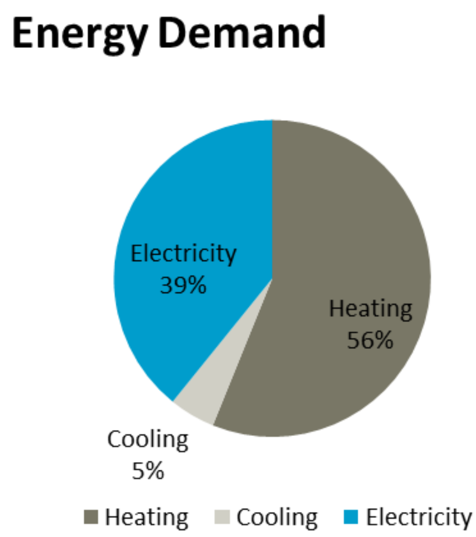

Figure 5: Energy Demand Split in Cambridge by Use Type

As can be seen in the figure above heating is the primary energy demand in Cambridge, with Electricity a close second. Cooling is currently a very distant third place; however, this is expected to change over time as described below in Table 2, due to warmer climates resulting from Climate Change affects and expected upgrades to buildings within Cambridge.

This highlights the importance of heating when considering how to reduce the carbon footprint of Cambridge's Energy Supply.

2.5 Existing Building Energy Use – Medium and Long Term Projections

In addition to understanding the city's current energy profile, low-carbon strategies must also consider future climate conditions as well as building improvements and how these changes may affect energy use at the building- and community-level.

Climate Change

While building improvements will help reduce energy consumption, consideration must be given to climate change and how future weather changes will impact building performance. Projected heating- and cooling-degree days were assessed based on the climate change assessment undertaken for the Vulnerability Assessment[1] in order to evaluate changes to heating and cooling loads. Results found that heating will see a reduction in energy use, and cooling will see an increase in energy use as outlined in Table 2 below. The impacts of applying climate change in this way does not account for any changes other than demand for heating and cooling. To account for changes to building fabric, controls and other measures the climate change factors were applied first and then additional factors were applied to account for building level measures as described in the Section below.

Full details of the assumptions regarding the climate change analysis are available in the Climate Projections and Scenario Development Report produced as part of the Climate Change Vulnerability Assessment for Cambridge, November 2015[1].

[1] Vulnerability Assessment, November 2015, Climate Projections and Scenario

Energy Demand for Space Heating	Energy Demand for Space Cooling
Warmer climates will reduce load on heating needs.	Warmer climates will cause more need for cooling.
• **16% reduction** by 2030 • **27% reduction** by 2040	• **78% increase** by 2030 • **129% increase** by 2040

Table 2 Projected changes to heating and cooling loads

Existing Building Improvements

According to the Kendall Square EcoDistrict Energy Demand Study, Cambridge has grown by over 10 million square feet[2] city-wide in the last decade. Further studies show that total energy use in Cambridge has also decreased over this same time period. Based on trend data and the Net Zero Action Plan[3], it was assumed that existing buildings will continue to realize a reduction in energy over the next 25 years.

Considering existing buildings only, the potential to reduce energy depends on a number of factors, the core items being:

- Building age
- Future building code for major renovations
- Lighting upgrades
- Heating and cooling plant retrofits, including upgrades to building automation and control
- Building envelope (insulation and glazing)

Referencing analysis produced by the Kendall Square EcoDistrict[2] and Integral Greenhouse Gas studies[4], a reduction factor (documented in Appendix 1) was applied to existing building benchmark data to forecast anticipated heating and cooling energy use for the year 2030 (medium-term) and 2040 (long-term).

Constraints and Limitations

The analysis for future cooling and heating energy use was based on regional weather patterns and projected building improvements for a portion of Cambridge that may not be representative of the city as a whole. Forecasting energy usage is entirely dependent on a variety of factors, and reasonable assumptions were made in order to capture anticipated cooling and heating energy profiles.

- **Cooling systems.** Only specific building types that were not shown to have central air systems were assumed to have these systems installed by 2030. These buildings were expected to be longer-term occupancy buildings such as multifamily housing, educational facilities and commercial offices.
- **Heating and cooling adjustment factors for existing building improvements** are based on 2012 CBECS energy end-use estimates for the greater northeast region. These values have been cross-checked with known operating trends for the Boston, MA area and

[2, 2.1] Kendall Square EcoDistrict Energy Study, June 2016

[3] http://www.cambridgema.gov/cdd/projects/climate/netzerotaskforce

[4] Cambridge Net Zero Action Plan, GHG Reduction Model, April 2015

have been determined to be reasonable assumptions to use in order to assess energy end-use for various building types.

2.6 Future Energy Demand

2.6.1 Planned Developments

There are three planned large scale new developments for the City of over the course of the LCESS study period (2017-2040). These proposals will result in the build-out of the last remaining large parcels of development land in the city and so account for the majority of planned future development in Cambridge.

These developments are:

- Northpoint
- Kendall Square
- Alewife

These projects are all at different planning stages and varying levels of information is available for each site.

Other development is expected to occur; this is expected to come about as infill development. No definite plans for such development are available with details such as location and magnitude of development. It is therefore not possible to map these projected changes to the built environment in Cambridge. Some high level estimates have been prepared by the City of Cambridge and are outlined below.

2.6.1.1 Northpoint

Figure 6 Northpoint Development Area

Northpoint is a 45 acre site in the north of Cambridge and is one of the largest (entitled for 5.2 million sq. ft.) undeveloped sites in the whole of the Boston/Cambridge area. Development of the site has been fully permitted but progress has been slower than originally anticipated. Of the sites in Figure 6 above only parcels N, S and T have been completed, 3 of a potential 20 parcels.

The phasing of the project is expected to come forward as Phase 1A and 1B, to be completed by 2021 and Phase 2 due for completion in 2023. This phasing information is based on best available information provided by the developer for the site. An end date for Phase 2 was not provided, the build out rate for Phases 1A and B was assumed. Phase 2 is dependent on completion of the MBTA's Green Line extension.

The total increase in energy demand due to Phases 1A and 1B is 151,900 MMBTU, the increase due to Phase 2 is 58,500 MMBTU. The energy demand for this site has been developed based on available information for the Kendall Square Development. The split in demand between heating, cooling and electricity is shown in Figure 7 below.

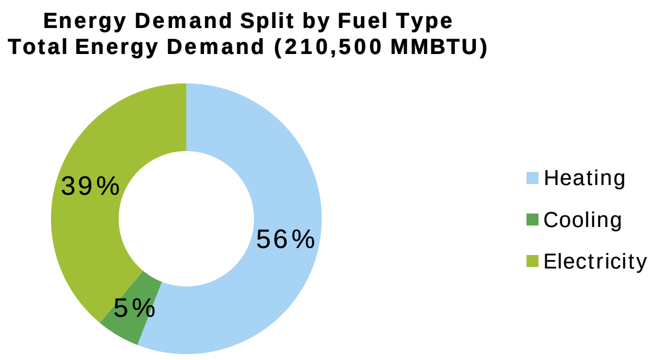

Figure 7 Energy Demand Split by Fuel Type

Energy demand from the Residential portion of the development represents 25% of the total energy demand. Mixed Use represents 35% and Commercial 40%.

2.6.1.2 Alewife

The development plans for Alewife are still being developed. A series of mapping and use type options has been developed. As the LCESS is not considering all possible development configurations a single scenario is represented here. This was agreed in advance with the City of Cambridge. The chosen scenario is: "Mixed Industrial" which has an FAR of 1.27.

Figure 8 below shows the possible development configuration for Alewife with Mixed Use light industrial, Commercial above (purple buildings) predominating. Other uses such as Commercial Retail and Residential are shown in red, orange and yellow.

Figure 8: Alewife Scenario for Assessment

Within the timeframe of this report the energy demand in Alewife is expected to increase by 478,000 MMBTU. Of this 51% will be for heating, 14% for cooling and 35% for electricity. Almost 475,000MMBTU is expected to be required by sites already in development.

As plans for Alewife develop the assumptions made in this first phase of the LCESS may need to be revisited.

2.6.1.3 Kendall Square

Kendall Square is due to undergo significant development over the next eighteen years. Much of the development will come forward as infill around existing buildings and so the demands recorded in the BEUDO dataset are still valid. Information used in the preparation of WP1 of the LCESS has been taken from the Energy Assessment and Study for Kendall Square completed by Arup Engineers.

The development will largely consist of the following building types:

- Commercial
- R&D
- Residential
- Education

Of these the majority of energy demand is for R&D buildings with an even distribution between Commercial and Residential demand. Limited detail is available with respect to each of the buildings given the early and high level nature of the planning process at this time. Floor areas and energy use intensity values have been reported based on the use types outlined above and this has enabled the total site energy demand to be estimated at the 2020, 2025 and 2035 milestone points. Milestone points are taken from the EcoDistrict Demand Study for Kendall Square. It was assumed that there would be no significant building energy retrofits in the five years to the end of the LCESS study period. MIT's Volpe Center is understood to have been included in the Arup assessment at the time of the study and so is included in the figures presented here at a high level.

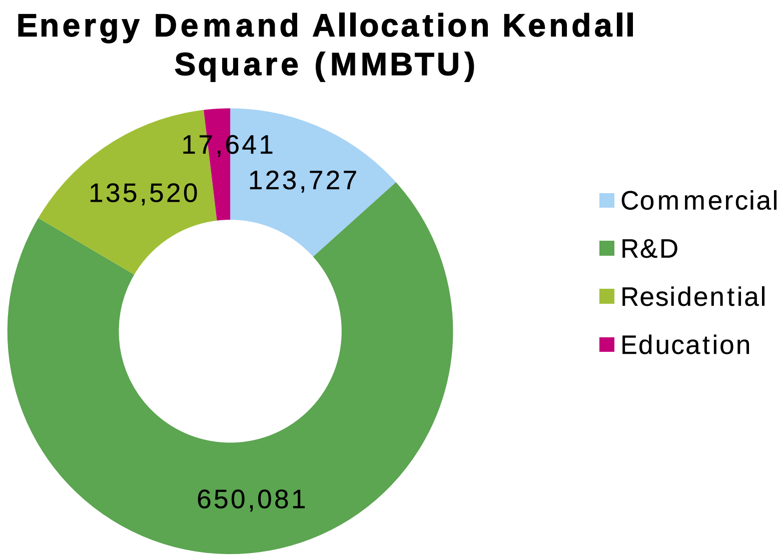

Figure 9 Energy Demand Allocation Kendall Square at Full Build Out

Heating accounts for approximately 45% of the total energy demand for Kendall Square with cooling requiring 25% and electricity 30%.

Figure 10 below shows the total energy demand for Kendall Square at full build out split between each energy use type at the build out milestones outlined in the Kendall Square Energy Assessment and Study.

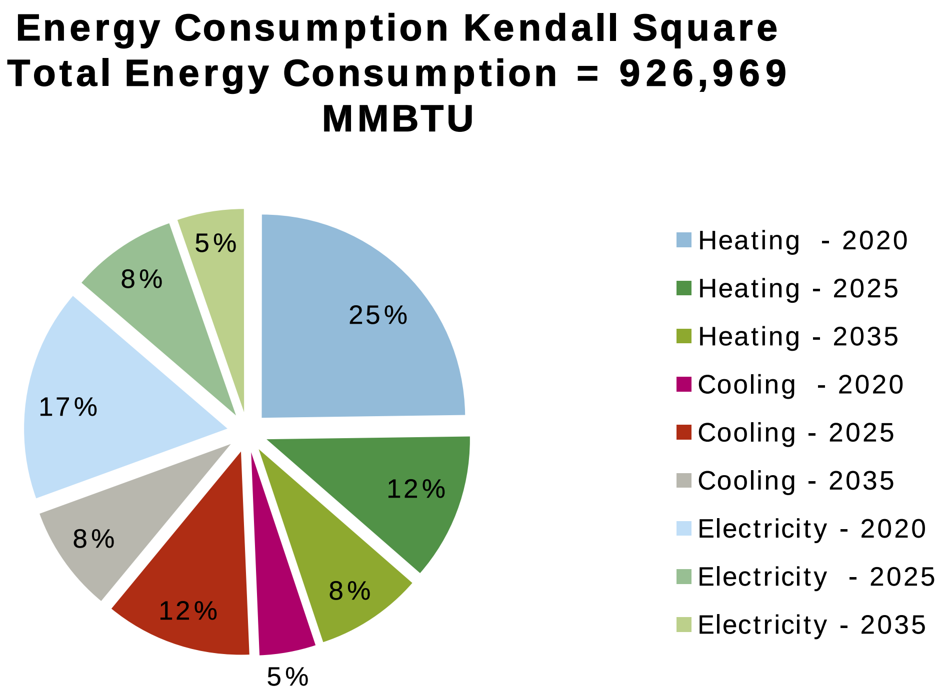

Figure 10 Energy Consumption Kendall Square

2.6.1.4 Additional Possible Development

Exact estimates as to how much additional development will happen in Cambridge in addition to the areas of Alewife, Northpoint and Kendall Square cannot be mapped as there is no location specific data available and the application of a blanket increase across the city would be misleading in energy planning terms. Without locations and timelines it is not possible to map these changes.

3. ENERGY SUPPLY IN CAMBRIDGE

3.1 Introduction

Energy supply in Cambridge is dominated by a number of cogeneration plants and the electricity and natural gas supplier, Eversource.

3.2 Existing Energy Supply in Cambridge

The primary existing large scale energy production within Cambridge is from cogeneration plants. There are three major plants in Cambridge. These are the plants at MIT, Harvard and Veolia's Kendall Square power plant.

Outside of plant generation, additional supply within Cambridge is generated primarily via renewable/alternative energy sources. Total solar capacity is roughly 5 MW and some larger facilities also utilize geothermal.

3.2.1 Cogeneration

- Cogeneration, also known as combined heat and power (CHP), refers to a group of proven technologies that operate together for the concurrent generation of electricity and heat in a process that is generally much more energy-efficient than the separate generation of electricity and useful heat.
- The typical method of separate centralized electricity generation and on-site heat generation has a combined efficiency of about 45 percent whereas cogeneration systems can reach efficiency levels of 80 percent. Cogeneration achieves high efficiencies due to the use of waste heat.
- In 2008, cogeneration accounted for 9 percent of total U.S. electricity generating capacity. A recent study by the Oak Ridge National Laboratory calculated that increasing that share to 20 percent by 2030 would lower U.S. greenhouse gas emissions by 600 million metric tons of CO_2 (equivalent to taking 109 million cars off the road) compared to "business as usual."

3.2.2 Veolia (eastern Cambridge)

The Kendall Cogeneration Station produces steam from its Combined Heat and Power (CHP) plant to meet the thermal energy needs of over 250 medical research institutions, hospitals, hotels, museums and government buildings throughout Boston and Cambridge. In Cambridge, Veolia supplies steam to office buildings, manufacturing, biotechnology and pharmaceutical facilities, in addition to operating Biogen's CHP plant as discussed further below.

Electricity and high pressure steam are generated by high efficient combined cycle gas turbines and heat recovery steam generators. Heat only steam boilers provide redundancy at the Kendall plant. Veolia currently produces 2.8 million lbs/hour of steam and their district energy steam distribution system comprises 26 miles of piping network[5].

[5] (Source: veolianorthamerica.com, accessed January 20, 2017)

3.2.3 Massachusetts Institute of Technology

The current MIT cogeneration plant is in reality a tri-generation plant as it supplies steam, chilled water, and electricity to the campus.[6] The cogeneration plant is a 21MW gas turbine that generates electricity, steam is then used for heating and cooling (via steam turbine driven chillers). The overall plant efficiency is estimated to be approximately 80% efficient. The turbine that was installed in 1995 is near the end of its useful life and is scheduled for replacement. The cogeneration plant meets the majority of campus electric needs.

3.2.3.1 MIT Energy plans

In 2015 MIT committed to reducing overall campus carbon emissions by 32% by 2030 (2014 baseline). This is illustrated in Figure 11 below which was provided to the study by MIT.

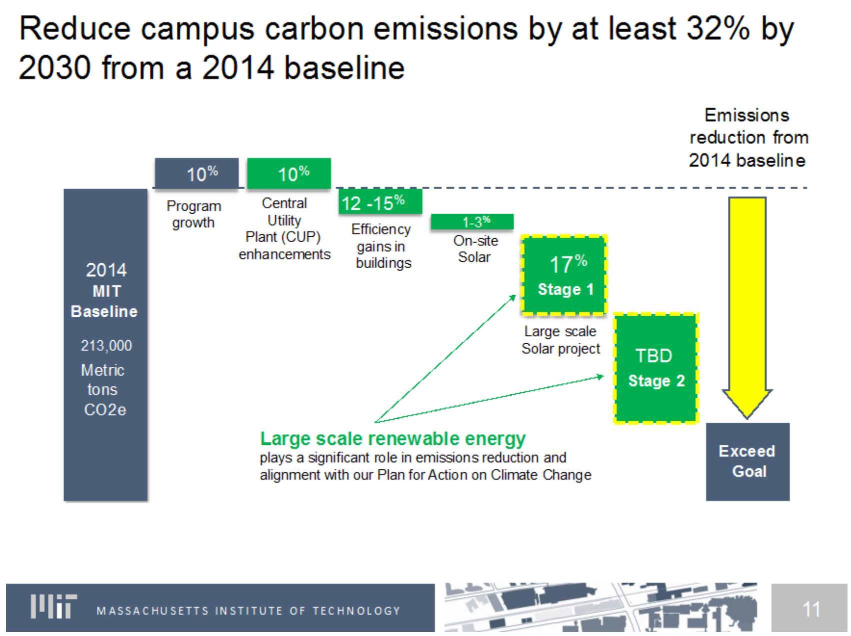

Figure 11: MIT Campus Emission Reduction Goals (Source: MIT)

MIT have been considering options and planning for the replacement of the existing generation plant on campus for the past 10 years. The plan for the campus energy supply is that the existing plant will be retired by 2020. Two new cogeneration units will be installed. Each cogeneration unit will produce approximately 22MW of electricity for a total installed capacity of 44 MW. The cogeneration units will be large combustion gas turbines firing on natural gas with ultra-low sulfur diesel as back up fuel. Waste heat will be recovered to produce steam through natural gas fired heat recovery steam generators (HRSGs). Upgrades to the chilled water plant will also be completed.

Overall the replacement of a single plant with two units will improve system resiliency and the improved plant efficiency will help to improve overall system efficiency. MIT has identified that heat recovery from their ice rink is not a major opportunity for them to consider; they currently have an ice melt system that utilizes the waste heat from the chiller's condenser to melt ice shavings from the Zamboni. MIT is continuing to explore other opportunities for waste heat recovery and will pursue them when it is technically and financially feasible to do so, there are no specific examples available at this time.

[6] (Source: MIT: https://powering.mit.edu/project-faq, accessed 1/20/2017)

3.2.4 Harvard University

For nearly a century Harvard has leveraged the benefits of on-site district energy to enhance reliability, improve the resiliency of its campus, and contribute to the University's ambitious greenhouse gas reduction goals.

The Harvard-owned Blackstone Steam Plant located on Blackstone Street, Cambridge supplies steam and electricity to 160 buildings on the Cambridge and Allston campuses. The Plant includes four steam boilers, 7.5 MW combustion turbine generator and heat recovery system, and a 5MW backpressure steam turbine generator. The fuel mix is predominantly natural gas with oil and ultra-low sulfur diesel being used only for emergency backup situations. Systems in operation on campus currently consist of:

- Three district chilled water plants, two in Cambridge and one in Allston, supply chilled water to approximately 100 buildings.
- An electric microgrid (13,800 V microgrid) for power distribution, supplying 250 buildings on the Cambridge and Allston campuses.
- On-site renewable and alternative energy installations serve buildings throughout campus, including 17 solar PV installations with a capacity of 1.5MW, 8 geothermal systems, 6 on-site solar hot water systems, and 1 biomass facility.
- Four smaller combined heat and power systems are also located on Harvard-owned properties including Harvard Athletics pools, Doubletree Hotel and Shad Hall at Harvard Business School.

Projects undertaken to improve the efficiency and performance of the steam plant and chilled water facilities resulted in a reduction of 20,500 metric tons of carbon dioxide equivalent–the largest portion of on-site emissions reduction to date. Additionally, as a result of these investments, the emissions intensity of the Blackstone Steam Plant dropped by 22% from 2006-2016.

3.2.4.1 Harvard Energy Plans

Harvard has achieved the short-term goal it set in 2008 to reduce greenhouse gas emissions 30% by 2016, from a 2006 baseline, inclusive of campus growth. Changes to energy supply and demand, including the decarbonization of the regional electric grid, resulted in a 24% absolute reduction in emissions. This progress includes over three million square feet of new space. Purchased electricity from local renewable energy and hydro power sources fulfilled the remaining 6% reduction needed to meet the goal. Excluding campus growth, emissions were reduced by 40%. This is illustrated in Figure 12 below from the Harvard Climate Goal Report.

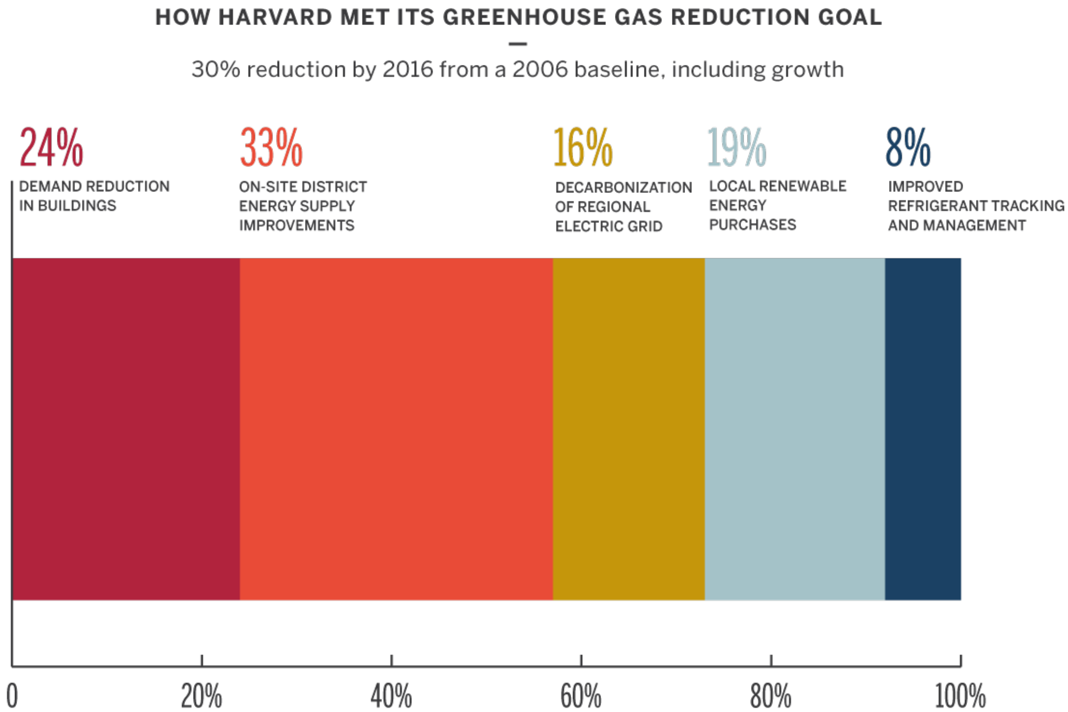

Figure 12: Harvard Climate Goal Summary

As a first step in meeting its climate goal, Harvard undertook a University-wide “energy efficiency first” initiative to reduce energy use in its buildings. Over 80% of the campus was energy audited, including all energy-intensive spaces, and energy reduction requirements were incorporated into the five-year capital planning process. Facilities teams and building managers took advantage of University-wide tools and resources including a Life Cycle Cost Policy and Green Revolving Fund, to install cutting-edge energy efficiency technologies and optimize existing systems through ongoing commissioning.

Over 1,600 energy conservation measures were implemented, and in 2015 and 2016 energy savings of 17,500,000 kWh were achieved. The most common types of improvements were HVAC (heating and cooling) and lighting upgrades. As a result, overall energy use is down 10% across the University, even as the campus grew (23% reduction excluding growth).

3.2.4.2 Renewable Energy

Harvard was an early leader in investing in renewable energy and off-site emissions reduction through the long-term PPA it signed in 2009 for 12MW of power and RECs from the Stetson II wind project in Maine. The University currently purchases 12MW of power and RECS from the Stetson II wind project and this accounts for 10% of power needs from renewable sources.

Harvard has also aggressively invested in on-site renewable energy generation by piloting emerging technologies, assessing wind energy potential along the Charles River and investing in solar projects to accelerate the transition to clean energy.

Source	Capacity
Solar PV	18 campus projects, total capacity 1.5 MW (Additionally, Harvard was responsible for installing a 500kW system on Arsenal Mall but the building was sold in 2013)
Roof Mounted Wind Turbines	2 x 10 kW
Geothermal with 1/30/35 ton water source heat pumps	10 x 1,500 foot open geothermal wells 3 x 400-600 foot open geothermal wells 88 x 500 foot closed vertical geothermal wells
Solar Hot Water	6 campus locations

Table 3 Harvard Renewable Energy Generation[7]

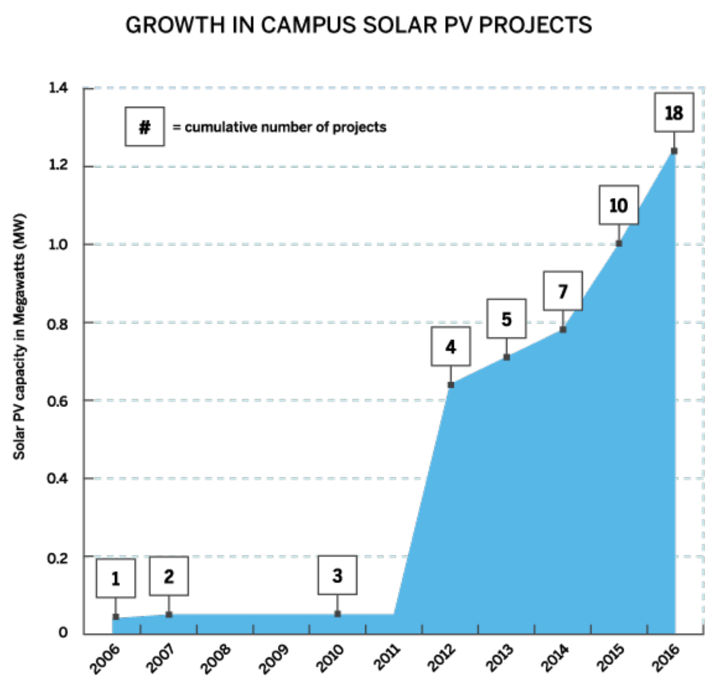

Figure 13: Growth in Campus Solar PV Projects

3.2.5 Biogen

The Biogen biotechnology company system in Cambridge is based on a 5 MW cogeneration system which includes steam distribution, electric distribution and a chilled-water loop that serves multiple buildings on their corporate campus in Kendall Square[8].

The Biogen central plant includes:

- 5.4 MW gas turbine,
- Heat recovery boiler with a capacity of 50,000 lb/hr,
- Two gas-fired boilers with a combined capacity of 50,000 lb/hr,

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[8] https://www.bostonplans.org/getattachment/0e8f81b8-4b32-4872-9c57-7c1d082ae7c3

- 1,200-ton absorption chiller.

The campus systems include steam distribution, electric distribution and a chilled-water loop. The Biogen campus system is interconnected with Veolia's adjacent district energy system, which allows Biogen the option of removing its peak load boiler which has infrequent use throughout the year. This improvement has increased the system reliability on both sides of the interconnection valve.

3.2.6 Novartis

The Novartis Institute for BioMedical Research has two 1.4 MW gas fired reciprocating engines. The cogeneration engines produce electricity and hot water. Hot water is generated from hot flue gas, the lube oil cooler, jacket water cooling, and engine intercooler. Hot water and electricity are used on site to offset utility costs.

3.3 New England Power Grid

Where the electricity supply is not coming from the sources of cogeneration or solar PV, it is coming from the New England Power Grid (NEPOOL). The New England ISO which operates NEPOOL plans to advance its supply mix so that it decreases its reliance on fossil fuels. The Massachusetts Renewable Energy Portfolio Standard (RPS) plays an important role in this for MA as a statutory obligation that suppliers must obtain a percentage of renewable electricity from qualifying Units for their retail customers. The RPS is further discussed in Section 6.1.3. Other states in New England also have RPS targets. The New England ISO plans to decreases its reliance on fossil fuels is as outlined below.

3.3.1 Wave One: Natural Gas

The late 1990s ushered in a steady shift to natural-gas-fired generation in New England. These resources are easier to site, cheaper to build, and generally more efficient to operate than oil-fired, coal-fired, and nuclear power plants. About 80% of new electric capacity built in the region since 1997 runs on natural gas. Gas-fired units remain the top choice for developers, representing more than 60%—about 8,200 megawatts (MW)—of all new generation currently proposed.

3.3.2 Wave Two: Renewable Energy and Demand Resources

In the 2000s, wind power, solar power, and demand resources began to make up a growing share of New England's resource mix, representing 16% (including hydroelectric) of supply in 2015..

	Wind Generation MA	Solar Generation MA
2016	9MW[9]	1,487MW[10]
2020 Target		1.6GW[10]
2027 Target	1,600MW[11]	

Table 4 Wind and Solar Generation Capacity in MA today and future targets

[9] http://www.mass.gov/eea/energy-utilities-clean-tech/renewable-energy/wind/why-wind.html
[10] http://www.seia.org/state-solar-policy/massachusetts
[11] https://www.northeastern.edu/climatereview/?p=294

The region's capacity market includes about 600 MW of active demand response, which relieves grid demand by reducing power consumption in real time, and 1,700 MW of energy-efficiency (EE) measures, which have essentially flattened demand growth over the next decade. Although renewable and demand resources comprise a small share of the power system's total capacity today, over 30% (about 4,200 MW) of all proposed new regional generation is wind-powered, and small-scale solar arrays are multiplying rapidly. While still many years off, renewable resources could in time satisfy a significant portion of New England's electricity needs.

Table 5 below shows the breakdown of different generation types that contributed to RPS compliance. This information is based on the most recent available compliance report for the RPS program, this report was for 2014 compliance[12].

Type	MWh	%
Anaerobic Digestion Gas	9,868	0.2
Other Biomass	375,109	8.1
Hydroelectric	129,790	2.8
Landfill Gas	820,001	17.7
Marine and Hydrokinetic	28,959	0.6
Solar PV	681,502	14.7
Wind	2,586,416	55.8

Table 5 RPS Class I Compliance by Generation Type 2014

3.3.3 Wave Three: Distributed Generation (DG)

In the next decade or so, New England could have a "hybrid grid." Up to 20% of power resources in New England could be connected directly to retail customers or to local distribution utilities—and not to the transmission system. Widespread residential solar power and storage systems, electric vehicles, and smart meters will change not only how much electricity people draw from the grid, but when they draw it.

3.3.4 Changes to the New England Power Pool (NEPOOL)

NEPOOL has shifted away from coal and oil towards natural gas (with fewer carbon emissions). Figure 14 outlines the dramatic shift in the energy supply of New England over the past 15 years.

[12] http://www.mass.gov/eea/docs/doer/rps-aps/rps-aps-2014-annual-compliance-report.pdf

Figure 14: Changes in Energy Supply to NEPOOL over 15 years[13]

Figure 14 above sets the outlines the changing nature of the electricity mix for NEPOOL over the past 15 years and is not specific to Massachusetts. Only ten years ago Massachusetts had approximately 5%[14] contribution to its electricity generation coming from renewable resources. By 2015 this had risen to over 10%[14], with wind and solar power accounting for almost two fifths of this. This has been possible in large part due to the RPS. Over 3 GW[15] of generating capacity is due to be retired in Massachusetts in the coming years. In order for the state to meet its 2030 goal of 25%[15] Class 1 or new renewable resources on the grid by 2030 and reducing GHG emissions to 80%[15] below 1990 levels by 2050 a large proportion of this retired supply will need to be met by renewable or low carbon resources.

By far the largest planned contributor to these goals is expected to be wind power with a short term goal of 2 GW of wind power on the Massachusetts grid by 2020, only 5% of this goal is currently in place.[14].

3.3.5 Opportunities

The following opportunities are taken from the ISO-New England document "2016 Regional Electricity output"[16] and provide a good overall summary of the key opportunities for NEPOOL.

- *"Natural gas resources and renewables are displacing less economic and higher-emitting resources in New England and will likely form part of the transition to a low carbon energy supply.*
- *The ability of many natural-gas-fired plants to change output quickly helps to balance an increasing amount of generation from intermittent power resources that rely on the wind and sun and will likely form part of the transition to a low carbon energy supply as a result.*

[13] Source: ISO-NE.com, ISO New England Assets Annual Report

[14] https://www.eia.gov/state/print.php?sid=MA

[15] https://www.iso-ne.com/static-assets/documents/2017/01/ne_power_grid_2016_2017_state_profile.pdf

[16] https://www.iso-ne.com/static-assets/documents/2016/03/2016_reo.pdf

- *Overall regional air emissions are down significantly. Between 1999 and 2014, nitrogen oxides fell by 66%, sulfur dioxide by 94%, and carbon dioxide by 26%.*
- *Wholesale electricity prices are being driven down—except when natural gas prices spike.*
- *Distributed generation may be able to help lessen the impact of local power outages.*
- *Smart grid technology and retail rate design changes will empower consumers to use electricity more efficiently and reduce their energy bills."*

Other opportunities identified in the course of completing WP1 of the LCESS are as follows:

- The RPS as discussed in more detail in Section 6 outlines the benefits of setting obligations to effect desired change in the energy supply market.

- The MA Global Warming Solutions Act[17] (GWSA) 2008, created a framework for reducing GHGs from all sectors of the economy to reach a target of a 25% reduction of by 2020 and an 80% reduction by 2050. This promotes the need for a clean energy economy through the development of smart, targeted policies that reduce emissions by promoting greater energy efficiency, developing renewable energy, and encouraging other alternatives to the combustion of fossil fuels.

- The Regional Greenhouse Gas Initiative[18] (RGGI) is a 9 state (including MA) market-based program to cap and reduce CO_2 emissions from the power sector. In 2014 the RGGI states implemented a cap of 91 million short tons, which then reduces 2.5 percent each year from 2015 to 2020. This results in states selling their emission allowances through auctions and investing proceeds in energy efficiency, renewable energy, and other consumer benefit programs. These programs are spurring innovation in the clean energy economy and creating green jobs in the RGGI states.

3.3.6 Challenges

The following challenges are taken from the ISO-New England document "2016 Regional Electricity output"[19] and provide a good overall summary of the key challenges for NEPOOL.

- *"Inadequate natural gas pipeline infrastructure is at times limiting the availability of gas-fired resources or causing them to switch to oil, which is creating reliability concerns and price volatility, and contributing to air emission increases in winter.*
- *Substantial non-gas generating capacity is retiring, limiting the options for reliable grid operation when natural gas infrastructure is constrained.*
- *The weather-dependent output from wind and solar resources and the increase in DG adds complexity to how the ISO must operate the power system to maintain reliability.*
- *Expensive transmission infrastructure upgrades are needed to connect more wind and hydro resources."*

[17] http://www.mass.gov/eea/air-water-climate-change/climate-change/massachusetts-global-warming-solutions-act/

[18] https://www.rggi.org/

[19] https://www.iso-ne.com/static-assets/documents/2016/03/2016_reo.pdf

3.4 Potential Energy Supplies in Cambridge

In addition to assessing the existing energy generation plants in Cambridge, potential alternative heating, cooling and electricity supply opportunities across Cambridge were also assessed. These included:

- Heat Recovery from Industrial stacks (flue gas heat recovery)
- Non-HVAC heat rejection from commercial facilities
  - Data Centers
  - Ice Rinks
  - Large Scale Grocery stores
- Cooling tower heat recovery - from process or large scale space cooling
- Water source heat pumps
- Heat recovery from wastewater treatment (from sewage sewer sumps via heat)
- Heat Recovery from Electricity Substations
- Ventilation Shafts from Underground Transportation
- Geothermal
- Solar
- Fuel cells

In some cases publically available information has enabled the overall capacity of these alternative supply assets to be assessed and quantified at a high level. In other cases information requests have been issued to the relevant stakeholders. Not all information requested has been made available at this time. Some of the requested information is expected to be provided as the project progresses; however for other asset types this data is simply not available. Where data is not available this is primarily because the information that informs energy capacity is not monitored. In order to quantify these assets field tests and monitoring would be required which is not within the scope of this project.

Many of the alternative “waste” energy sources require a heat pump in order for heat to be provided at a temperature that is usable as a heat supply for buildings. Heat pumps allow the heat energy from low temperature heat sources to be used to supply higher temperature systems using electricity. Unlike traditional electrical resistance heating systems, these are high efficiency units, often producing more than 3 units of heat energy for every unit of electricity consumed. This provides both energy conservation and carbon emission reduction benefits compared to traditional technologies.

Energy storage shall be considered as an opportunity as the project develops. Energy storage is not addressed in this report as it is not a standalone generation technology and is dependent on other technologies to supply it. Energy storage will likely form an integral part of the scenario development to be undertaken under WP2.

3.4.1 Heat Recovery from Rejected Heat

3.4.1.1 Flue gas Heat Recovery from Industrial Facilities

A review of BEUDO data revealed twenty records for buildings defined as “Manufacturing / Industrial” within the city of Cambridge. A more detailed desktop analysis of these sites indicated that there is limited large scale energy intensive industry in Cambridge.

Both Biogen and Novartis have large flues which under certain circumstances could potentially be used as heat sources. These stacks are likely from their reciprocating CHPs engine and not from process plant. Novartis already has flue gas heat recovery in place. It is unknown whether Biogen have a similar system, though this would be likely.

AT&T has a significant stack at 238 Bent Street Cambridge MA. No details are known for this plant at present. This is located in the Kendall Square area.

Retrofitting heat recovery into existing stacks can be costly and would likely be a small scale opportunity. In other regions approximately 3.4 MMTBU/hr of heat was the limit of available heat from industrial processes such as glass manufacturing. These will likely be small scale local opportunities which could eventually interconnect to larger opportunities in the long term.

3.4.1.2 Non-HVAC Heat Rejection from Commercial Facilities

Heat can be recovered from non-HVAC systems such as Data Centers, Ice Rinks and Large Grocery Stores. These facilities reject heat in order to cool computers, maintain ice conditions and for refrigeration respectively.

Data Centers:
A review of BEUDO data for the Cambridge area returned one entry for a data center in Cambridge, located at 205 Bent Street. No additional information as to the capacity of the site was available, as such it is not possible to estimate the volume of rejected heat that could potentially be utilized as a heat supply to a district energy network. Due to multiuse buildings it is very possible that there are more buildings with some data center uses but that these are not the primary building type.

Ice Rinks:
There are two indoor skating rinks in Cambridge, the Simoni Memorial Skating Rink and the Johnson Ice Rink at MIT.

No information on the heat rejection from the Simoni Skating Rink is available. Information was requested from MIT regarding their rink and the response is set out in Section 3.2.3.1, they noted that this was not an opportunity for them to recover waste heat.

These will likely be small scale local opportunities which could eventually interconnect to larger opportunities in the long term. Skating Rinks often reject up to 3,412 MMBTU[20] in a season, the peak rejected load would likely be less than 350 kTBU/ hr

Grocery Stores:
Heat recovery from large grocery stores is a possibility however the scale of the task for Cambridge would make this more of a future opportunity for supplementing an energy system rather than representing a large opportunity of its own.

3.4.1.3 Cooling Tower Heat Recovery

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[20] http://www.stoppsladd.se/Evaluation_of_heat_pump_concepts_in_ice%20_rinks.pdf

A desktop study of Cambridge revealed no significant large scale cooling towers outside of those utilized at the main power and cogeneration plants in Cambridge. Information requests to plant owners have included questions as to availability and practicality of heat recovery from these sites. Data collection is still being progressed by stakeholders.

3.4.1.4 Electricity Substations

There are approximately seventeen minor substations in Cambridge and five Eversource electrical substations as per Figure 15 below.

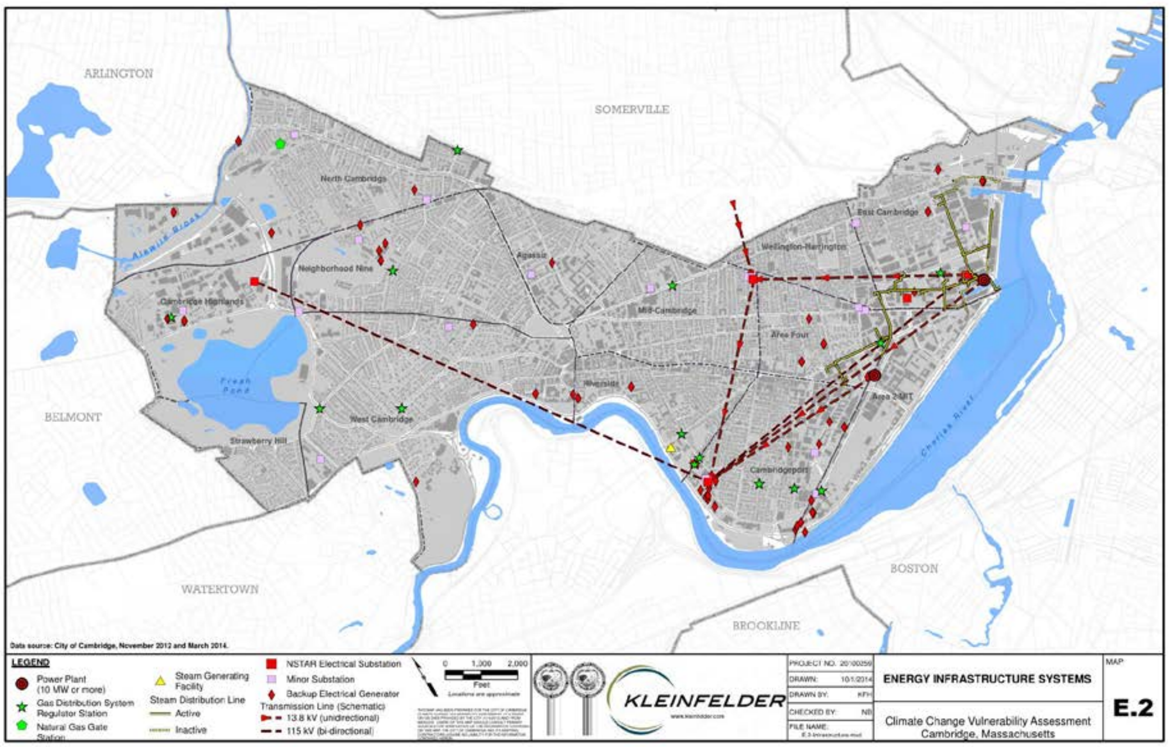

Figure 15: Electricity Infrastructure in Cambridge

The ability to extract heat from an existing transformer depends on the existing cooling system. A common arrangement that works with the sort of heat recovery system reference here is the OFAF type (Oil Forced Air Forced) with oil/water heat exchangers.

Liquid/liquid heat exchangers are superior to air to liquid systems in terms of heat recovery for the heat pump. Liquid/liquid heat exchangers are more compact, more efficient and easier to maintain.

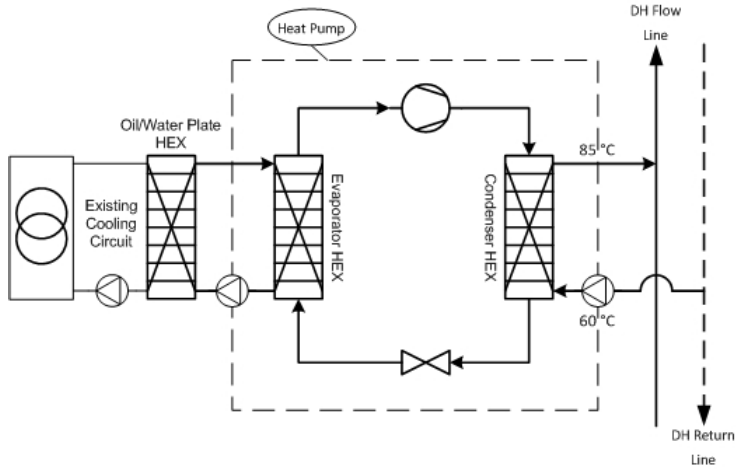

Figure 16 - System layout of Transformer HP

Heat is transferred from the oil system to the intermediate water loop which is the supply stream through the evaporator of the heat pump.

Such heat pumps in other systems have achieved heat offtakes of 1,700 kBTU/hr with a coefficient of performance of almost 5 (based on system data).

In order to assess the potential for utilizing this potential heat source, details of transformer capacities, cooling arrangements, operation and temperature are required. This information could not be provided at the time of reporting. Conversations with the local electricity utility indicated that this information would not be provided, but that if there was a specific opportunity the conversation could be picked up again.

3.4.1.5 Ventilation Shafts

There are five existing MBTA “T” stations in Cambridge and one planned station (which will be above ground).

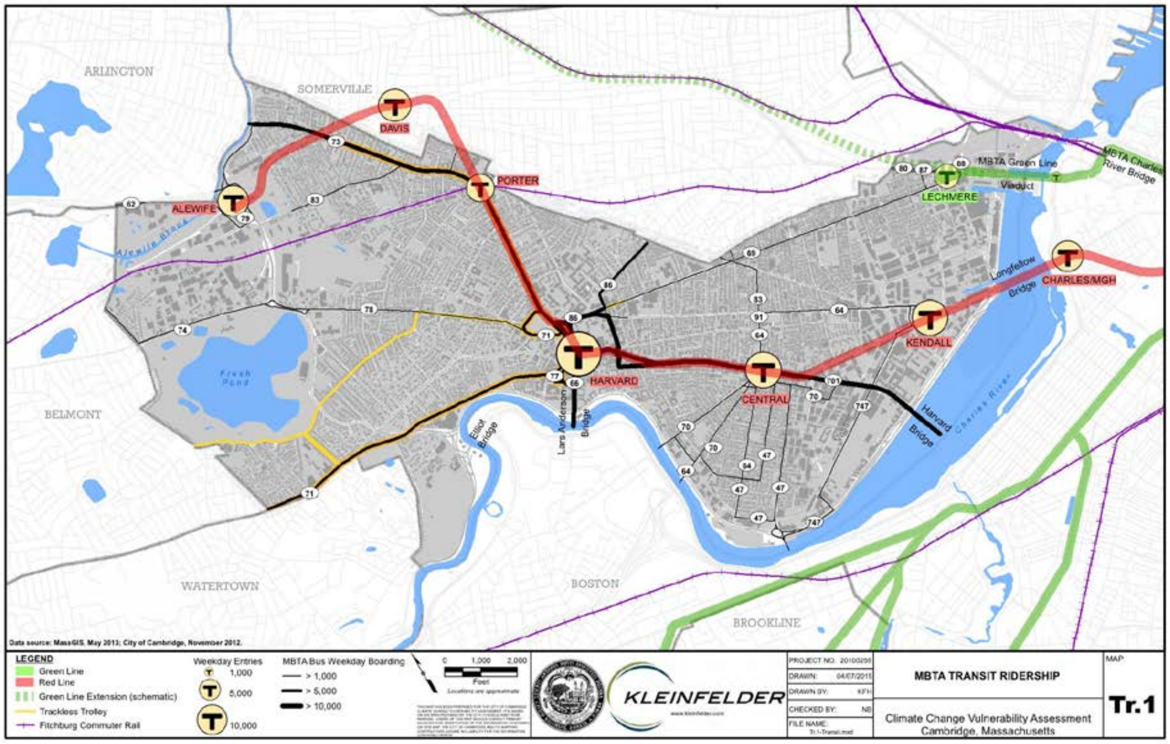

Figure 17 MBTA Stations in Cambridge

There is limited monitoring of ventilation shaft conditions such as flow rate and average temperatures. As such quantifying the available heat is not possible without further field work.

In other cities the potential heat extraction from vent shafts has been of the order of 1,000 – 2,000 kBTU/hr.

As such there is a limit to how much this could contribute to the overall heat demand in Cambridge, but this could form part of a wider, more diversified heat supply picture.

There are some key technical issues that can impact the feasibility of utilizing ventilation shafts as heat sources:

- Temperatures available
- Depth of the shafts

Some key points were raised during discussions of this with the Massachusetts Bay Transportation Authority (MBTA). Concerns were primarily regarding available temperatures, the T is not as deep as the London Underground (where this technology has been successfully employed). The T is also open-air in places, further reducing available heat. Many stations in Cambridge are heated and there are concerns that this would mean a limited scope for utilizing heat for other purposes.

3.4.2 Water Source Heat Pumps

The Charles River has for many years been used as a source of cooling for Kendall Cogeneration station. This involved extracting up to 77 million gallons of water from the river every day and returning the same volume at 10-20 degrees warmer. This combined with the low flow in the Charles river in the summertime led to algal blooms and fish kills. Since the deployment of the “Green Steam” district heating network in Cambridge and Boston this has ceased.

Because of these previous issues the Environmental Protection Agency (EPA) would likely not look favorably on any new schemes that involved using the Charles River.

However Cambridge’s ambitious targets for GHG emission reduction mean that every possible medium and long term opportunity must be assessed.

From a technical perspective it is possible that the Charles River could support some small to medium scale installations. These would be very different to the old Kendall system in that water source heat pumps can be designed to be open or closed loop. Open loop systems extract and return water to its source, closed loop systems involve no extraction of water from the source. Systems can be designed to meet the environmental requirements of the water body to protect the integrity and sustainability of the source. In general temperature changes can be kept to a few (1-2) degrees.

Water in the Charles River is by law not to exceed 83F. This could be an issue for using the river as a cooling source, as in the summer of 2016 this temperature was exceeded on multiple occasions (the blue line in Figure 18 below shows the threshold point). At this time the Veolia plant was still sending heated water into the river. To use the Charles River as a heating source would not pose an issue considering this temperature cap, as the temperature in the river would be reduced as heat was removed from it.

A detailed study would be required to rule this in or out as the temperature data received is for a single location only, and no bathymetric information is available for the river.

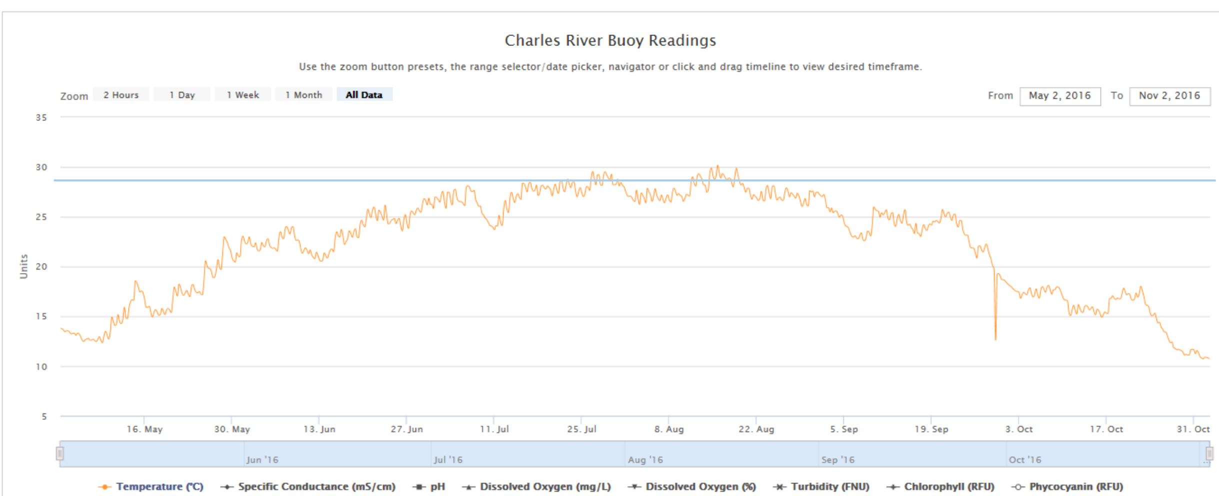

Figure 18: Charles River Temperature Data for 2016 (in Celsius)

Another potential heat source or cooling sink is the Fresh Pond reservoir in the northwest of Cambridge. In order to understand the potential of this source an information request was issued to Cambridge. They bathymetric survey for the Fresh Pond demonstrates the depth of the water body at the sampling point is approximately 36m. The Fresh Pond is mixed with an aeration system for environmental reasons. Temperatures at the deepest sampling point vary from 7 to 18 degrees

Celsius across the year. There is also significant variation in temperature with depth and a high degree of seasonality.

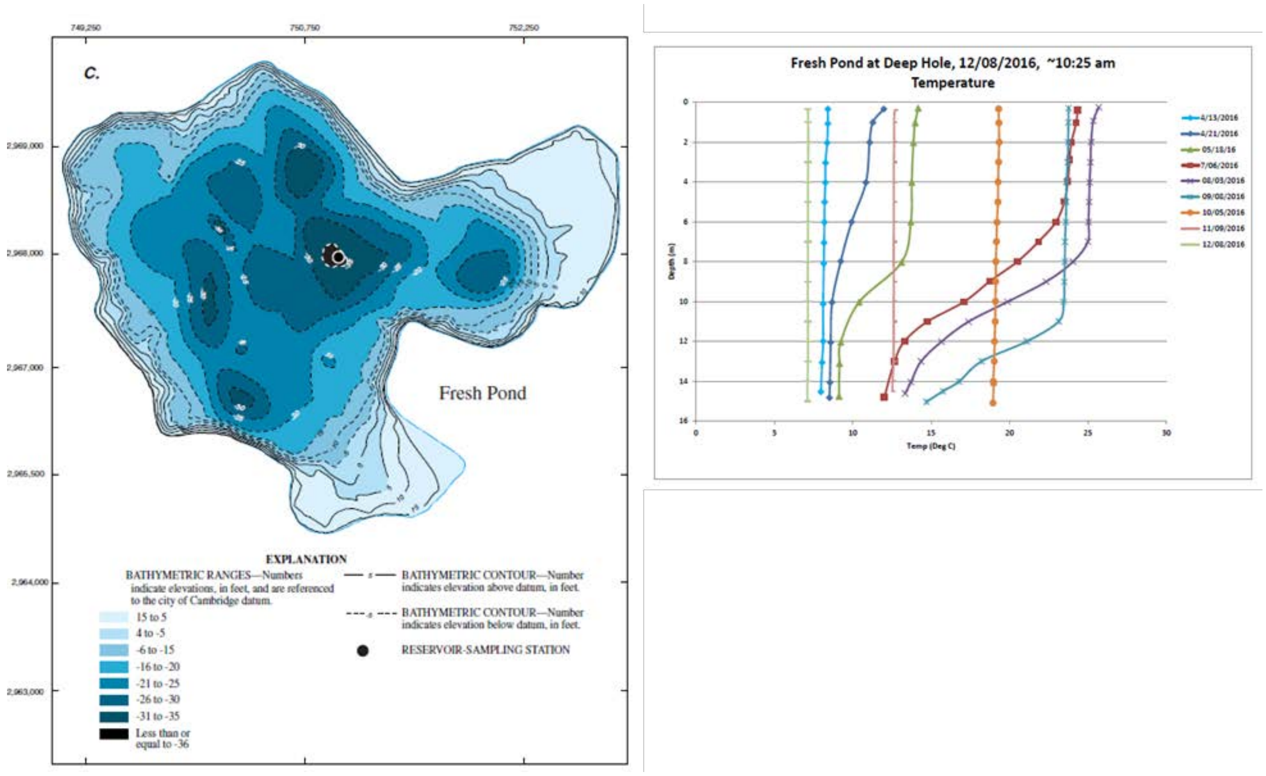

Figure 19 : Fresh Pond Teperature Data

3.4.3 Wastewater

Heat can be recovered from wastewater through the use of heat pumps which can increase the temperature of wastewater to up to 150F, suitable for use in a district energy system. Wastewater can also be used as a cooling sink in the summer time, where heat from buildings is rejected into the sewer.

Massachusetts Water Resources Authority (MWRA) is responsible for sewer services in Cambridge. Sewage from the Cambridge catchment area is treated at the Deer Island wastewater treatment plant. This plant is too far from central Cambridge to be a practical source of heat energy through heat exchangers.

Methane gas produced by the digesters is combusted in boilers and the heat produced provides heating for the buildings on-site and a portion is used in the treatment process. Steam produced by the boilers is used to generate up to $3MW_e$ of electricity.

It is not known how excess heat is utilized in the summer but there may well be excess of heat available, however the distance from the plant is too great to enable this to be used in Cambridge.

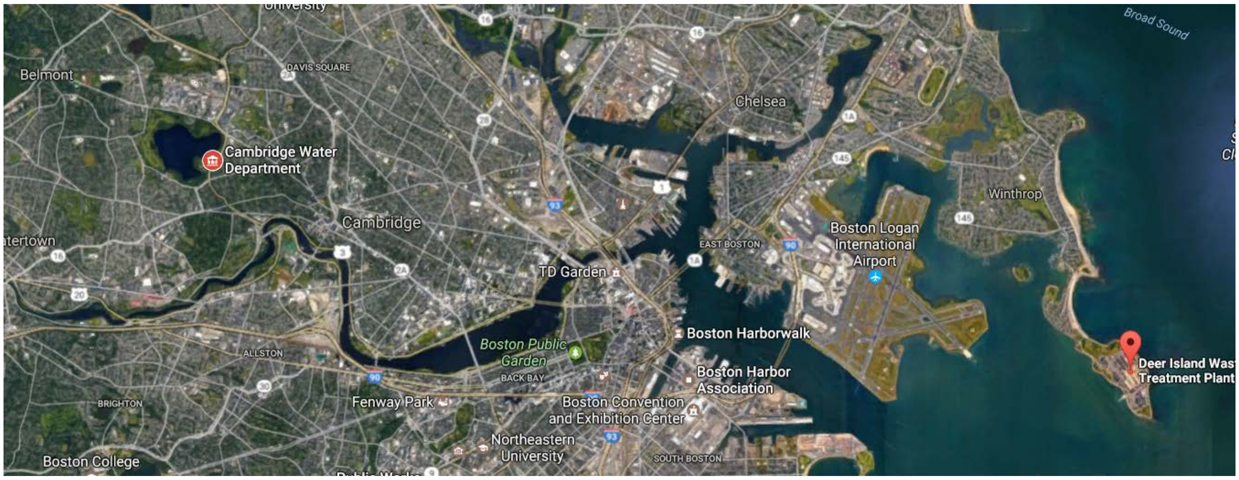

Figure 20: Map Showing the Location of the Deer Island Wastewater Treatment Plant.

As the treatment plant itself is not an option, there may be potential for using the sewer network in Cambridge as a heat source. Detailed network maps of the sewers in Cambridge were not available at the time of developing this report, however some of this information was collated for the recent Vulnerability Assessment and are shown in Figure 21 below. This map shows sewer mains with a diameter greater than 18 inches. The map also identifies combined sewer overflows (CSOs) as pink and yellow triangles on the map, these are owned by the Cambridge Department of Public Works (CDPW) and MWRA respectively. In addition details of sanitary and stormwater pumping locations were provided and are shown in Figure 22 below.

Heat recovery in sewer systems tend to require a sump or collection point. CSOs or pumping stations could be potential opportunities for deploying this technology.

Capacity depends on temperature of the sewage and the flow rate. This technology can be used to provide heating in winter and cooling in the summertime. More detailed information on the sewer system is required to quantify this opportunity. In other regions close to Cambridge the potential heating capacity of a sewer pumping station was estimated at 11,275 kBTU/hr. Cooling capacity was calculated at 15,620 kBTU/hr.

This indicates that there may well be a good opportunity for deploying this technology (although discounted when considered under the Kendall EcoDistrict Study) as part of the energy mix in Cambridge, subject to relevant codes, environmental regulations and further assessment.

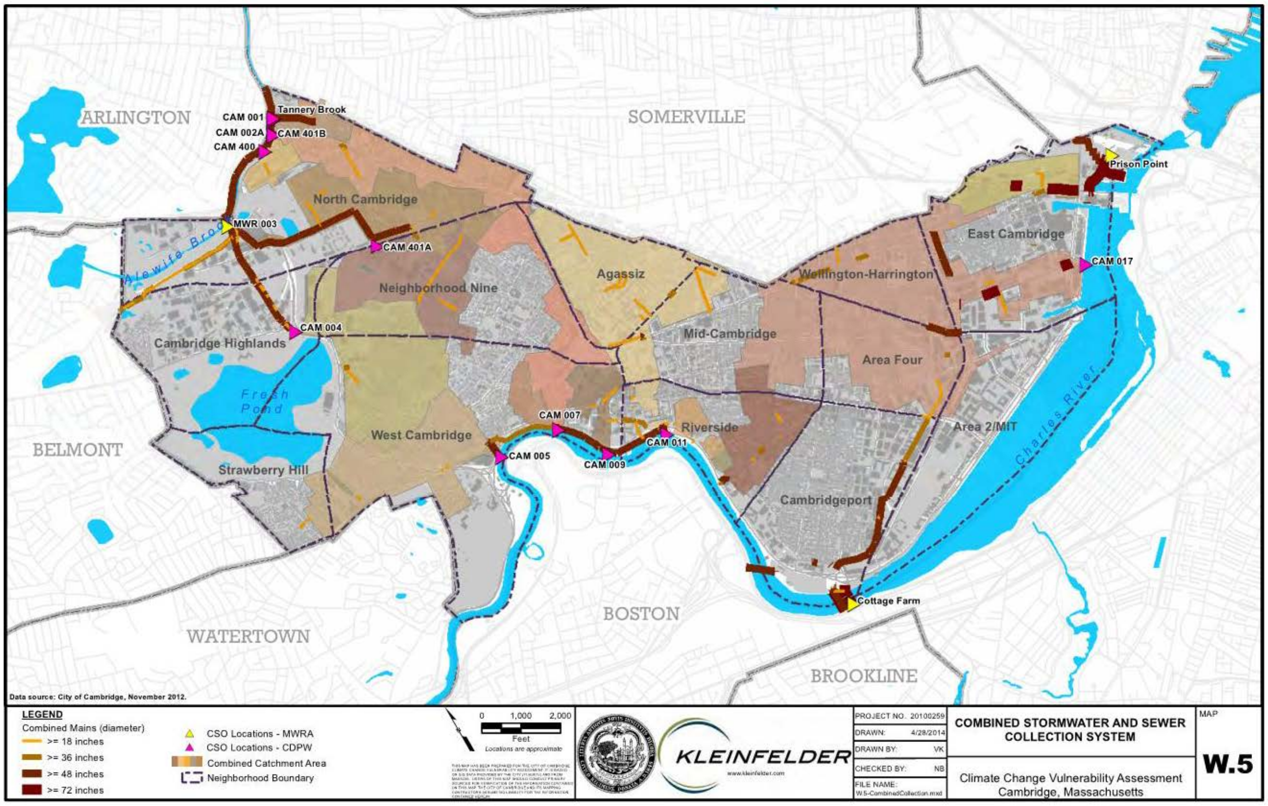

Figure 21: Vulnerability Assessment Map Showing Part of the Sewer Network in Cambridge

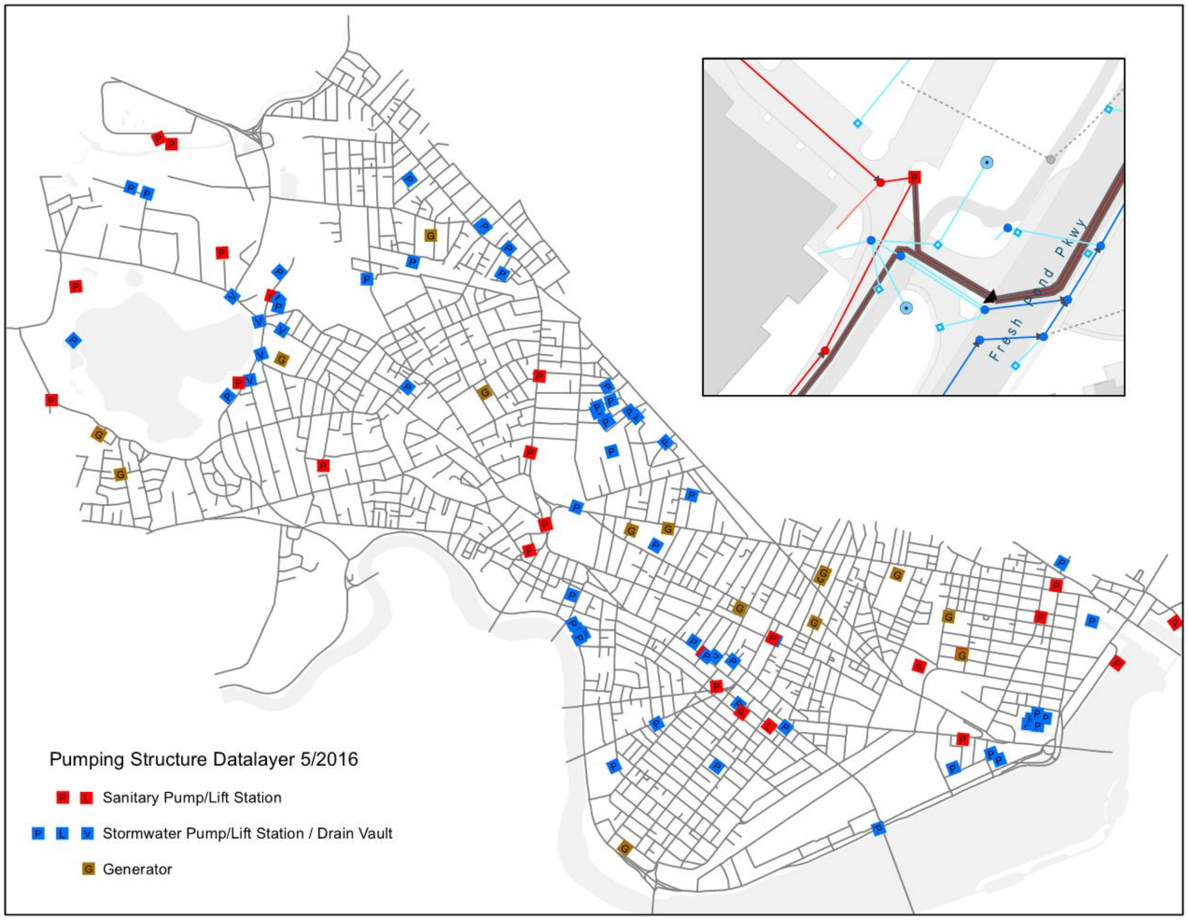

Figure 22: Details of Sanitary and Storm water Pumping in Cambridge (Source: DPW)

3.4.4 Geothermal Opportunities

Geothermal opportunities can be either shallow or deep geothermal, the differences are described below.

3.4.4.1 Shallow Geothermal

Shallow geothermal (either vertical or horizontal) extracts heat at low temperatures from the ground. Temperatures are raised to an adequate temperature for connected buildings using a heat pump. The temperature of the soil is used as heat source for the heat pump.

Such heat pumps can have Coefficients of Performance (COP[21]) of approx. 3 to 3.5, i.e. one unit of electricity produces 3 to 3.5 units of heat. The necessary length of ground piping is significant and the technology is often used for larger buildings such as offices, commercial etc.

Vertical wells will most likely be between approximately 100 and 500 meter.

[21] Coefficient of Performance. Measure of the amount of heat units per necessary power input to the heat pump

The technology is well proven and used on many locations in the US. The City of Cambridge already has a1200 ft deep geothermal installation at their City Hall Annex and additional installations at schools. Harvard has numerous well locations providing geothermal heat though discussions with Harvard have indicated that they have had problems with some of these installations.. This demonstrates the potential for the deployment of this technology in Cambridge.

Anecdotal information from other stakeholders suggests that there have been issues with water quality impacting the deployment of this technology in Cambridge, specifically relating to corrosion of pipes and that these issues have deterred further development of district energy projects. Corrosion proof materials and additives have addressed this in City facilities.

3.4.4.2 Deep Geothermal

Deep geothermal technology benefits from the fact that the temperature increases with depth in locations where it is possible to find good resources with extractable water. The depth of the wells is often more than 6,500 ft. Temperatures vary a lot depending on location and depth. Even where high temperature resources can be found it is not always possible to extract the water.

Even with very good preparation and good understanding of the geology it is still risky to drill. The costs are high; however, if the resources are present as expected it could be a prolific and cheap source for base heating.

Due to the high investment costs it is not usually feasible unless the heating demand is significant.
A very high level assessment has been undertaken for Massachusetts by the University of Massachusetts as shown in Figure 23 below.

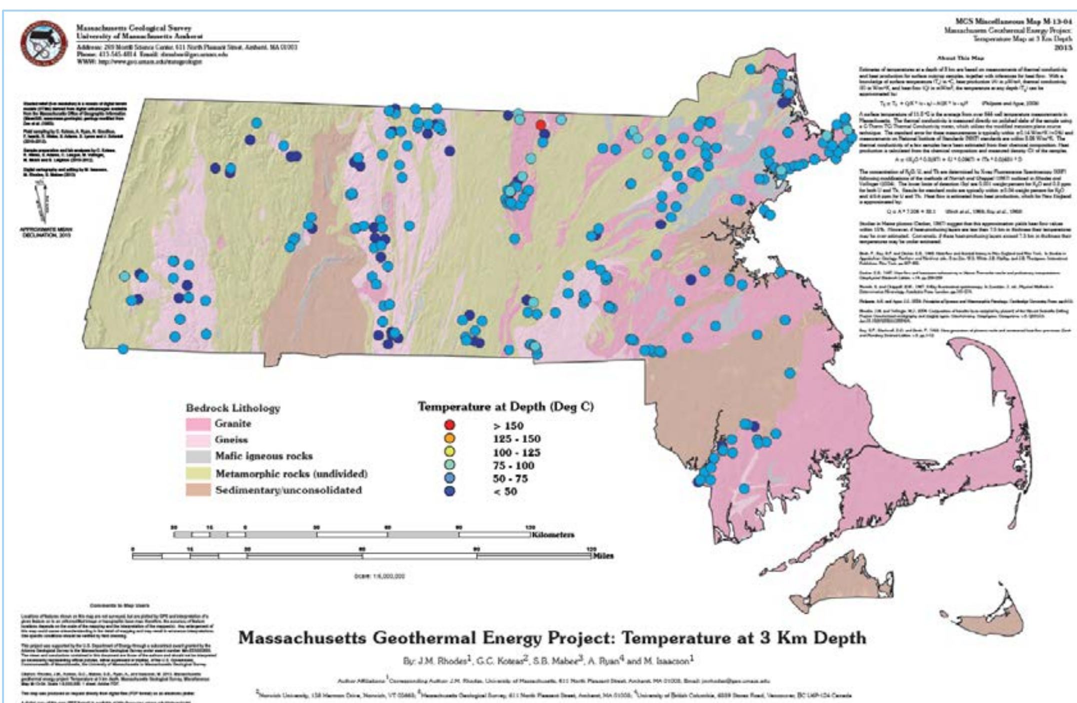

Figure 23: Geothermal Potential for Massachusetts[22]

Even at a depth of approx. 9,800 ft the general temperature is still too low for direct use of the available heat source without a heat pump (122F to 167F) (requiring the need for additional electricity input to utilize the heat). In a few locations it is possible to reach higher temperatures.

As a preliminary estimate the core depth should be between 9,800 and 13,100 feet. Even if temperature is adequately high, it is however not certain that it is possible to pump from these depths. This will be explored further in the subsequent phase of the project.

3.4.5 Solar Opportunities

Energy from the sun or solar energy for cities usually takes the form of Solar Photovoltaic (PV) or Solar Thermal. Solar PV uses the energy in the sun's rays to generate electricity, solar thermal uses the same energy to generate thermal energy for heating and hot water uses.

There is an online mapping system available for Cambridge which estimates the solar PV potential for every building in Cambridge. This resource also lists all known PV systems in the city. The number of PV systems currently installed in the city stands at 422 (4.5 MW_e) and includes the City Hall Annex which has a 26.5 kW_e system on its roof, supplying 10% of its electric energy. The City is on track to exceed a goal of producing 5% of its municipal energy demand with on-site solar PV by 2020.

The total solar potential in the city was estimated to be 340 GWh/annum[23], or 27% of the total electricity demand in Cambridge. This however is based on a number of assumptions which were tested as part of the Vulnerability Assessment and Net Zero Action Plan for the city. This assessment found that the real figure for roof-top solar PV was of the order of 91 GWh/annum.

The paper also identified a further 16.3GWh/annum that could be achieved if Cambridge developed some large scale solar on land at the city boundary.

Given the drive behind solar PV in the city Solar thermal may not be as attractive a solution given the lack of funding support which it attracts. Solar Thermal in a city context would provide a base load heat supply (likely the Domestic Hot Water (DHW)) proportion on a per building basis. This would however need to be supplemented with additional generation in the building, likely gas or electric boilers.

Solar thermal is generally used for baseload and domestic hot water supply, for this reason solar thermal can often be a barrier to other low carbon and sustainable energy supplies that rely on a base load to be economically viable. In the context of Cambridge this could essentially be an impediment to the deployment of other technologies as well as taking up space that could be used for solar PV.

3.4.6 Biomass

[22] Source: http://repository.stategeothermaldata.org/repository/

[23] https://www.mapdwell.com/en/solar/cambridge/terms

Biomass fueled technologies have potential for Cambridge to produce heat and/or power in a sustainable fashion. There are many arguments for and against using biomass, with the most commonly used being the actual sustainability of biomass. In Europe and in the US there is an overall agreement that biomass is not 100 % sustainable.

However when discussing the sustainability of biomass, this should be done in the context of the alternatives to biomass. The only fully sustainable source (from a carbon emissions view) is solar thermal, solar PV and wind power. The potential for utilizing biomass technology for the LCESS will be further considered in the next work package. Below the fuel types and technologies involved are discussed further.

3.4.6.1 Fuels

The most likely fuel for a biomass scheme would include wood chips. Using of larger amounts of wood chips would require a flexible and secure sourcing of the fuel. The city's position on biomass as a "renewable" resource is currently under review.

There is often a resistance of using biomass in city areas due to increased transport and expected increase dust nuisance. There will be increased transportation of biomass, however transport of other fuels will be less. In addition transportation of biomass by water is a real possibility for certain parts of Cambridge.

Energy production from biomass could be located on the outskirts of the city and fed into a district heating system which will minimize any potential nuisance. Given Cambridge's position surrounded by other high density urban areas, this is not likely to be a viable solution. It should be noted that many cities worldwide successfully accommodate biomass and waste combustion CHP plants within their boundaries.

There are likely to be concerns expressed regarding a plan such as this and a high degree of community engagement and education would be required. There are already combustion facilities within the city limits at Veolia, MIT, Harvard, Biogen and Novartis.

Modern biomass energy plants have very efficient filters which prevent dust nuisance.

3.4.6.2 Relevant technologies

Relevant energy production technologies for biomass would include:

1. Biomass heat only boilers
2. Biomass steam based cogeneration (larger plants)
3. Biomass Organic Rankine Cycle plants ("ORC")

With proper planning and design of a district heating system with reduced supply and return temperatures, it is possible to achieve very high efficiencies for biomass energy plants. If e.g. supply and return temperatures of 185F / 113F are achieved the efficiency will be approx. 110 % based on the lower heating value, in which energy from condensation of flue gasses is taken into account.

A biomass heat only boiler is a simple and well-proven technology. Many plants exist globally.

The most viable technology for small to mid-sized plants (up to approx. 30-50 MW heat) is often ORC. Again, the total efficiency could reach more than 100 % and the electrical efficiency about 18 %. The plants consist of two major components – the biomass boiler and the ORC unit. Depending on the capacity, both technologies are pre-fabricated which means low investment costs and relatively short construction time. In Europe there are more than 300 ORC units in operation. Other advantages are relatively low pressures and temperatures compared to a steam based plant and low O&M costs, including staffing, compared to a steam based plant.

Larger plants are steam based. The main advantage of the steam based plant is higher electrical efficiency, which can reach 26-28 %. The plants are constructed on site and are thus heavier with regard to investments.

4. CREATING DEMAND AND SUPPLY MAPPING

4.1 Demand mapping

4.1.1 Data Collection

The initial energy demand mapping phase involved collecting and analyzing data. The provenance and critical characteristics of these datasets are outlined in Appendix 1.

4.1.2 Demand Mapping Procedures

The energy demand dataset produced by combining the BEUDO dataset with the Property Database for Cambridge was imported into GIS.

Demands were assigned to maplots as this was found to be the most accurate match that could be attained.

All energy demand within a certain maplot was summed. Kernal Density maps were then produced for existing buildings. Kernal density maps were chosen because they demonstrate how energy demand changes across the city in an easy to understand visual.

Maps were produced for heating, cooling and electricity.

In addition a change map was developed for the medium and long term, showing how energy demand is expected to change in Cambridge over time.

The three major new developments have been included as points of increased demand in the maps also. Their boundary outlines are shown as dotted lines in the maps.

Heat maps are shown in a red color, cooling as blue and electricity as green.

4.1.3 GIS Demand Maps Produced

Name	Location
Cambridge Cooling Demand Map	Appendix 4
Cambridge Heating Demand Map	Appendix 2
Cambridge Electricity Demand Map	Appendix 3
Cambridge Cooling Demand Map – NW focus	Appendix 4
Cambridge Heating Demand Map – NW focus	Appendix 2
Cambridge Electricity Demand Map – NW focus	Appendix 3
Cambridge Cooling Demand Map – SE focus	Appendix 4
Cambridge Heating Demand Map – SE focus	Appendix 2
Cambridge Electricity Demand Map – SE focus	Appendix 3

Table 6: List of Demand Maps Produced

4.2 Supply Asset Mapping

4.2.1 Mapping Existing and Potential Future Sources of Low Carbon Heat

A heat supply opportunity database was created. This contains information about existing energy supply opportunities across Cambridge. The primary supply opportunity technologies identified as currently operating or under development in Cambridge are:

- Veolia
- MIT
- Harvard
- Eversource
- Biogen

The mapping process involved a combination of desktop research and stakeholder consultation. Site surveys were not carried out as these were outside the scope of the project brief.

4.2.2 Characterization of Supply Opportunities

Each supply opportunity, for which data has been made available, has been characterized according to a number of parameters including:

- Existing thermal capacity
- Existing electricity capacity
- Capacity available for export
- Temperatures available

- Age
- Condition

In many cases the heat extraction potential from heat sources has been inferred (that is calculated based on other known parameters which can be used to estimate the availability of heat). As this is information that has been inferred and not provided directly from the source it has been decided to characterize the heat supply opportunity database according to known, verifiable parameters such as electricity capacity. This has not been possible for a number of asset types, a full description of the approach to each is outlined in Section 3.

The outcome has been captured on a supply layer within the GIS database as shown in Appendix 5.

In some cases potential low carbon energy supplies have been mapped where the opportunity for utilization is still to be determined. For example, MBTA stations, transformer Substations, the Charles River etc. are all shown on the main supply map. These are possible future opportunities whose potential will be assessed as scenarios are developed.

4.2.3 GIS Supply Maps Produced

Name	Location
Existing and Potential supply sources Cambridge	Appendix 5

Table 7 List of Supply Map Produced

4.3 Demand and Supply Analysis

4.3.1 Demand Mapping

An assessment of the findings of the demand and supply mapping exercises was undertaken. This assessment considered the implications of the information presented in the mapping process.

As can be seen in Figure 24 below the majority of the heat demand is in the east part of Cambridge closest to central Boston. This is where the building density is highest and where many of the largest scale energy consumers in Cambridge are located (such as: MIT, Biogen, Novartis etc.). Heat demand then slowly reduces to the west as the building density and demand intensity of single family homes become the norm. A notable demand spot in the center of the map is also notable.

In terms of changes over time, in general the trend is for a reduction in heat demand brought about by the projected building fabric efficiency programs to be implemented under the Net Zero Action Plan, as described in Section 2.5. Projected changes in climate also contribute to the overall energy demand variation.

Also represented on this map is the change in energy demand due to the three major new developments expected to come forward in the years to 2030 (medium term) and 2040 (long term). These are seen here as large positive change areas within their development polygons.

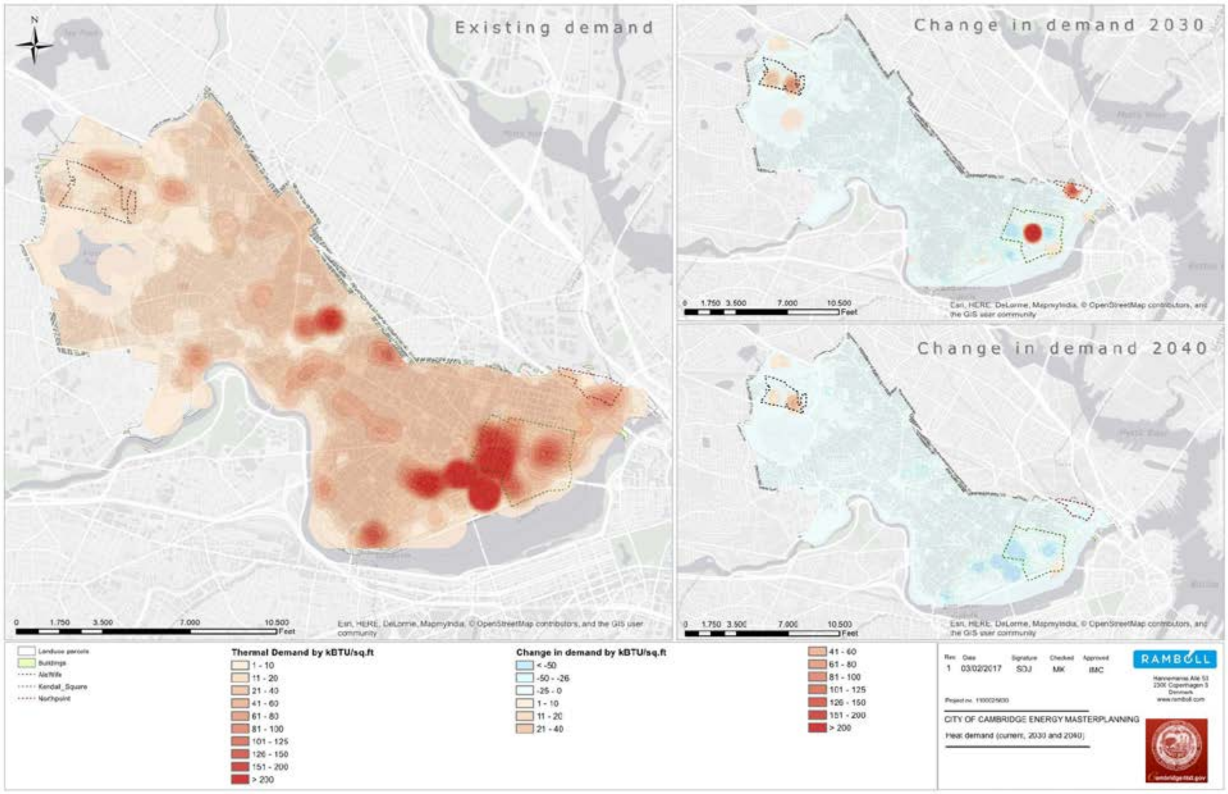

Figure 24: Heating Demand in Cambridge

Even at this early stage in the process, potential scenarios for low carbon energy supply are starting to develop. There is a definite area of opportunity for district heating in the high demand density parts of the map with a boundary to the northwest defined by the lower demand density and a central demand corridor.

For the cooling, a similar pattern emerges, the majority of demand is in the Kendall Square/MIT area. There is a lot of light blue on the main map indicating cooling demand between 0-2 kBTU/hr, this is primarily due to single family homes with no air conditioning (individual window air conditioning units are not captured here). Significant changes are expected in cooling demand across Cambridge due to climate change, increased retrofitting of air conditioning to existing buildings and of course the new development areas. Because of the centralized nature of the cooling demand there may be a good opportunity for a partial water network in part of Cambridge.

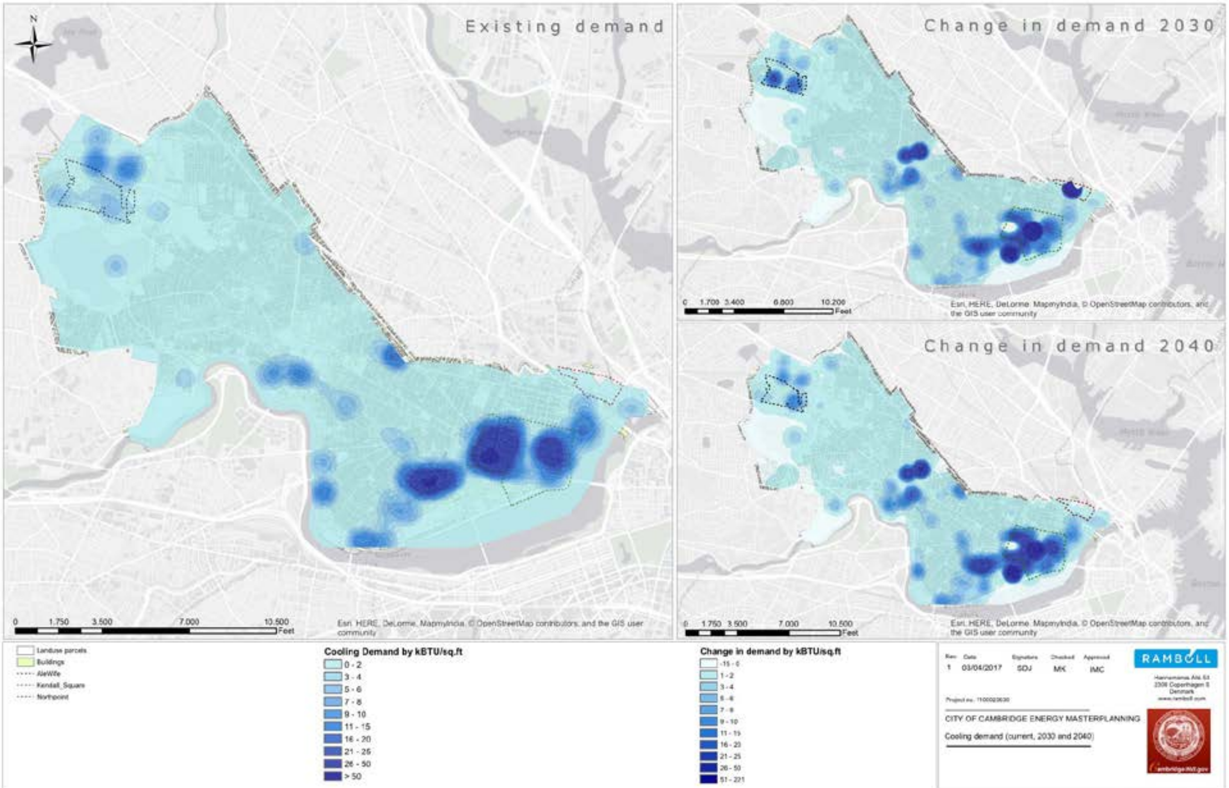

Figure 25: Cooling Demand in Cambridge

Electricity demand in Cambridge is shown in Figure 26 below. This demonstrates the areas of significant demand and the areas where changes are expected. Reductions in demand are expected across the city due to improved energy efficiency measures, the only areas where increases are expected is at the new development sites. These sites offer potential opportunities for dedicated low carbon cogeneration facilities and potential microgrid options.

Microgrids can save on distribution costs (as supplier doesn't have to pay the grid operator their set tariff) and provide resilience in black out situations. 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.

No microgrid geographical information was received as part of this study and could therefore not be mapped.

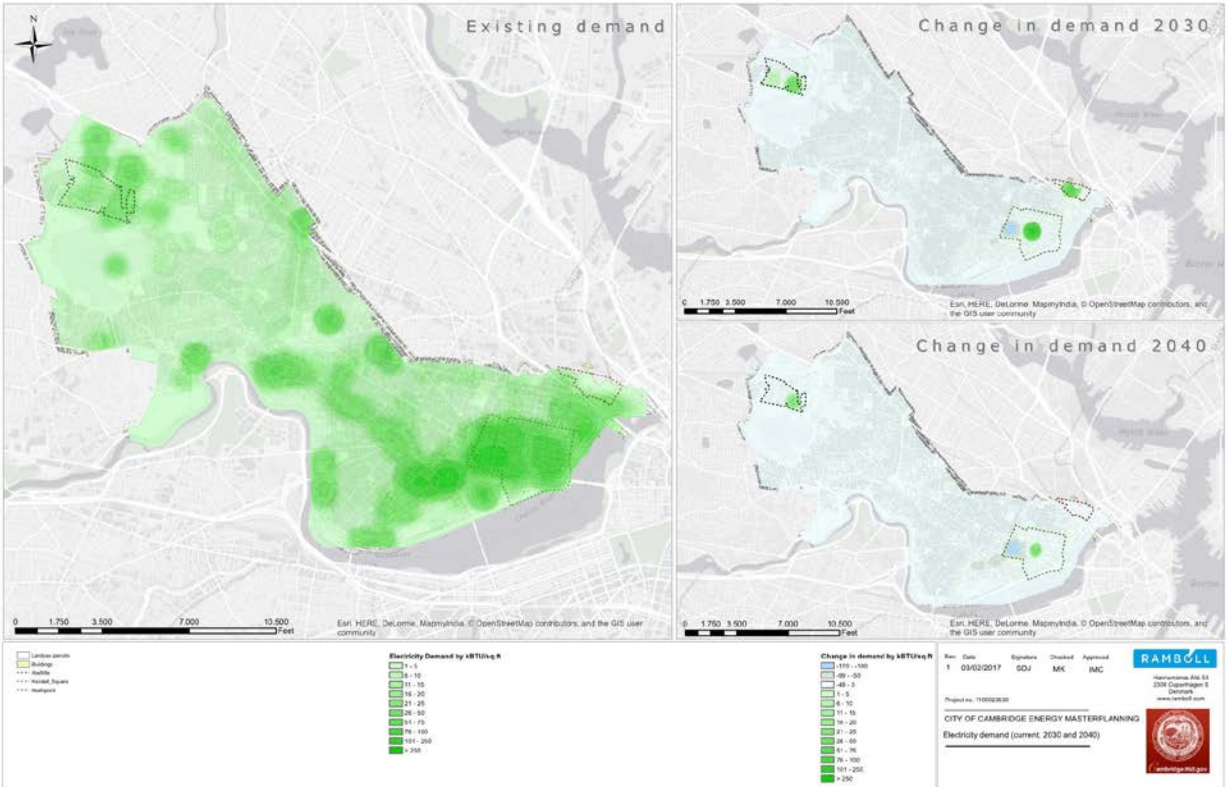

Figure 26: Electricity Demand in Cambridge

4.3.2 Supply Mapping

By understanding the spread of heating fuel in the city this can help to inform the development of scenarios.

The GIS data indicates that the gas network in Cambridge is spread throughout the city and that the business as usual case for most buildings will be natural gas furnaces connected to forced air systems. Natural gas is currently a low cost heating fuel and as such the economic competitiveness of other heating systems such as heat only supply generation of district energy can be impacted.

Conversely areas of the city where higher cost fuels are used for heating (oil and electricity) could be good opportunities for cost savings for the city and the energy consumers.

Neither of these aspects rule options in or out but rather serve to inform the conversation around energy scenarios.

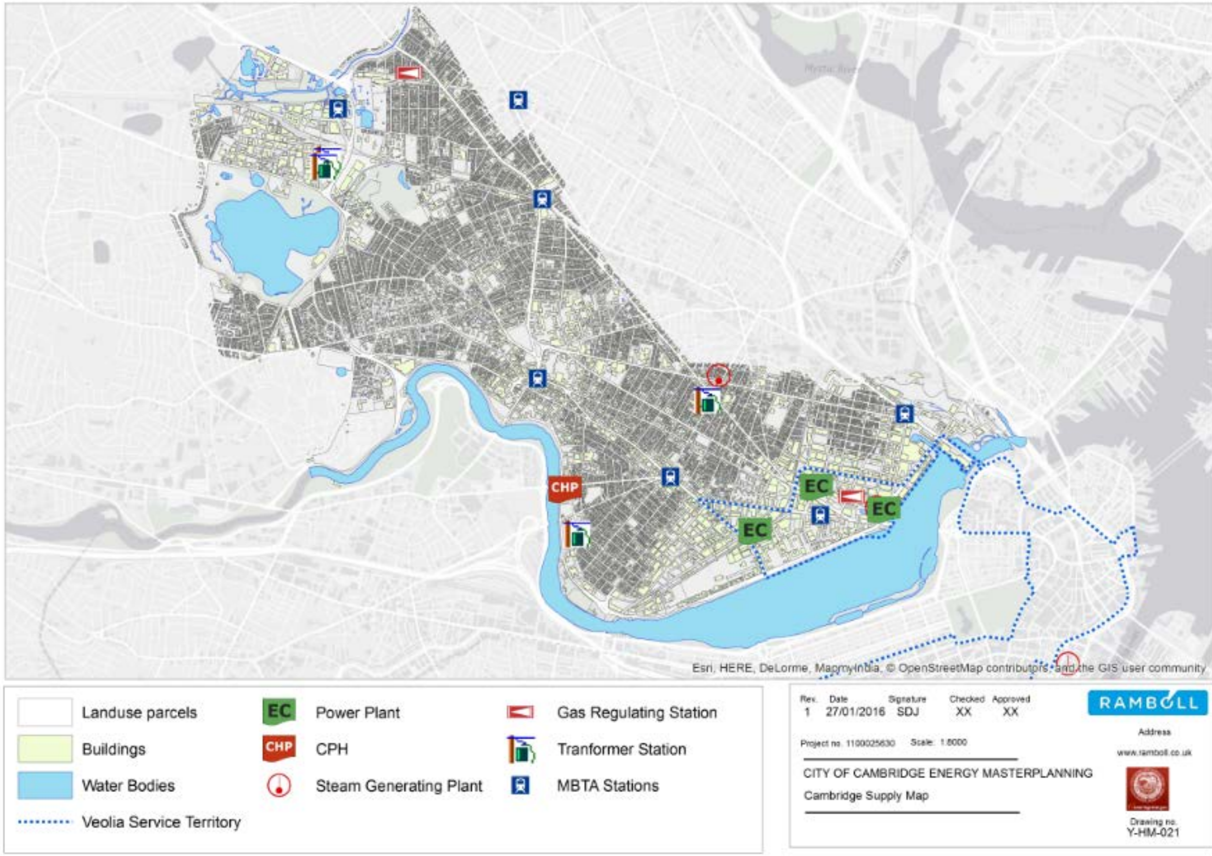

Figure 27: Supply Asset Map Cambridge

The asset map for Cambridge shows both existing and potential supplies. As can be seen the majority of the available existing supply is focused on the main demand areas in Cambridge, namely Kendall Square, MIT and Harvard. Other opportunities for supply are limited in terms of location and capacity, though the spread of sewer sumps could be an opportunity.

In general in the lower demand areas there is little in the way of existing or potential supply assets, so alternative and advanced solutions such as heat pumps, solar and dedicated new low carbon supply assets such as biofuel generators will need to be considered if the transformational nature of the project ambitions are to be met.

5. CONSTRAINTS AND OPPORTUNITIES

5.1 Constraints and Opportunities

Constraints and opportunities for the development of energy solutions are essentially non-exhaustive. For WP1, constraints and opportunities have been assessed based on available information. This section will be expanded and more detail added as the project moves to its next stages.

Regulatory issues are dealt with in Section 6, environmental concerns relating to specific technologies are addressed in Section 3.

Constraints and opportunities were assessed for:

- Energy Networks
- Supply Assets
- Demand Side

5.2 Energy Networks

Energy networks in this context refers to heating, cooling and electricity networks.

When building energy networks, the greatest cost is often the civil works. This is particularly true in busy metropolitan centers such as Cambridge. Any opportunity to de-risk network routing should be considered at the earliest possible stages of a project.

Some information that is available is the main routes for large diameter water mains in the city and the locations of some stormwater and sewer pipes.

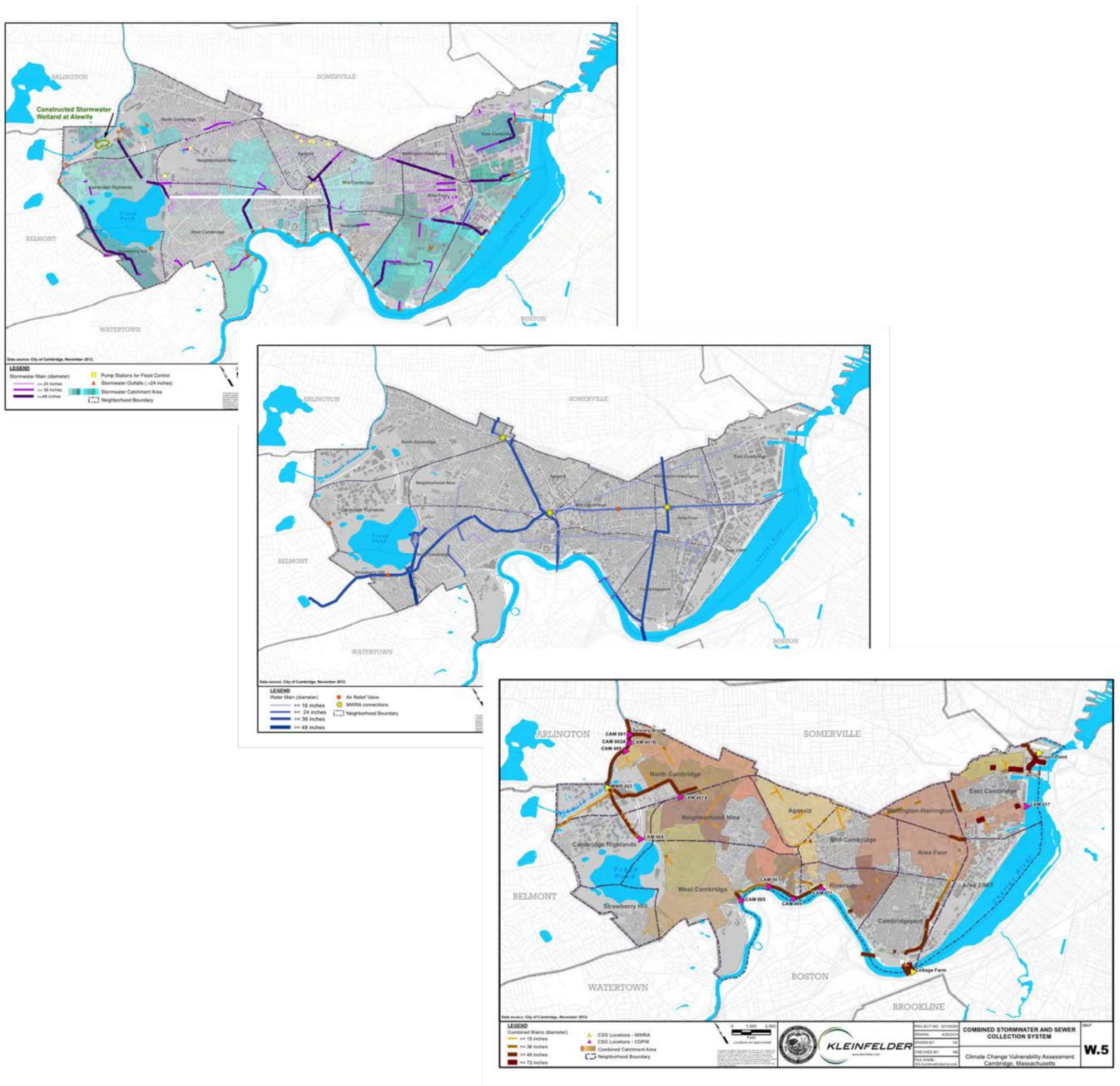

Figure 28: Stormwater, Watermain and Sewer Information from Vulnerability Assessment[24]

Due to a lack of available data the exact locations of other existing and planned services are not known and so it is not possible to comment on their impact on a potential project at this time. This information has been requested and will be incorporated into WP4 if received.

It is known that the Green Line Extension of the T is planned by 202, this may offer opportunities for working with the MBTA to consider co-location of services.

Figure 29 below shows the extent of the cycle network in Cambridge including opportunities for planned routes. Timing the installation of energy networks with other disruptive construction could help to reduce costs for both projects and reduce the disruption to the public. This information will continue to be considered as the project develops. In addition to this information the Vulnerability

[24] Vulnerability Assessment, Appendix A, Maps produced by Kleinfelder

Assessment for Cambridge identified highly trafficked areas and critical bicycle areas, this can help to further inform network routing to ensure minimum disruption and reduce costs.

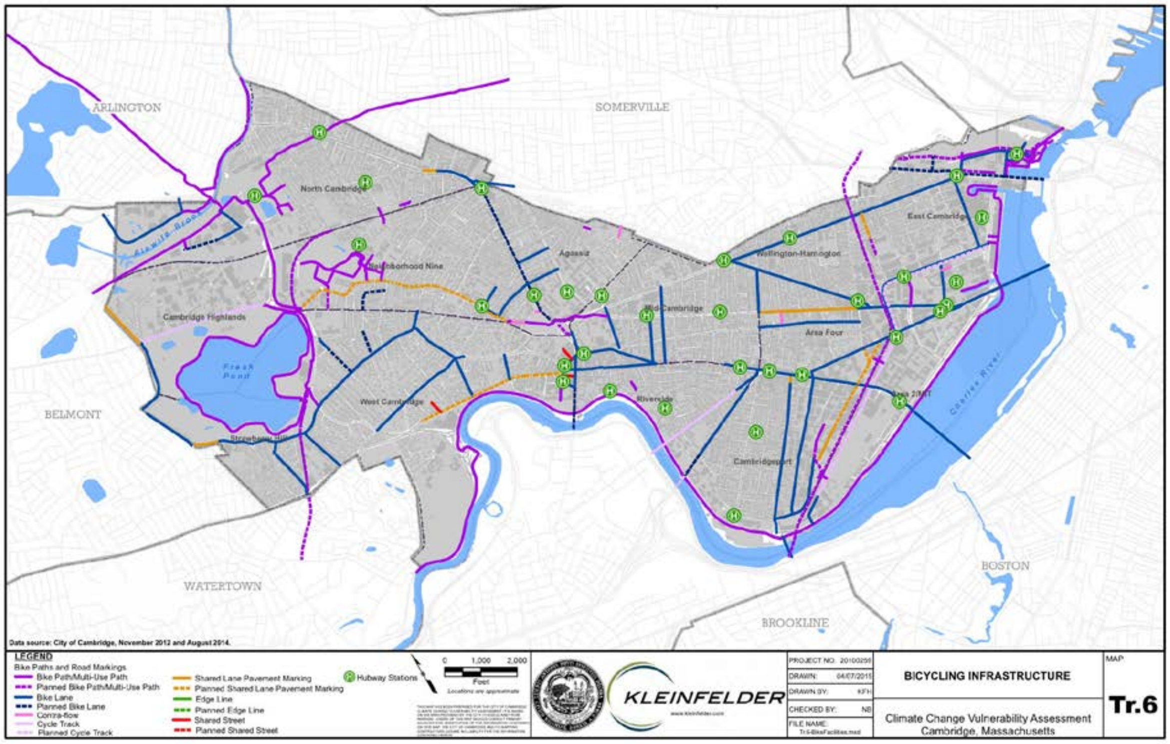

Figure 29: Bicycling Infrastructure in Cambridge[25]

A key opportunity and constraint for the development of energy networks in Cambridge will be the new developments planned for the duration of the LCESS. If energy networks and policies and regulations to support them can be put in place in time, this represents an excellent opportunity for these new developments to be involved from day one. If however these developments begin before decisions are made and policies are put in place, then opportunities in the early years may be lost. Developers will be resistant to going back into buildings and finished surfaces to retrofit new energy systems.

The Charles River is a major constraint to the possibility of extending energy networks to Boston; however extension to other neighboring cities such as Somerville is not restricted by waterways.

5.3 Supply Assets

Natural Gas is the incumbent heat supply in Cambridge. The City of Cambridge is committed to considering non-fossil fuel alternatives for the city. However the City does not have direct control over any of the existing plants and the future plants that the operators of these facilities may have.

Each of the three main plant operators (Veolia, Harvard, MIT) have plans for reducing their own GHG emissions and have engaged in a meaningful way with this process. However given the city's vision, the limitations imposed by not having direct control of supply may prove to be a constraint to meeting the goals of the City.

[25] Vulnerability Assessment, Appendix A, Maps produced by Kleinfelder

5.4 Demand Side

A key element of the Net Zero Action Plan for Cambridge is to ensure that existing buildings are retrofitted to improve building envelope efficiency. The climate change model also predicts several changes to demand over time. As this happens the energy demand on which energy networks are sized will change.

This could have the effect of reducing the demand (in the case of heating), freeing up capacity in the network for new connections, this could also be a constraint whereby the business case of the network is impacted by reduced heat sales if new connections do not materialize.

For cooling networks it is predicted that demand will increase, which could mean that networks would not be capable of supplying the full demand of customers.

6. REGULATORY FRAMEWORK[26]

The findings and recommendations that result from this Study, will ultimately sit within a regulatory framework within which they (the report findings and recommendations) must comply. This section outlines the existing regulatory framework for energy supply in Cambridge.

The Department of Public Utilities (DPU) is responsible for the structure and control of energy provision in the Commonwealth of Massachusetts; monitoring service quality; regulating safety in the transportation and gas pipeline areas; and for the siting of energy facilities.

The mission of the Department is:

- to ensure that utility consumers are provided with the most reliable service at the lowest possible cost;
- to protect the public safety from transportation and gas pipeline related accidents;
- to oversee the energy facilities siting process; and
- to ensure that ratepayers' rights are protected.

6.1 Electricity

6.1.1 Electricity Supply to customers

Massachusetts operates an unbundled electricity sector where privately- and publicly-owned electric utilities transmit, distribute, and/or sell electricity primarily for use by the public. Generation is also separate to the transmission, distribution and sale of electricity in Massachusets where competitive suppliers sell into NEPOOL. These include investor-owned electric utilities, municipal and state utilities, Federal electric utilities, and rural electric cooperatives.

DPU Regulation 220 CMR 8.00 outlines the conditions for the sale of electricity by qualified facilities and on-site generating facilities to distribution companies, and the conditions for the sale of electricity by distribution companies to qualifying facilities and on-site generating facilities.

The City of Cambridge is currently served by the investor owned company Eversource (www.eversource.com).

Massachusetts is part of the New England Independent System Operator (ISO-NE). The New England ISO engages in long-term planning that involves identifying effective, cost-efficient ways to ensure grid reliability and system-wide benefits. Coordination and cooperation between utilities, state Public Utility Commissions and RTOs (regional transmission organizations)/ISOs are often required to advance energy efficiency goals.

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[26]The following resources were used in the writing of this section: http://www.mass.gov/eea/pr-2016/pr-massachusetts-clean-energy-and-climate-plan-for-2020.html; http://www.mass.gov/eea/energy-utilities-clean-tech/natural-gas-utility/; https://www.ferc.gov/about/ferc-does.asp; http://www.mass.gov/eea/grants-and-tech-assistance/laws-and-regulations/utility-statues-and-regs/dpu-regulations/220-cmr-dpu/; http://programs.dsireusa.org/system/program?state=MA; http://www.mass.gov/eea/grants-and-tech-assistance/laws-and-regulations/utility-statues-and-regs/dpu-regulations/220-cmr-dpu/; http://www.masssave.com/en/about-mass-save ; http://www.mass.gov/eea/energy-utilities-clean-tech/renewable-energy/energy-storage-initiative/ .

6.1.2 Connecting new supply to the Grid

Net metering allows customers with distributed generation systems, typically wind or solar, to be compensated when their systems generates more electricity than the customer is using onsite by exporting to the grid. The size threshold for net metering varies; for example, for some technologies and situations, net metering may be allowed up to 2 MW.

Eligibility varies by technology and project owner. For public entities installing wind or solar systems, the cap is 2 MW per unit. For private entities installing wind or solar, the cap is 2 MW per project. In some cases, larger generators may also establish power purchase agreements with their utility. Onsite generating facilities of any type are eligible for net metering if they are 60 kW or smaller in size.

Net metering is allowed by all of the investor-owned utilities in Massachusetts, including Eversource. Massachusetts law previously limited net metering capacity to 6% of each utility's historical system peak load. Half of that capacity (3% of the total) was available for public facilities and half for private. As of April 2016, the legislation was changed to increase the cap to 7% for private projects and 8% for public projects and lowers the net metering credit for most private projects to near wholesale rates. Under the next solar incentive program developed by DOER and currently under approval, further net metering capacity changes[27] are expected and will be in operation from January 2018.

All distributed generation looking to connect to the distribution grid must follow the interconnection process. All investor-owned utilities in Massachusetts (such as Eversource) must follow this same interconnection process, as required by tariffs regulated by the Department of Public Utilities.

This interconnection process includes the steps to obtain approval from the local utility / distribution company to connect a distributed generation system to the electric grid (or distribution system). Municipally owned facilities are not required to follow this same process and may use different criteria for review. When you apply to an investor-owned utility for interconnection, the utility reviews your project to make sure there are no negative impacts on the grid. If potential impacts are identified, the utility will request additional review and in some cases will require you to pay for new equipment to protect the grid. Additional reviews and equipment upgrades are not usually necessary for most small renewable generators, but may be required for larger projects, more complex projects, or generation that is located on a network system.

6.1.3 Sustainability Promotion Initiatives in the Electricity Sector

The Green Communities Act of 2008 sets a goal for the Commonwealth of Massachusetts to have clean energy generation serve 20% of customer load by 2020.

The Massachusetts **Renewable Energy Portfolio Standard (RPS)** is a statutory obligation that suppliers (both regulated distribution utilities and competitive suppliers) must obtain a percentage of electricity from qualifying Units for their retail customers.

Suppliers meet their annual RPS obligations by acquiring a sufficient quantity of RPS-qualified renewable energy certificates (RECs) that are created and recorded at the New England Power Pool (NEPOOL) Generation Information System (GIS).

[27] http://www.mass.gov/eea/docs/doer/rps-aps/final-program-design-1-31-17.pdf

Under the 2008 Act, the Renewable Energy Portfolio Standard (RPS) was broken into RPS Class I and RPS Class II. RPS Class I applies to renewable generation units that began operation in 1998 onward, and RPS Class II to renewable generation units which began operation prior to 1998.

The technologies which qualify as Renewable Generation are as follows:

- Solar photovoltaic
- Solar thermal electric
- Wind energy
- Small hydropower
- Landfill methane and anaerobic digester gas
- Marine or hydrokinetic energy
- Geothermal energy
- Eligible biomass fuel

In 2010, RPS Class I requirements were altered to require a greater portion of Solar Photovoltaic energy to be supplied. This was called the **RPS Solar Carve Out** and supported distributed solar PV energy facilities across the Commonwealth. In 2014 this was further amended to continue supporting new solar photovoltaic (PV) installations until 1,600 MW of capacity is installed across the entire Commonwealth.

On June 30, 2016 the 1,600 MW capacity was met. As a result DOER has been working to create a long-term sustainable solar incentive program to follow on from the Solar Carve Out program, take account of recent development in the PV market and promote cost-effective solar development in the Commonwealth. The final proposal for the design of the next generation incentive program was presented to stakeholders on January 31st 2017 and is called the Solar Massachusetts Renewable Target (SMART) program[28][29]. Significantly, this new incentive program includes a Declining Block tariff program that is designed to provide more long-term stability (10-20 years) than the previous market driven RECs. This will reduce financing risks and reduce costs accordingly.

The Declining Block Program means the solar facility receiving the incentive will receive a single compensation rate which accounts for both the energy and the incentive. The resulting value of the incentive is the net difference between the all in rate and the value of the energy. The incentive will decline with the declining cost of solar. Compensation rate are still being finalised, but the SMART program and associated Block Tariff will come into effect in January 2018.

The 2016 RPS Class I requirement is eleven percent, and is set to increase by one percent each year.

RPS Class II is different from Class I in that generation is from older plant and that it mandates that a minimum percentage of electricity sales come from each of two sources, renewable energy and waste energy. As a result, Waste to Energy units which burn Municipal Solid Waste to generate heat and power are included within Class II generation units.

The current RPS Class II Renewable Generation obligation is 3.6 percent, and the Waste Energy Generation obligation is 3.5 percent. The obligation does not increase annually. A Supplier must comply with both the minimum percentage of Renewable and Waste Energy obligations.

The **Alternative Energy Portfolio Standard (APS)** (225 CMR 16.00) offers the opportunity for Massachusetts businesses, institutions, and governments to receive an incentive for installing eligible

[28] https://solect.com/doer-solar-massachusetts-renewable-target-incentive-program/
[29] http://www.mass.gov/eea/docs/doer/rps-aps/final-program-design-1-31-17.pdf

alternative energy systems, which are not renewable. Similar to the RPS, it requires a certain percentage of the state's electric load to be met by eligible technologies, which for APS include Combined Heat and Power (CHP), flywheel storage, coal gasification, and efficient steam technologies (draft revisions of this APS propose to additionally include rebates/subsidies towards wood pellet boilers/stoves, air source heat pumps, ground source heat pumps, heat pump water heaters and solar water heating). These resources contribute to the Commonwealth's clean energy goals by increasing energy efficiency and reducing the need for conventional fossil fuel-based power generation. In 2009, the Suppliers obligation was 1%, and is set to increase 0.5% each following year until 2014, when the growth rate will be reduced to 0.25% per year.

Retail Electric Suppliers are required to document compliance with RPS and APS in annual filings submitted to the Department of Energy Resources (DOER). Suppliers who cannot meet their compliance obligations through their plant, can meet them by purchasing **Renewable Energy Certificates (RECs)** from qualified generators and/or making **Alternative Compliance Payments (ACPs)** to the Massachusetts Clean Energy Center.

DOER sets an Alternative Compliance Payment (ACP) Rate which serves as a ceiling price for RECs and acts as a penalty which must be paid by RES, should they not purchase RECs from qualified projects for something less than the ACP in order to meet their compliance obligation and avoid ACP payments. The revenue generated from ACPs is used to fund new renewable generation projects throughout the Commonwealth.

In June 2015 in order to comply with these requirements, Eversource, in conjunction with other electric distribution companies, sought proposals for the supply of electric energy and/or Renewable Energy Certificates (“RECs”) from newly developed, small, emerging or diverse renewable energy distributed generation facilities under long-term power purchase agreements pursuant to Section 83A of the Green Communities Act (“Section 83A”). Preferred bidders were selected and contracts sent for MDPU approval in early 2016. This shows the RPS and APS compliance system in operation and how these technologies are incentivized.

Energy efficiency is also planned and incentivized for in Massachusetts. Currently there is a statewide energy efficiency plan for 2016-2018, which follows on from the 2013-2015 Three Year Plan, and was developed in collaboration with the Energy Efficiency Advisory Council (EEAC) and approved by the Massachusetts Department of Public Utilities[30]. This plan sets annual savings levels for both electricity (2.93% of retail sales) and gas (1.24% of retail sales)[31]. The proposed plan also ensures continued growth of energy efficiency in MA with year over year increases in annual and lifetime savings goals for both electric and gas.

Mass Save is contracted by numerous energy supply companies (including Eversource) to administer energy efficiency incentives. Under Mass Save, the Massachusetts Program Administrators (PAs) offer financial incentives and technical assistance to commercial, industrial, and institutional customers who are building new facilities or undergoing a major renovation; adding capacity; or replacing or upgrading equipment. They provide technical assistance and incentives to help optimize energy efficiency investment. Mass Save also provide assistance to home owners to incentivize energy efficiency in the home.

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[30] http://ma-eeac.org/plans-updates/

[31] http://www.mass.gov/eea/pr-2015/energy-efficiency-plan-proposed-in-massachusetts.html

The Database of State Incentives for Renewables and Efficiency (DSIRE) website lists 163 programs that offer incentives, policies or technical resources to promote distributed generation, including those offered by small municipals and cooperatives for the state of Massachusetts.

6.1.4 Grid Organization

Massachusetts has implemented **Integrated Resource Planning** to structure its grid supply. By incorporating least-cost and integrated resource planning (IRP), a utility is required to report its load and resource forecast for a specified period, and utilize the least-cost resource mix, including both supply and demand-side options. Because energy efficiency is such a low-cost resource, proper utilization of IRP tends to result in the incorporation of energy efficiency as a utility system resource and reduce the need for additional supply resources. This also reduces total resource costs for utilities.

The impact of this in Cambridge is to have Eversource to objectively analyze the potential of all its available resources – supply and demand – and identify the mix of resources that produces a least-cost, reliable resource plan.

6.1.5 Grid Modernization

In June, 2014, the Department of Public Utilities issued order D.P.U. 12-76-B requiring each electric distribution company develop and implement a ten-year grid modernization plan. The Department determined that grid modernization will provide several benefits including:

- Empowering customers to better manage and reduce electricity costs;
- Enhancing the reliability and resiliency of electricity service in the face of increasingly extreme weather;
- Encouraging innovation and investment in new technology and infrastructure;
- Addressing climate change and meeting clean energy requirements.

In the interim, Eversource have developed and sought approval for their Grid Modernization Plan. In January 2017, Eversource filed a $400 million grid modernization plan with state regulators, proposing significant investment in energy storage, electric vehicle infrastructure as well as an extensive grid management and resource integration system. Proposed changes are expected to increase monthly bills by 7% based on 2016 usage and could come into effect in January 2018.

Approximately 25% of the proposed budget is to be spent on Storage, 10% on electric vehicle charging and 65% on distribution automation. The plan also includes implementing a performance-based ratemaking mechanism that would adjust rates annually in step with a revenue-cap formula approved by regulators.

6.2 Heating / Cooling

6.2.1 Regulation of Heating and Cooling

Supply of steam for heating is regulated in Massachusetts according to 220 CMR 20.00, excluding design, fabrication, and installation of piping downstream of the customer's property line. This regulation covers the following headings:

20.01: Purpose and Scope
20.02: Definitions
20.03: Compliance with Standard Code
20.04: Notification of Construction
20.05: Operating and Maintenance Plan
20.06: Emergency Plan

20.07: Customer Education and Information Program
20.08: Employee Training
20.09: Periodic Inspections
20.10: Welding - Qualification and Nondestructive Testing
20.11: Leaks and Vapor Conditions
20.12: Logging and Analysis of Steam Emergency Event Report
20.13: Reports of Incidents and Interruptions
20.14: Facility Failure Investigation
20.15: Corporate Filings
20.16: Department Examinations and Investigations; Fines
20.17: Records
20.18: Miscellaneous

District energy systems supplied by hot or chilled water are not specifically regulated through the Department of Public Utilities.

6.2.2 Incentives available for thermal energy supplies

The Massachusetts Department of Energy Resources (DOER) is preparing draft regulations to include Renewable Thermal in the Massachusetts Alternative Portfolio Standard (APS 225 CMR 16.00) discussed above pursuant to Chapter 251 of the Acts of 2014. These draft regulations were put out for consultation with oral hearings in June 2016.

Waste heat usage from Energy from Waste or combined Heat and Power plants is incentivized through the Alternative Energy Portfolio Standard (APS) discussed above.

Additionally the Massachusetts Clean Energy Center (MassCEC) in partnership with the Massachusetts Department of Energy Resources (DOER) run the Clean Heating and Cooling program[32]. This provides renewable heat incentives for residential, business, commercial and industrial heat consumers. These incentives relate to rebates/subsidies towards wood pellet boilers/stoves, air source heat pumps, ground source heat pumps, heat pump water heaters and solar water heating.

6.2.3 Heating and Cooling System Regulation in Buildings

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). The Eight Edition, Massachusetts Building Code (780 CMR), consists of both a basic building code (the Massachusetts Basic Building Code) and a stand-alone one-and two-family dwelling code (the Massachusetts One- and Two-Family Dwelling Code).

The technical content of the Massachusetts Basic Building Code is based on the 2003 International Code Council (ICC) International Building Code. The technical content of the Massachusetts One-and Two-family Dwelling Code is based on the 2003 ICC International Residential Code.

6.3 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 Department of Public Utilities' Gas Division ensures that gas companies provide their customers with the most reliable resource at the lowest possible cost.

[32] http://www.masscec.com/residential/clean-heating-and-cooling

The Gas Division is responsible for the regulation of the eight investor-owned gas distribution companies in Massachusetts. The regulation of the natural gas industry requires the Gas Division to, among others, review forecast and supply plan filings, long-term supply contracts, numerous non-tariffed contracts for the sale and transportation of natural gas, energy efficiency programs as well as all Cost of Gas Adjustment filings that determine the rates customers are charged for the gas commodity.

In addition, 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. The Gas Division is in charge of ensuring that the natural gas market in Massachusetts remains competitive at the retail level.

Eversource is the gas supplier in Cambridge.

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. The Code is to apply to all new construction and new installations made subsequent to the effective date of the code.

6.4 Energy Storage

In May of 2015, Massachusetts launched the Energy Storage Initiative, with the goal of advancing energy storage capability within the states by attracting storage companies, accelerating technology development, expanding markets and progressing policies, regulations and programs that promote energy storage.

The program was later expanded in August of 2016 via ‘An Act Relative to Energy Diversity’ which opened public and stakeholder comment to set energy storage goals in January of 2017. These energy storage targets are still pending.

Electricity currently has the least amount of storage capacity in its supply chain and thus has become the focus for future energy storage development projects. Recent studies estimate that Massachusetts has the capability to generate upwards of 600 MW of advanced energy storage by 2025 (ESI Study, Mass.gov).

To date, energy storage in Massachusetts has been primarily concentrated on pumped hydro-storage. This technology is commonly used and therefore, minimal advancement to existing and/or new pumped hydro infrastructure is expected in the future.

Other, more conventional energy storage applications include batteries, pumped storage, ice storage and heat-based thermal storage. ‘Advanced’ applications have also come to the forefront, such as compressed air energy storage, flywheel and flow batteries.

Massachusetts currently offers a number of incentives for residents of Cambridge for energy storage applications primarily limited to fuel cells operating at the building level.

New incentives and programs launched in 2017 should further develop the energy storage market in Massachusetts. As part of the SMART program discussed above, energy storage will be compensated via a variable adder system which is based on the ratio of storage capacity to solar capacity as well as the duration of the storage. This will incentivize storage capacity in tandem with solar generation in the state.

Additionally, DOER and MassCEC have requested proposals for energy storage demonstration projects in Massachusetts. The projects proposed should provide solutions to the barriers and technical challenges storage deployment face in Massachusetts.

6.5 New Energy Facility Construction

The Energy Facilities Siting Board ("Siting Board ") is a nine-member review board charged with ensuring a reliable energy supply for the Commonwealth with a minimum impact on the environment at the lowest possible cost. The Siting Board's primary function is to license the construction of major energy infrastructure in Massachusetts, including large power plants, electric transmission lines, natural gas pipelines and natural gas storage facilities.

7. CITY CAPABILITY

In order to meet the Net Zero ambition of the City, it is likely that it will be necessary for the City to take an active part in the development of the city's future energy supply, as it has done with the sustainability improvements it has implemented in its building stock.

This section outlines the City's capacity for becoming involved in addressing the future energy supply of Cambridge under the headings of financial capability, public interest and drivers.

7.1 Financial Capability

The financial capacity of the City of Cambridge is described as being very healthy, based on sound financial practices which have left the City with substantial reserves, including $150M in Free Cash and $155M in excess levy capacity. It is anticipated that the City will also end FY17 in a very strong financial position.

The City has AAA rated bond issuing capability and there is precedence in the City issuing bonds to fund capital projects with, for example, $35M in General Obligation Bonds being issued in March 2016 to fund capital projects.. Capital projects funded by the City to date include utility projects such as storm water, sewer and drinking water supply. The City is generally conservative in its appetite for risk taking. When funding new projects the City aims to limit increases in property taxes and user fees. There are also municipal finance regulations that limit financial activities that municipal governments are allowed to undertake.

7.2 Public Interest

The City of Cambridge has developed a Participatory Budgeting (PB) process through which the community members directly decide how to spend part of a public budget and involve residents in the budgeting and City-building process. In December 2016, over 4,700 (~4%) residents voted in Cambridge's 3rd PB process on how to spend $700,000 on capital projects to improve the community. The projects were brainstormed and developed by community members in the summer of 2016. Three of the top four projects voted for investment related to renewable energy sources, totaling 65% of the available investment total for the 7 projects selected.

This indicates a strong interest of the community in its development and in its understanding of the need for alternatives to fossil fuel supplied energy.

7.3 Drivers

Net Zero Action Plan

In June 2015, the Net Zero Action Plan was adopted by the City Council of Cambridge. The action plan contains the following 5 actions to be addressed over the next 25 years in order to meet the objective of reducing Green House Gas Emissions by 70% by 2040, based on 2014 emissions data.

1. Energy Efficiency in Existing Buildings
2. Net Zero New Construction
3. Energy Supply
    - 3.1 Low Carbon Energy Supply Strategy
    - 3.2 Rooftop Solar Ready Requirement
    - 3.3 Develop a Memorandum of Understanding with Local Utilities

4. Local Carbon Fund Investigate Local Carbon Fund
5. Engagement & Capacity Building

The action plan will set 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

Under the Metropolitan Mayors Coalition (MMC) established in 2015, the Metro Boston Climate Preparedness Taskforce was created to guide regional climate decisions in a collaborative manner for communities in metro Boston.

The Taskforce identified four priority areas for 2017:

- Enhance local alignment and capacity building;
- Mitigate heat impacts;
- Mitigate flooding; and
- Deepen regional, state and federal coordination on public and private infrastructure activities.

In November 2016, as part of the second Metro Mayors Climate Preparedness Summit, the MMC members, including the City of Cambridge, pledged to develop and/or update a local climate mitigation plan and implement at least three climate mitigation actions by 2020. In addition, the member cities and towns committed that the region will achieve net zero/carbon-neutral status by 2050.

This GHG emission reduction target and the City's commitment to climate preparedness, in addition to the City's various goals outlined in Section 8, are a significant driver for the city to take an active part in the in the development of the city's future energy supply.

8. OVERALL GOAL COMPARISON

The City of Cambridge has set ambitious carbon reduction targets to be met by 2040, with additional challenging targets by 2050. In order to achieve these targets, the City has set itself multiple goals and sub-task targets as set out in the RFP for this project and the Net Zero Action Plan. The consultant has captured these stated goals of the City, as listed below, and categorized these into respective groupings of Energy Supply Goals, Policy Goals, Emission Reduction and Improved City Resiliency Goals, City Capacity Development Goals, Energy Consumption Reduction Goals and Communication Goals.

Appendix 6 outlines the goal mapping tool which will be used by the Consultant in subsequent work packages to facilitate relating the final scenario and action plan to the relevant goals and targets of the City. The purpose of the process is to facilitate the City in its tracking of goal realization and how the selected scenario for implementation will assist in meeting these.

8.1 Energy Supply 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.

8.2 Policy Goals

- “Net Zero Community” trajectory for City
- New municipal buildings achieve net zero emissions beginning in 2020
- Other new building types achieve net zero emissions between 2022-2030
- Energy efficiency retrofit regulation through BEUDO ordinance and at time of renovation and/or sale of property
- Solar ready new construction requirements with option for future solar generation requirement
- Support provision for community solar projects
- Establishment of a Local Carbon Fund offset mechanism
- “Utility of the future” policy and model: enable energy system transformation through grid modernization, new utility revenue models, and rules which incentivize energy savings and integration of renewable energy sources.
- Target energy retrofit activity using BEUDO

8.3 Emission Reduction And Improved City Resiliency Goals

- 70% emissions reduction by 2040 from buildings

- Carbon neutral city-wide by 2050
-
- Decarbonizing energy supply
- Increase renewable energy consumption
- Decarbonized imported electricity
- Increased local production of renewable power
- Elimination of fossil fuel heating and cooling sources
- Increase energy system resilience

8.4 City Capacity Development

- Technical energy system understanding
- Energy policy development and implementation understanding
- Understanding of energy system capital investment requirements and facilitation / management of same. (Investment requirements are typically the criteria which projects must meet in order for the City or an external investor to invest in an energy project)

8.5 Energy Consumption Reduction Goals

- Reduce energy demand

8.6 Communication

- Coordinated communication and engagement with residents and key stakeholders

9. RECOMMENDATIONS AND NEXT STEPS

The findings of WP1 were presented to the AC, comments from the AC were incorporated and the report was then re-issued. The demand models, maps and data will be issued once this phase is closed out.

WP2 has now commenced and is ongoing. The purpose of WP2 is to take the outcomes of WP1 and build on these to identify low carbon energy supply scenarios for the City of Cambridge. The outcome of this work package will be a short list of scenarios which will be taken forward for feasibility assessment.

Frontloading of certain items of WP2 has already begun, specifically strategy sessions involving the consultant and the City of Cambridge to establish the preferred methodology for comparing scenario opportunities. It is important that this discussion occurs at the very beginning of the scenario development so that the methodology has buy-in from all team members which will facilitate the development of successful solutions for Cambridge. These discussions are ongoing and are at all times referenced to Cambridge's main goals and objectives.

The key elements of WP2 will be:

- Consultant internal review of data and workshops to develop a longlist of scenarios
- Consultant to present and walk through the longlist with the City
- City to review summary memo of scenarios
- Following this review, the Consultant and the City will score the scenarios together to refine the long list of supply scenarios
- The Consultant will then prepare a more detailed summary memo of the refined scenario shortlist. This may involve:
  - Identifying any gaps in the data collected under WP1
  - Re-engaging with key stakeholders to gather data and discuss scenario specific issues such as the potential for interconnection
- Present shortlist of scenarios to AC to receive further input and discuss for agreement
- The Consultant and the City will then further assess and score the scenarios to agree a final shortlist of scenarios
- Develop maps and narratives for scenarios
- Proceed to WP4 feasibility assessment of shortlisted scenarios

A critical element of WP2 will be to establish risk management for each scenario; WP1 was too early in the project process to establish this, however WP2 provides an excellent opportunity to ensure that risk management is incorporated into the shortlisted scenarios at the earliest possible stages. This will ensure that key issues such as regulatory impacts and required mitigation measures can be identified and allowed for at all stages of project development.

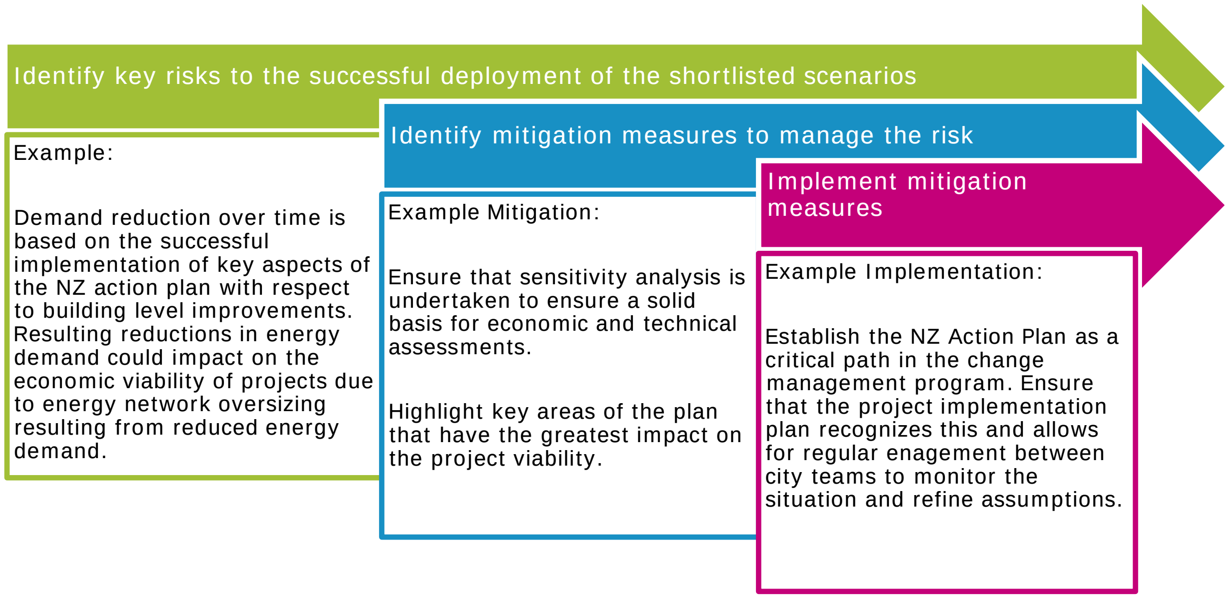


Figure 30: Example Risk Management

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 interconnection 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 initial project shortlist is completed, the AC committee will be consulted and a follow up meeting will be held between Ramboll and the City of Cambridge, at which point WP2 will be concluded with an agreement on preferred shortlist opportunities.

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.

The feasibility assessment of the shortlisted scenarios will occur in WP4. This phase will involve integrated demand and supply modelling linked to an economic and carbon appraisal of the shortlisted scenarios. These scenarios will then be assessed against the prioritization criteria to be agreed in WP2.

The outcome of WP4 will be an agreed project scenario for which an implementation plan will be developed. Ramboll will work with the City of Cambridge to develop this implementation plan to ensure that risk, change and benefit management are incorporated into this as well as communication and engagement planning.

APPENDIX 1
ENERGY DEMAND ASSUMPTIONS

INTRODUCTION

The information provided in this appendix represents the data processing and benchmarking methods undertaken and agreed with the City of Cambridge for the Cambridge Low Carbon Energy Supply Strategy Study.

The project team established benchmarks using actual energy data as well as typical building type energy use estimates derived from sources such as the Commercial Building Energy Consumption Survey and the Department of Energy.

DATA FROM CAMBRIDGE

Vanderweil used two datasets to create a baseline energy consumption for Cambridge, Massachusetts:

1. Cambridge Property Database (CPDB)
2. Cambridge Building Energy Use Disclosure Ordinance (BEUDO)

The Cambridge Property Dataset includes 28,884 data entries:

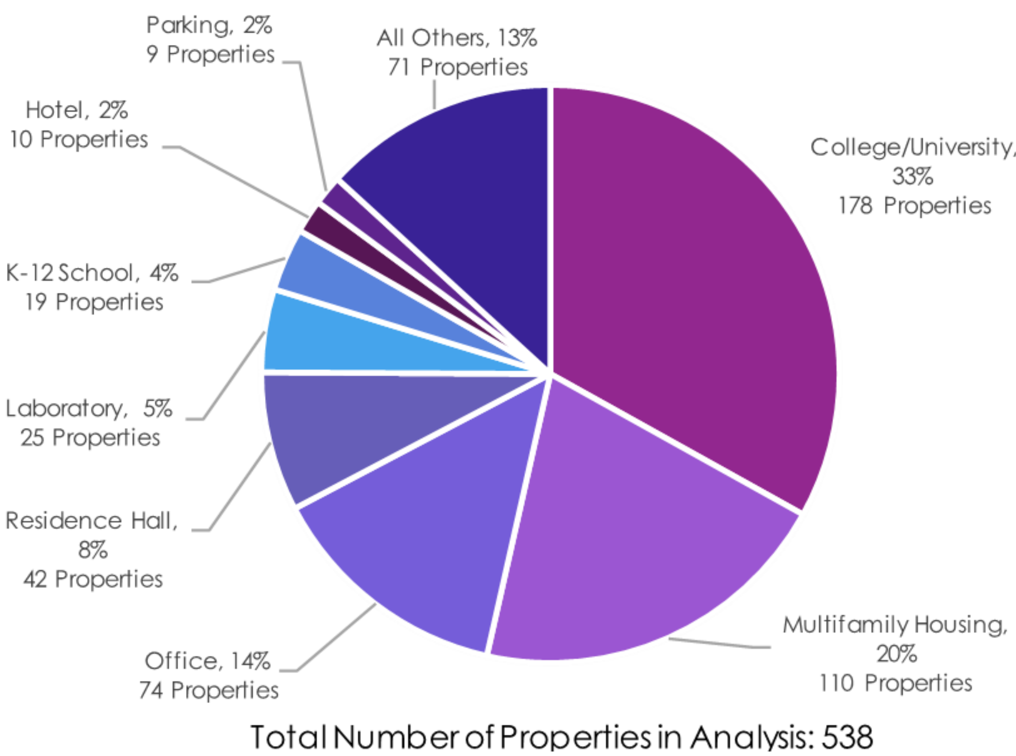
Cambridge Property Database	
Contains property data for all properties located in Cambridge. Sample of data points provided include: owner name, owner address, year built, assessed value, interior square footage, building type, heating system.	
Property Types	Input "Property Class" was converted to BEUDO building-use type classification (includes approximately 39 building types). BEUDO building types are based on classifications defined by EPA Energy Star.
Energy Use	A site EUI value was assigned to each property, based on building type. Site EUI by building type was derived from median EUI calculated from 2015 BEUDO data AND EIA.gov Residential Energy Consumption Survey.

The Cambridge Building Energy Use Disclosure Ordinance (BEUDO) dataset includes 785 data entries.

2015 Cambridge Building Energy Use Disclosure Ordinance (BEUDO)	
Contains all energy data disclosed during annual BEUDO effort. Captures 95% of buildings in Cambridge that are: ▪ Non-residential singly or together and contain 25,000+ sf. ▪ Residential singly or together contain 50+ units. ▪ Municipal buildings 10,000+ sf.	
Property Types	Input 'Primary Property Type' was left-as is. Building-use type classification (includes approximately 39 building types. See Table 1.0
Energy Use	Input 'Site EUI' was used to calculate an average- and median-site EUI based on building type. The median-site EUI was then "assigned" to properties that were missing energy data and/or listed in the Cambridge Property Database.

Coverage	This dataset represents 57.8% of the building area (square footage) in Cambridge, MA.

2015 BEUDO Report



PROCESSING METHODS:

BEUDO DATASET

1. Using the available energy information, Vanderweil calculated actual total energy use intensity values (kBTU/sf) for each property in the BEUDO database.
2. For any BEUDO properties that did not have energy information, these properties were assigned a median EUI which was calculated from properties with actual energy information. EUIs were assigned to properties with missing energy information based on building type (refer to Table 1.0).
3. To avoid accounting for central plant efficiencies for properties that are not served by a central plant, thermal energy demand only accounts for non-central plant fuel use (natural gas, fuel oil, propane, etc). Properties served by a central plant will be assessed separately.
4. Cooling and heating demand end-use breakouts were established via the 2012 Commercial Building Energy Consumption Survey.
5. Table 1.0 details the breakdown of energy use by building type in the BEUDO dataset.

ESTABLISHING NORMALIZED BUILDING PROPERTY TYPES

The two datasets (BEUDO and CPDB) included different building property types; the CPDB included nearly 100 building property types and the BEUDO set included the 39 types identified by EPA Energy Star. The 39 building types are nationally recognized in databases of energy use and therefore, we re-categorized the CPDB to use the 39 types from the BEUDO dataset, so that the final dataset would be consistent.

CPDB DATASET

1. With CPDB property types re-categorized, each property was assigned an EUI based on median calculations from the BEUDO dataset (Table 1.0).
2. Smaller residential properties (single, double-family homes) were assigned an EUI based on the Energy Information Administration, 2009 Residential Energy Consumption Survey.
3. For building types that listed inputs for heating system and heating fuel type, an average efficiency factor was used to account for source energy use.
4. Building types that listed inputs for steam heating and/or chilled water were assumed to be connected to a central plant.
5. Cooling and heating demand were established either via the 2012 CBECS or 2009 Residential Energy Consumption Survey (RECS), for smaller housing stock.

TABLE 1.0 – Median EUI Summary – BEUDO Dataset

All energy use intensity values are from BEUDO median energy use intensity calculations, except where noted in red. Several building types either did not have enough data points to provide an accurate benchmarking value or were missing data entirely. These property types were assigned similar property type EUIs from the BEUDO dataset (i.e. Automobile Dealership EUI reassigned as Retail Store EUI).

BEUDO Property Type	Median Site EUI (kBTU/sf)
Automobile Dealership [Retail Store]	134
College/University	111
Data Center [DOE- Data Center]	336
Distribution Center	58
Drinking Water Treatment & Distribution	241
Enclosed Mall	82
Financial Office	157
Fire Station	83
Fitness Center/Health Club/Gym	86
Food Service [Supermarket/Grocery Store]	298
Hospital (General Medical & Surgical)	204
Hotel	111
K-12 School	64
Laboratory [EcoDistrict – R+D]	286
Library	76
Manufacturing/Industrial Plant	149
Medical Office	77
Mixed Use Property	104
Movie Theater [Retail Store]	134
Multifamily Housing	65

[2009 RECS – Multifamily]	
Museum	152
Non-Refrigerated Warehouse	40
Office	84
Other [2012 CBECS - Other]	236
Other - Mall	52
Other - Recreation	98
Other - Technology/Science [EcoDistrict – R+D]	286
Parking	8
Police Station	96
Pre-school/Daycare [K-12 School]	64
Residence Hall/Dormitory	76
Retail Store	133
Self-Storage Facility [Non-refrigerated Warehouse]	40
Senior Care Community	133
Strip Mall	118
Supermarket/Grocery Store	298
Urgent Care/Clinic/Other Outpatient	229
Vocational School	80

Smaller housing stock with no energy data utilized pre-defined benchmarks established by the 2009 Residential Energy Consumption Survey.

RECS Property Type	Site EUI (kBTU/sf)
Residential 8+ Unit	86
Residential 4-8 Unit	86
Single Family Unit	73
Two Family Unit	78
Three Family Unit	86

ESTABLISHING THERMAL ENERGY DEMAND

It is critical for an energy masterplan that the thermal energy demand of the city be understood both spatially and temporally. In general the information available from the BEUDO dataset for Cambridge identifies the fuel consumption used to provide space heating and domestic hot water to buildings. For an energy masterplan, it is the space heating and DHW demand that enables an understanding of the thermal needs of the city, its buildings and occupants. Because of this the fuel consumed for supplying heat to buildings needs to be converted to the actual heat required. When considering alternative heat supply technology this avoids issues with plant oversizing and identifies areas where thermal energy efficiency measures can be effective. The BEUDO dataset and other information for Cambridge does not identify the types of heating systems for every building, though it does contain a substantial amount of this information and does not identify estimated plant efficiencies. To enable the conversion to be undertaken assumptions are required on both the type of heat system (for those buildings with no records) and the thermal efficiency with which these systems convert fuel consumed to useful heat.

A list of all heating system and fuel combinations was extracted from the BEUDO dataset. This provided over 100 records for heating and cooling systems. This was assessed line by line to understand the most likely heating system employed and the potential efficiency of fuel conversion based on experience of similar systems. This was then assessed according to the predominant building use type that employs the technology. An average efficiency was assumed due to a lack of information with regards to the plant's age. Refer to Table 2.0.

TABLE 2.0 – Heating System Efficiency

Heating System Type	Efficiency
Air Source Heat Pump	250%
Assume gas absorption heat pump	131%
Assume oil absorption heat pump	131%
Biomass boiler	80%
District Energy	100%
Electric Heating	95%
Gas Boiler	85%
Gas fired steam boiler	75%
None	0%
Oil Boiler	80%
Oil steam boiler	75%
Unknown	80%

ENERGY USE BY TYPE

From the Energy Use Index in Table 1.0, we used the Commercial Building Energy Consumptions Survey and Department of Energy references to determine the appropriate breakdowns in thermal and electrical energy consumption in relation to site energy use. BEUDO Property type were assigned CBECS Principal Building Activity type. Refer to Table 3.1 and 3.2.

TABLE 3.1 – Energy Use by Type Breakdown – 2012 CBECS

Principal Building Activity	Electric %	Heating %	Cooling %	DHW %	*Other %	Total
Education	33%	35%	12%	8%	12%	100%
Food sales	65%	12%	2%	1%	19%	100%
Food service	32%	9%	6%	8%	44%	100%
Health care	28%	28%	11%	11%	22%	100%
Inpatient	24%	30%	13%	14%	20%	100%
Outpatient	43%	25%	7%	2%	22%	100%
Lodging	28%	11%	7%	23%	30%	100%
Mercantile	47%	18%	8%	6%	21%	100%
Retail (other than mall)	50%	21%	10%	1%	18%	100%
Enclosed and strip malls	46%	16%	8%	9%	21%	100%
Office	49%	25%	10%	3%	13%	100%

Public assembly	21%	38%	19%	1%	20%	100%
Public order and safety	25%	28%	12%	17%	20%	100%
Religious worship	20%	45%	9%		26%	100%
Service	24%	43%	8%	9%	16%	100%
Warehouse and storage	40%	30%	9%	3%	18%	100%
Other	39%	24%	9%	1%	26%	100%
Vacant	35%	31%	7%	3%	25%	100%

**Other* represents cooking and miscellaneous process equipment (i.e. motors).*

TABLE 3.2 – Energy Use by Type Breakdown – 2012 RECS

RECS Property Type	Electric %	Space Heating %	DHW %	Total
Residential 8+ Unit	26%	57%	17%	100%
Residential 4-8 Unit	26%	57%	17%	100%
Single Family Unit	30%	54%	16%	100%
Two Family Unit	25%	58%	17%	100%
Three Family Unit	25%	58%	17%	100%

TABLE 4.1 – Total, Thermal and Electric EUI Assignments – BEUDO Properties

*Data Center and Laboratory EUIs were obtained from DOE and BEUDO, respectively.
**Parking assumed 80% electric, 20% space heating.

Cambridge Property Type	CBECS Property Type Adjustment	Site EUI	Electric EUI	Space Heating EUI	Space Cooling EUI	DHW EUI	Other EUI
Automobile Dealership	Mercantile	134	62	23	11	8	28
College/University	Education	111	37	39	13	9	14
Data Center	DOE - Data Center*	336	235	0	101	0	0
Distribution Center	Warehouse and storage	58	23	17	5	2	10
Drinking Water Treatment & Distribution	Public order and safety	241	59	67	28	40	48
Enclosed Mall	Enclosed and strip malls	82	38	14	6	8	17
Financial Office	Office	157	77	40	16	5	20
Fire Station	Public order and safety	83	20	23	10	14	17
Fitness Center/Health Club/Gym	Public order and safety	86	21	24	10	14	17
Food Service	Food service	298	96	27	18	25	132
Hospital (General Medical & Surgical)	Inpatient	204	49	61	26	29	40

Hotel	Lodging	111	32	13	8	26	33
K-12 School	Education	64	21	22	8	5	8
Laboratory	Labs- BEUDO	286	106	126	31	23	0
Library	Public assembly	76	16	29	15	1	15
Manufacturing/Industrial Plant	Other	149	59	36	14	1	39
Medical Office	Office	77	38	20	8	2	10
Mixed Use Property	Public assembly	104	22	40	20	2	21
Movie Theater	Public assembly	134	28	51	26	2	27
Multifamily Housing	Lodging	65	18	7	5	15	19
Museum	Public assembly	152	32	58	29	2	30
Non-Refrigerated Warehouse	Warehouse and storage	40	16	12	4	1	7
Office	Office	84	41	21	9	3	11
Other	Other	236	93	57	22	2	61
Other - Mall	Enclosed and strip malls	52	24	9	4	5	11
Other - Recreation	Public assembly	98	21	38	19	1	20
Other - Technology/Science	Labs- BEUDO	286	106	126	31	23	0
Parking**		8	6	2	0	0	0
Police Station	Public order and safety	96	23	26	11	16	19
Pre-school/Daycare	Education	64	21	22	8	5	8
Residence Hall/Dormitory	Lodging	76	22	9	5	18	23
Retail Store	Retail (other than mall)	133	67	28	14	2	23
Self-Storage Facility	Warehouse and storage	40	16	12	4	1	7
Senior Care Community	Inpatient	133	32	40	17	19	26
Strip Mall	Enclosed and strip malls	118	54	19	9	11	25
Supermarket/Grocery Store	Food service	298	96	27	18	25	132
Urgent Care/Clinic/Other Outpatient	Outpatient	229	99	58	15	5	51
Vocational School	Education	80	27	28	10	6	10
Worship Facility	Public assembly	59	12	22	11	1	12

TABLE 4.2 – Total, Thermal and Electric EUI Assignments – RECS Properties

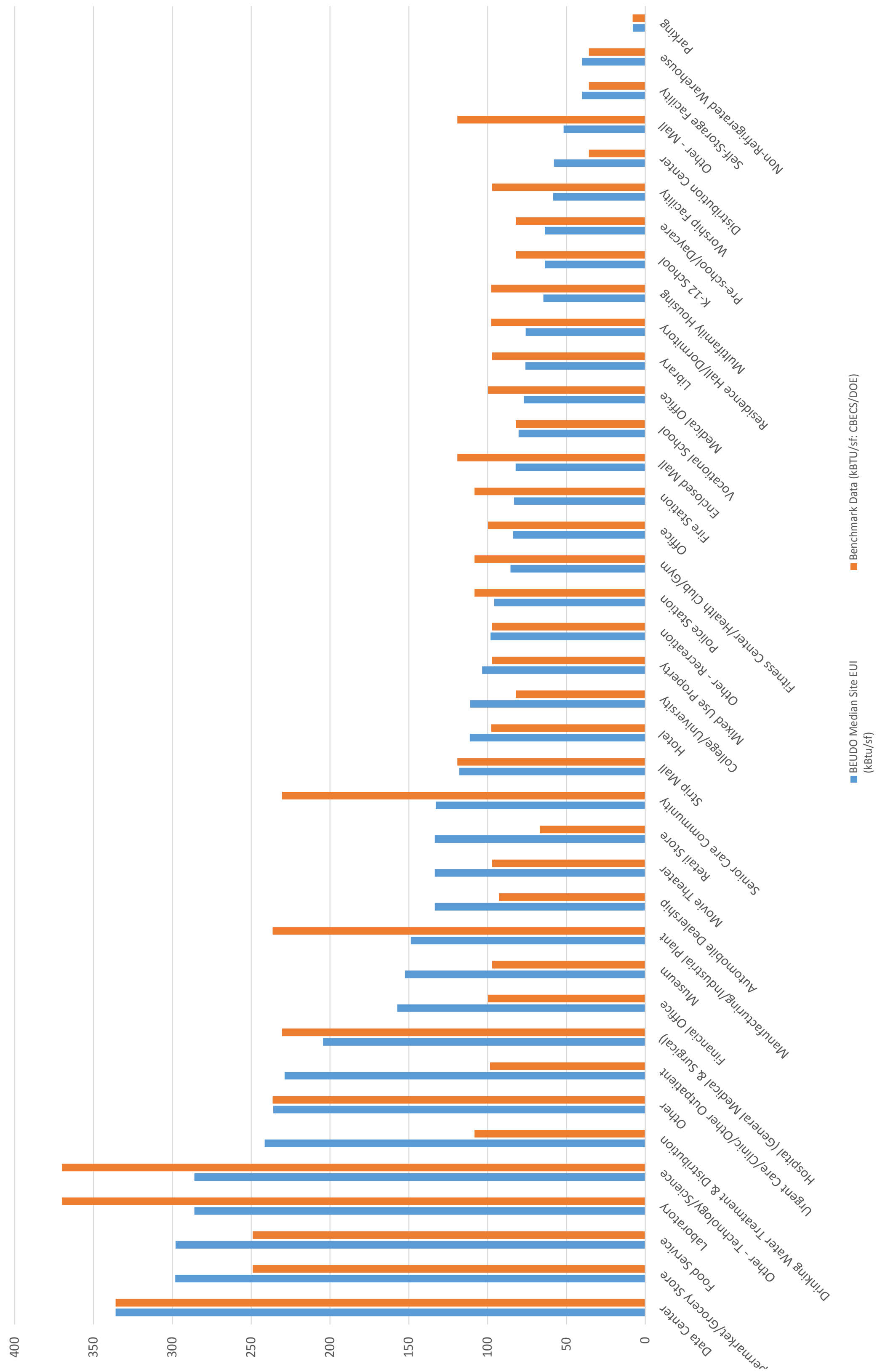
RECS Property Type	Site EUI	Electric EUI	Space Heating EUI	DHW EUI
Residential 8+ Unit	86	22	49	14

Residential 4-8 Unit	86	22	49	14
Single Family Unit	73	22	39	12
Two Family Unit	78	19	46	13
Three Family Unit	86	22	49	14

COOLING LOAD

Determining cooling demand for smaller housing stock is dependent on whether property entries within the Cambridge Property database included an input that defines whether cooling equipment is present. If cooling equipment is present a cooling factor has been defined for each REC Property Type, and will be applied against the Electric EUI.

RECS Property Type	Cooling Demand as % of Total Energy Use
Residential 8+ Unit	2.4%
Residential 4-8 Unit	2.4%
Single Family Unit	2.1%
Two Family Unit	1.5%
Three Family Unit	2.4%


BEUDO Median Site EUI (kBtu/sf)
Benchmark Data (kBTU/sf: CBECS/DOE)
0
50
100
150
200
250
300
350
400
Parking
Non-Refrigerated Warehouse
Self-Storage Facility
Other - Mall
Distribution Center
Worship Facility
Pre-school/Daycare
K-12 School
Multifamily Housing
Residence Hall/Dormitory
Library
Medical Office
Vocational School
Enclosed Mall
Fire Station
Office
Fitness Center/Health Club/Gym
Police Station
Other - Recreation
Mixed Use Property
College/University
Hotel
Strip Mall
Senior Care Community
Retail Store
Movie Theater
Automobile Dealership
Manufacturing/Industrial Plant
Museum
Financial Office
Hospital (General Medical & Surgical)
Urgent Care/Clinic/Other Outpatient
Other
Drinking Water Treatment & Distribution
Other - Technology/Science
Laboratory
Food Service
Supermarket/Grocery Store
Data Center

OTHER DATABASE REFINEMENTS AND CLARIFICATIONS:

2012 Commercial Building Energy Consumption Survey Methodology

Energy end use breakdown details:

- Electric end use includes: Ventilation, Lighting, Refrigeration, Office Equipment, Computing
- Space Heating end use includes: Space Heating
- Space Cooling end use includes: Cooling
- Domestic Hot Water (DHW) end use includes: Water Heating
- Other includes: Cooking, Other

2009 Residential Energy Use Consumption Survey

- Energy end use breakdown details:
- Electric end use includes: Lighting, Computing, Refrigerators
- Space Heating end use includes: Space Heating
- DHW end use includes: Water Heating

New Building Energy Use Benchmarking

Energy benchmarking values for new developments are generated by the Kendall Square EcoDistrict standards from the 2016 data set: Energy Load & Profiles. The Study provided aggregate energy use intensity values for six building types (Commercial, Research and Development, Residential, Education, Hotel, Data Center). EUI values for each building type were forecasted for the years 2020, 2025, and 2035 by applying a percentage reduction based on anticipated energy performance for those years. Refer to Table 5.0. For Industrial buildings in Alewife, projections from the Alewife team were utilized to develop these as there are no industrial loads in the Eco-District benchmarks.

TABLE 5.0 – New Building Energy Use Benchmarking

BEUDO Property Type	Eco-District Assignment	% Reduction		
		2020	2025	2035
Automobile Dealership	Commercial	17%	33%	67%
College/University	Education	17%	33%	67%
Data Center	Research and Development	8%	17%	33%
Distribution Center	Commercial	17%	33%	67%
Drinking Water Treatment & Distribution	Research and Development	8%	17%	33%
Enclosed Mall	Commercial	17%	33%	67%
Financial Office	Commercial	17%	33%	67%
Fire Station	Commercial	17%	33%	67%
Fitness Center/Health Club/Gym	Commercial	17%	33%	67%
Food Service	Research and Development	8%	17%	33%
Hospital (General Medical & Surgical)	Research and Development	8%	17%	33%
Hotel	Residential	17%	33%	67%
K-12 School	Education	17%	33%	67%
Laboratory	Research and Development	8%	17%	33%
Library	Commercial	17%	33%	67%

Manufacturing/Industrial Plant	Research and Development	8%	17%	33%
Medical Office	Commercial	17%	33%	67%
Mixed Use Property	Commercial	17%	33%	67%
Movie Theater	Commercial	17%	33%	67%
Multifamily Housing	Residential	17%	33%	67%
Museum	Commercial	17%	33%	67%
Non-Refrigerated Warehouse	Commercial	17%	33%	67%
Office	Commercial	17%	33%	67%
Other	Commercial	17%	33%	67%
Other - Mall	Commercial	17%	33%	67%
Other - Recreation	Commercial	17%	33%	67%
Other - Technology/Science	Research and Development	8%	17%	33%
Parking	Commercial	17%	33%	67%
Police Station	Commercial	17%	33%	67%
Pre-school/Daycare	Education	17%	33%	67%
Residence Hall/Dormitory	Residential	17%	33%	67%
Retail Store	Commercial	17%	33%	67%
Self-Storage Facility	Commercial	17%	33%	67%
Senior Care Community	Residential	17%	33%	67%
Strip Mall	Commercial	17%	33%	67%
Supermarket/Grocery Store	Research and Development	8%	17%	33%
Urgent Care/Clinic/Other Outpatient	Research and Development	8%	17%	33%
Vocational School	Education	17%	33%	67%
Worship Facility	Commercial	17%	33%	67%

Existing Building Energy Use Benchmarking – Forecasting into the Future

Energy benchmarking for improvements to existing buildings in the future will be established by the existing green-house gas (GHG) Model information supplied by the City of Cambridge, as part of the Net Zero Action Plan. The GHG Model provides greenhouse gas saving approximations for commercial, municipal and residential from 2015 through 2040. For the purpose of the Low Carbon Energy Supply Study, the Study has assumed that these reductions are reasonable estimates that correlate with energy efficiency improvements to existing building infrastructure. This would include upgrades such as insulation, lighting and heating/cooling systems. Refer to Figure 1 for summary of anticipated improvements to existing buildings over the medium term (2025) and long term (2040).

TABLE 6.0 – GHG Improvement Summary

GHG Model Type	2025 Improvement	2040 Improvement
Commerical Lab	14%	21%
Commercial Office	16%	23%
Hotel	16%	23%
Retail	20%	27%
Hospital	20%	27%
Warehouse	20%	27%
University Lab	9%	16%
Acedemic/Admin	21%	34%
Univeristy Residential	21%	28%
Athletics/Museums/Support	21%	28%
Government	21%	28%
Other	21%	28%
1-Family	14%	21%
2-3 Family	14%	21%
4-8 Units	14%	21%
8-51 Units	14%	21%
51 + Units	14%	21%

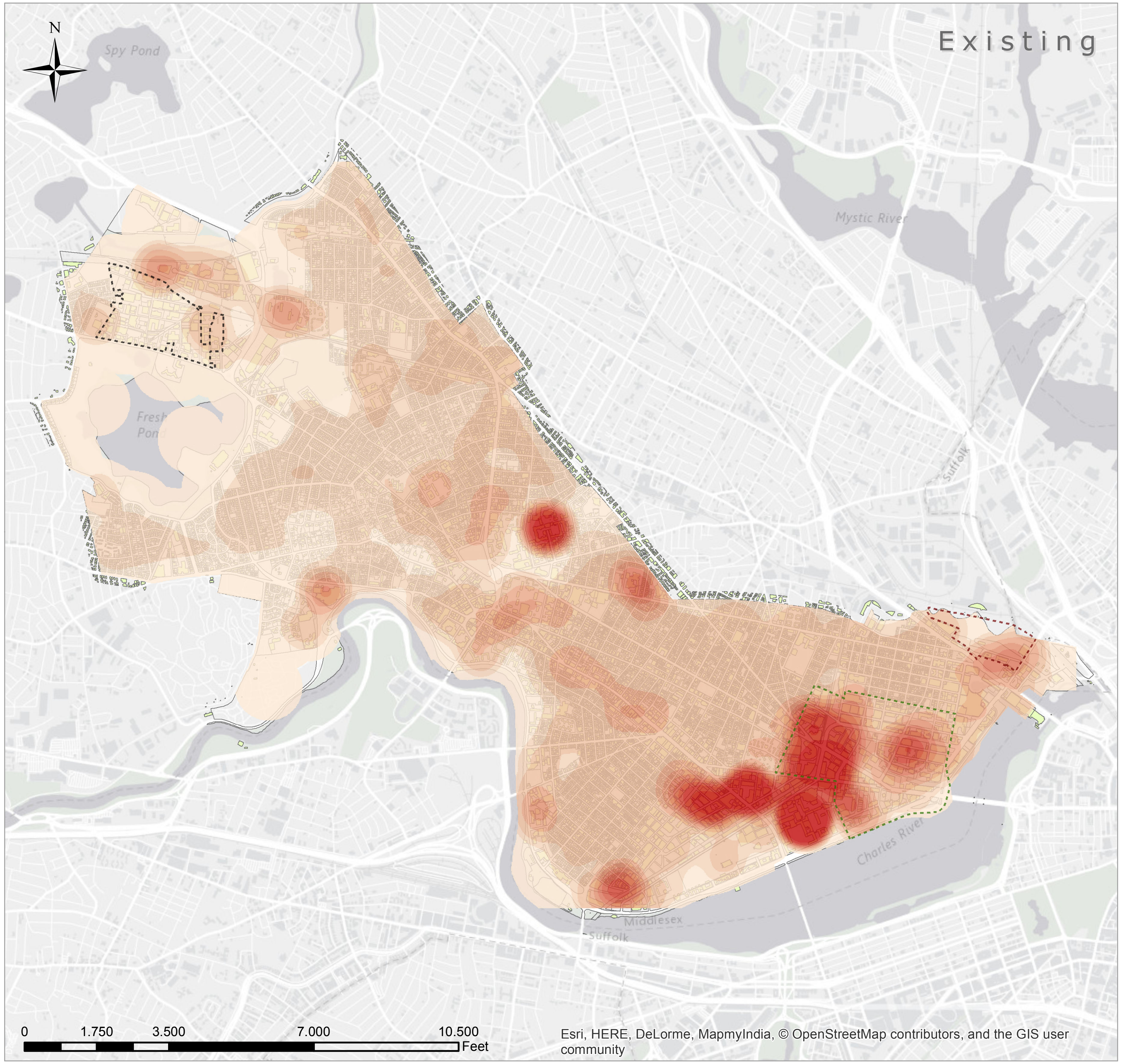
Benchmarking for Missing and/or Inaccurate Data

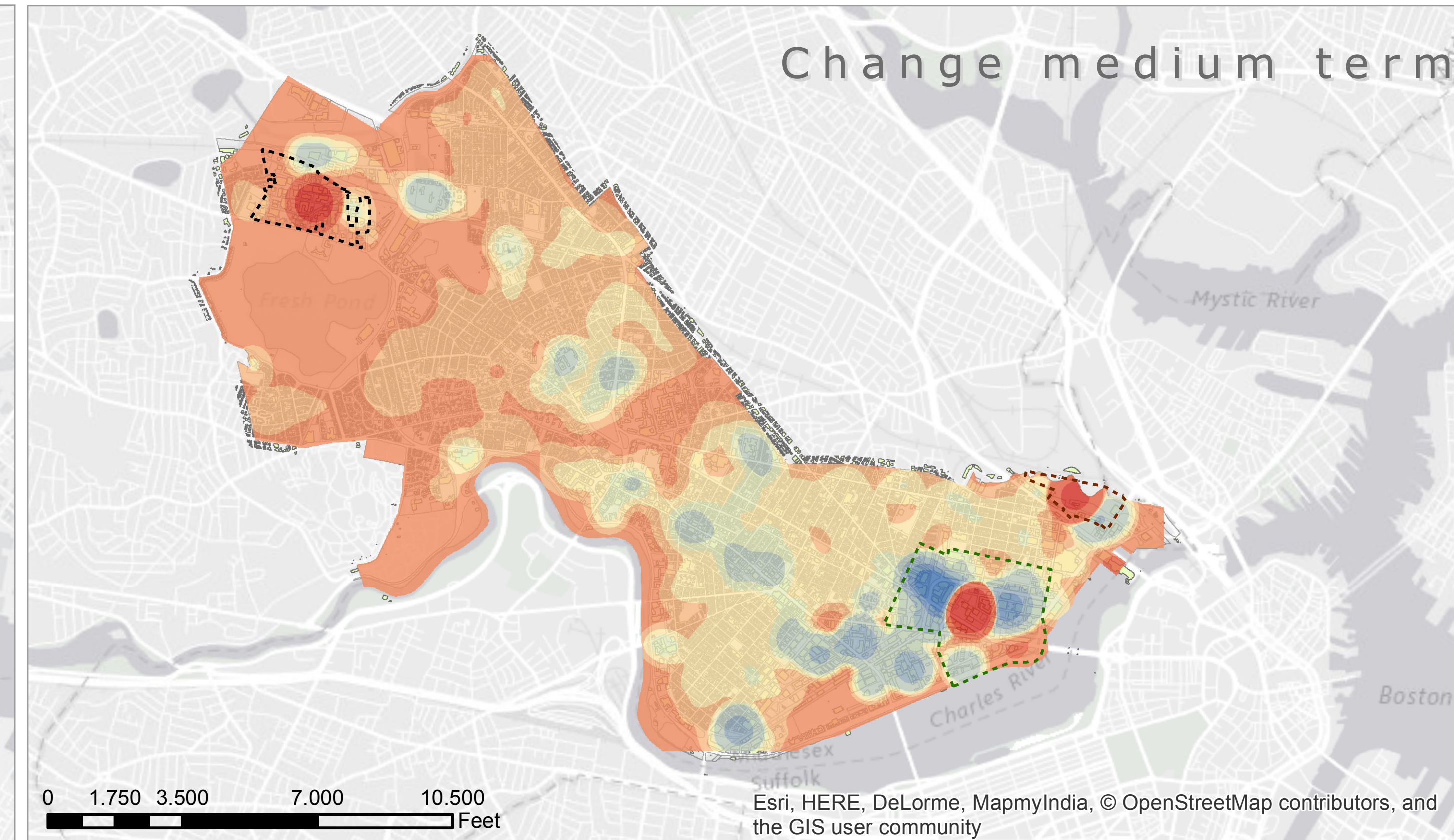
Several property types in the BEUDO dataset either did not have enough data points or were missing data entirely, both of which are needed to calculate an accurate EUI. For those building types, Vanderweil assigned a total, electric and thermal EUI derived from relatively similar building types in the BEUDO set, or from CBECS and Department of Energy benchmarks.

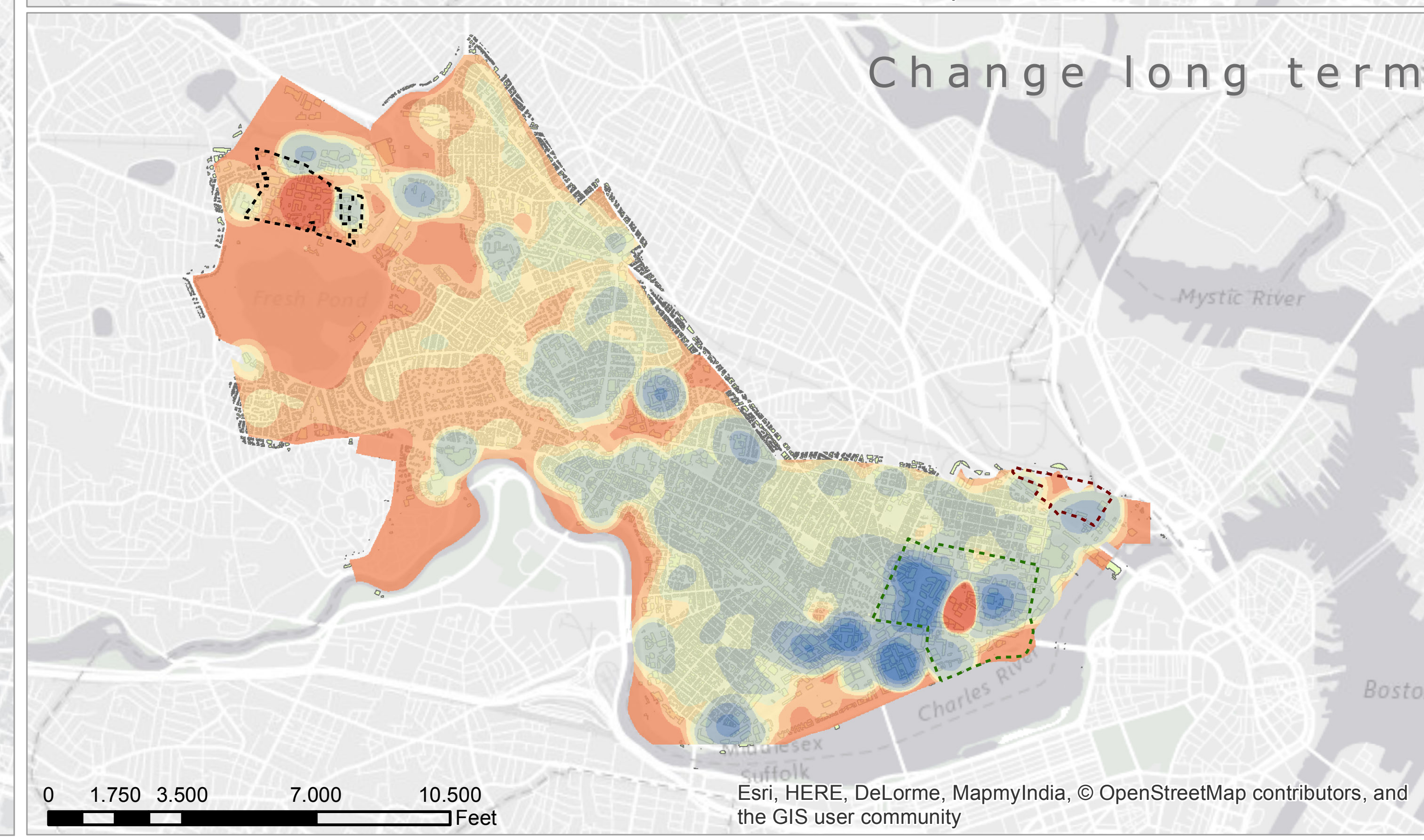
Database Join

The primary matching parameter for each dataset was the Map Lot identifier in the BEUDO dataset, and the GIS identifier in the CPDB. BEUDO properties were matched with the associated CPDB property and associated energy information pulled into the CPDB. Vanderweil found that while most of the properties matched well, there were still some that did not have exact-matching identifiers and/or were missing property type, energy demand, or square footage values – all of which can skew data for those specific properties. In these cases, such as supermarkets and food service, the appropriate EUI was assigned from the BEUDO database.

APPENDIX 2
HEAT DEMAND MAPS







- 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

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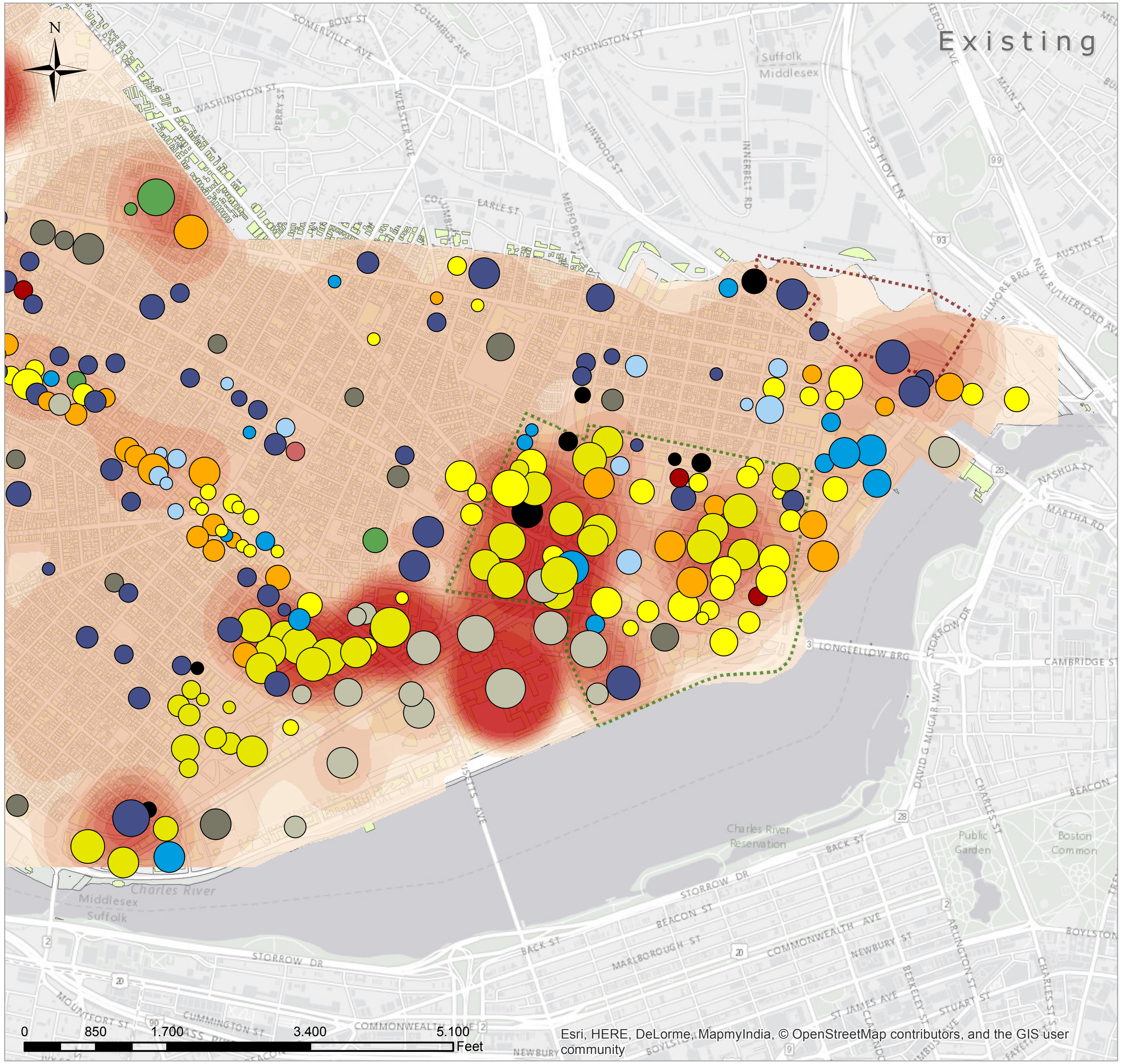
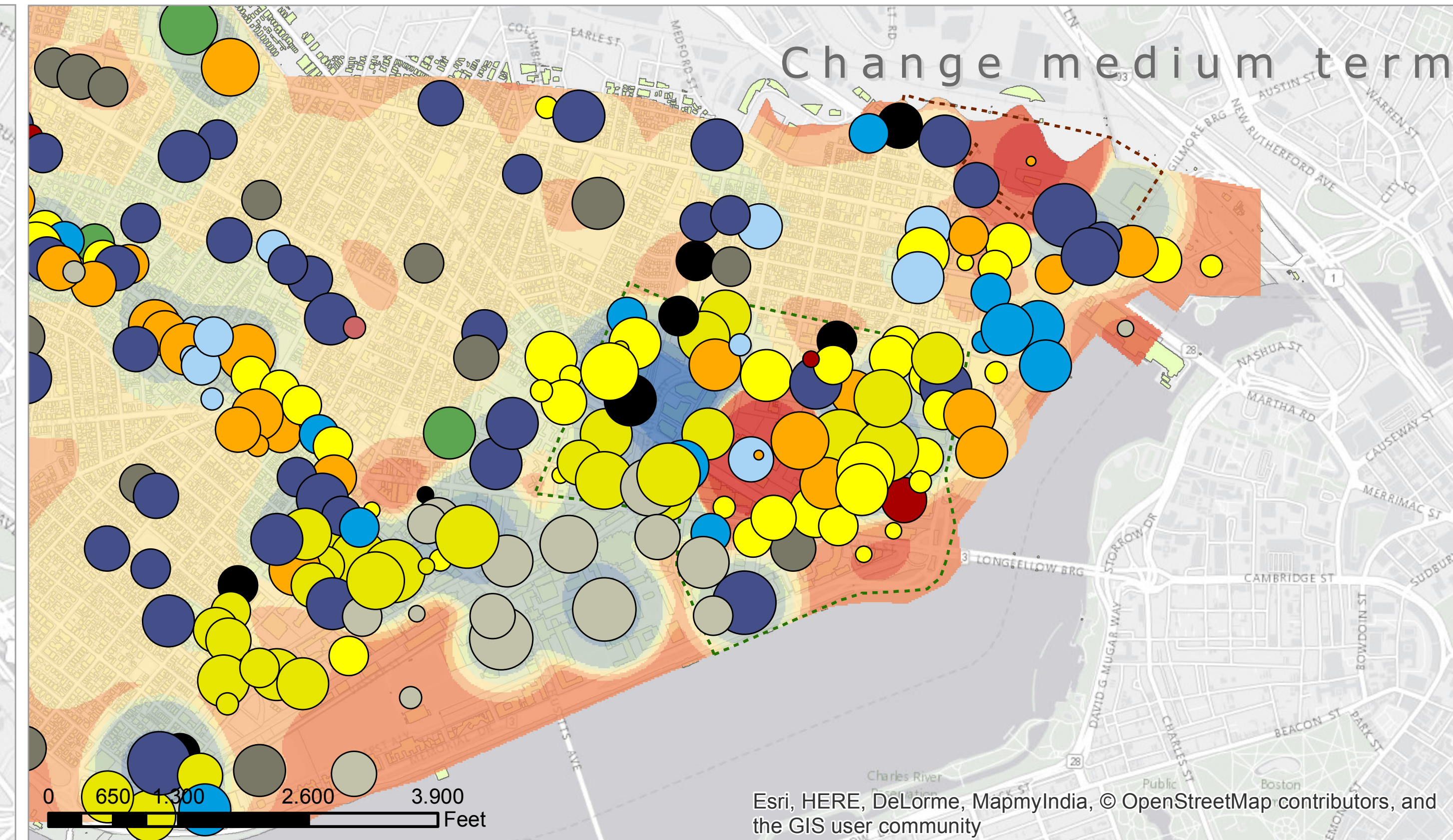
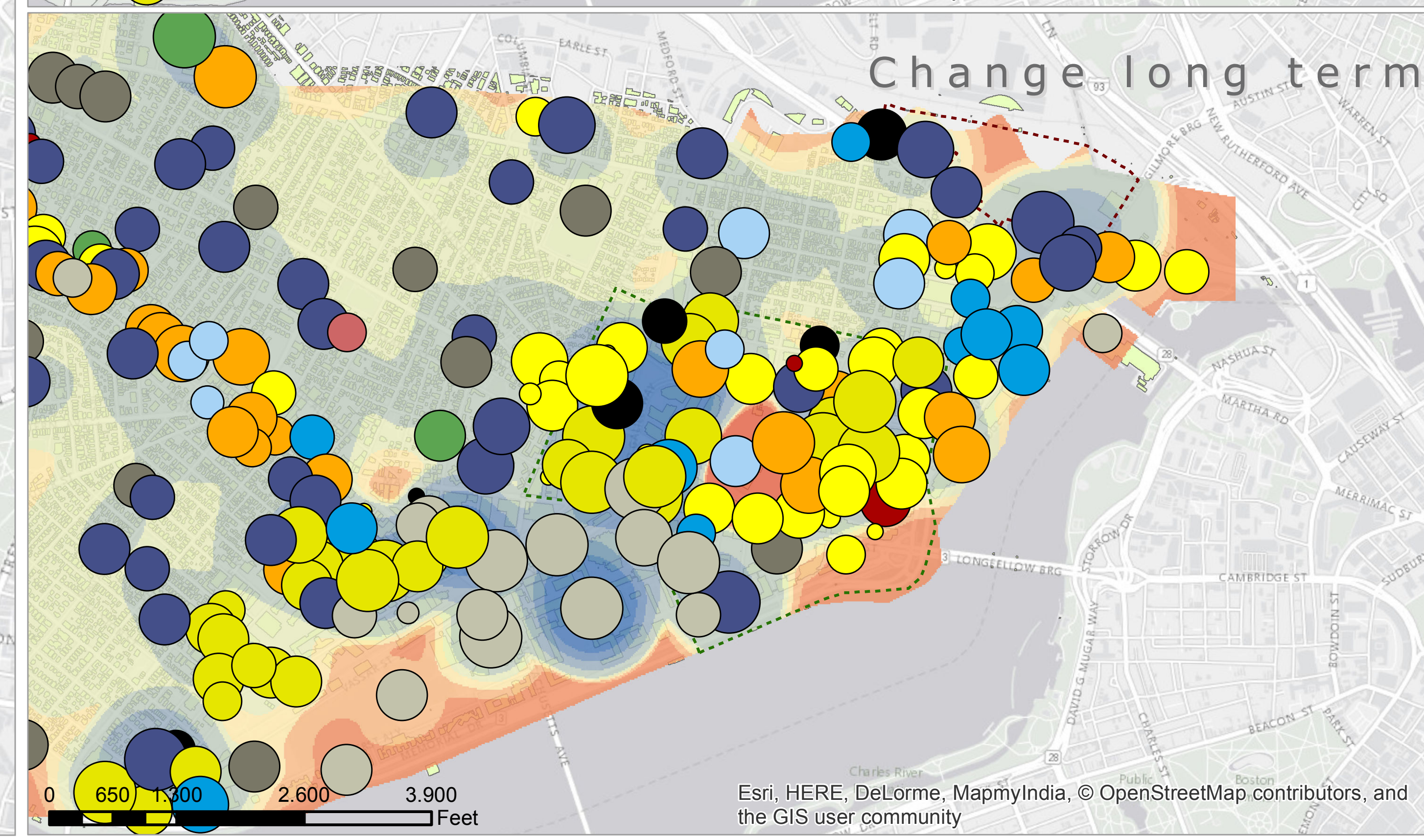
CITY OF CAMBRIDGE ENERGY MASTERPLANNING

Heat demand (current, medium and long term)

Cambridgema.gov







Landuse parcels
Buildings
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

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

Thermal 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
- > 100,000,000

Change by kBTU/sq.ft
- -130.8 - -75.0
- -74.9 - -50.0
- -49.9 - -25.0
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- -7.4 - -5.0
- -4.9 - -2.5
- -2,4 - 2.5
- 2.6 - 100.0
- 100.1 - 451.8

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 - 500,000
- 500,001 - 1,000,000
- > 1,000,000

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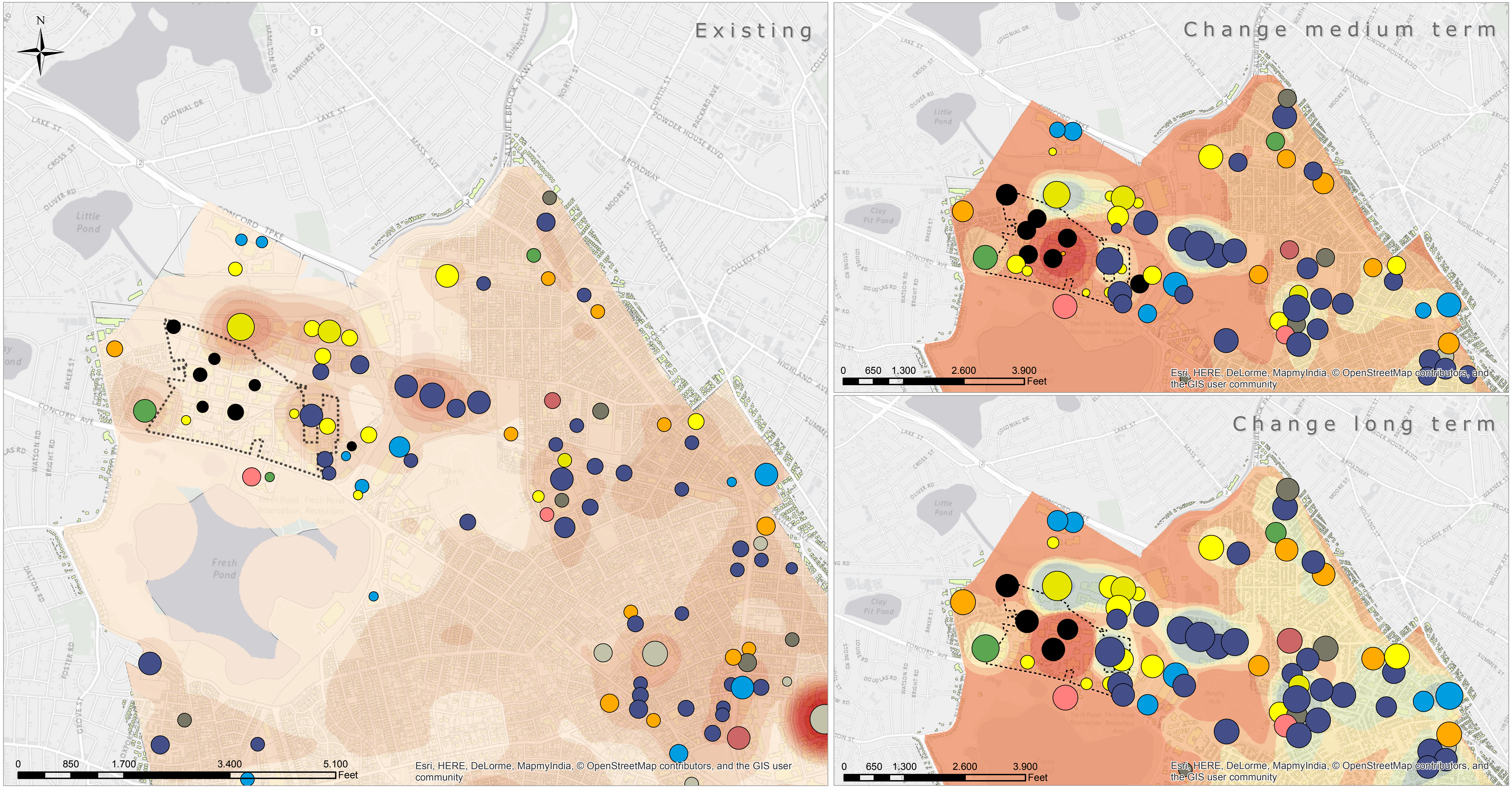
CITY OF CAMBRIDGE ENERGY MASTERPLANNING

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

Cambridgema.gov



Landuse parcels
Buildings
AleWife

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

Building type
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- Charitable/Religious
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- Office
- Office/R&D
- Residential
- Transportation
- Utility

Thermal 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
- > 100,000,000

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- -7.4 - -5.0
- -4.9 - -2.5
- -2,4 - 2.5
- 2.6 - 100.0
- 100.1 - 451.8

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 - 500,000
- 500,001 - 1,000,000
- > 1,000,000

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CITY OF CAMBRIDGE ENERGY MASTERPLANNING

Heat demand (current, medium and long term)
North west city focus

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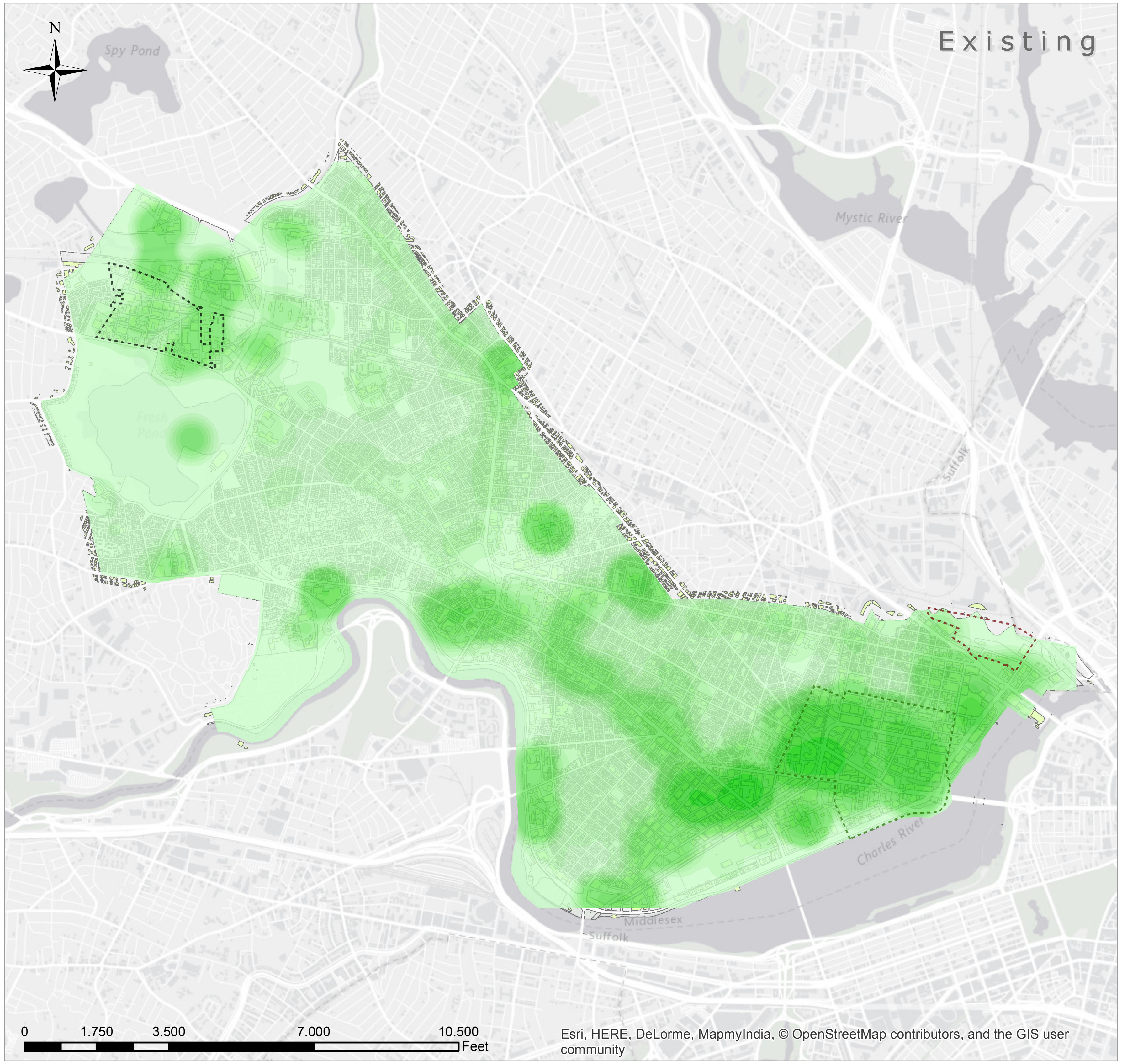
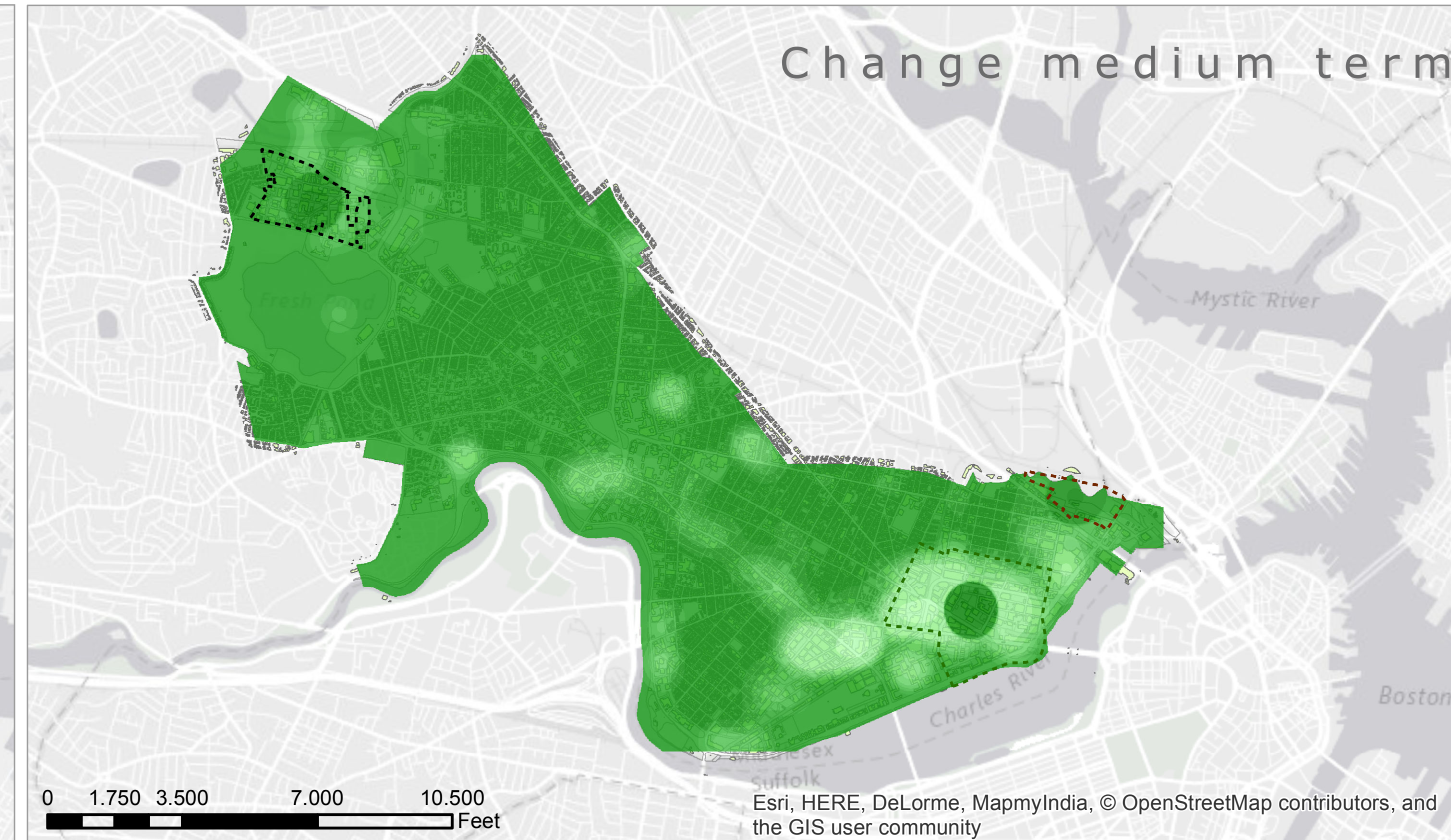
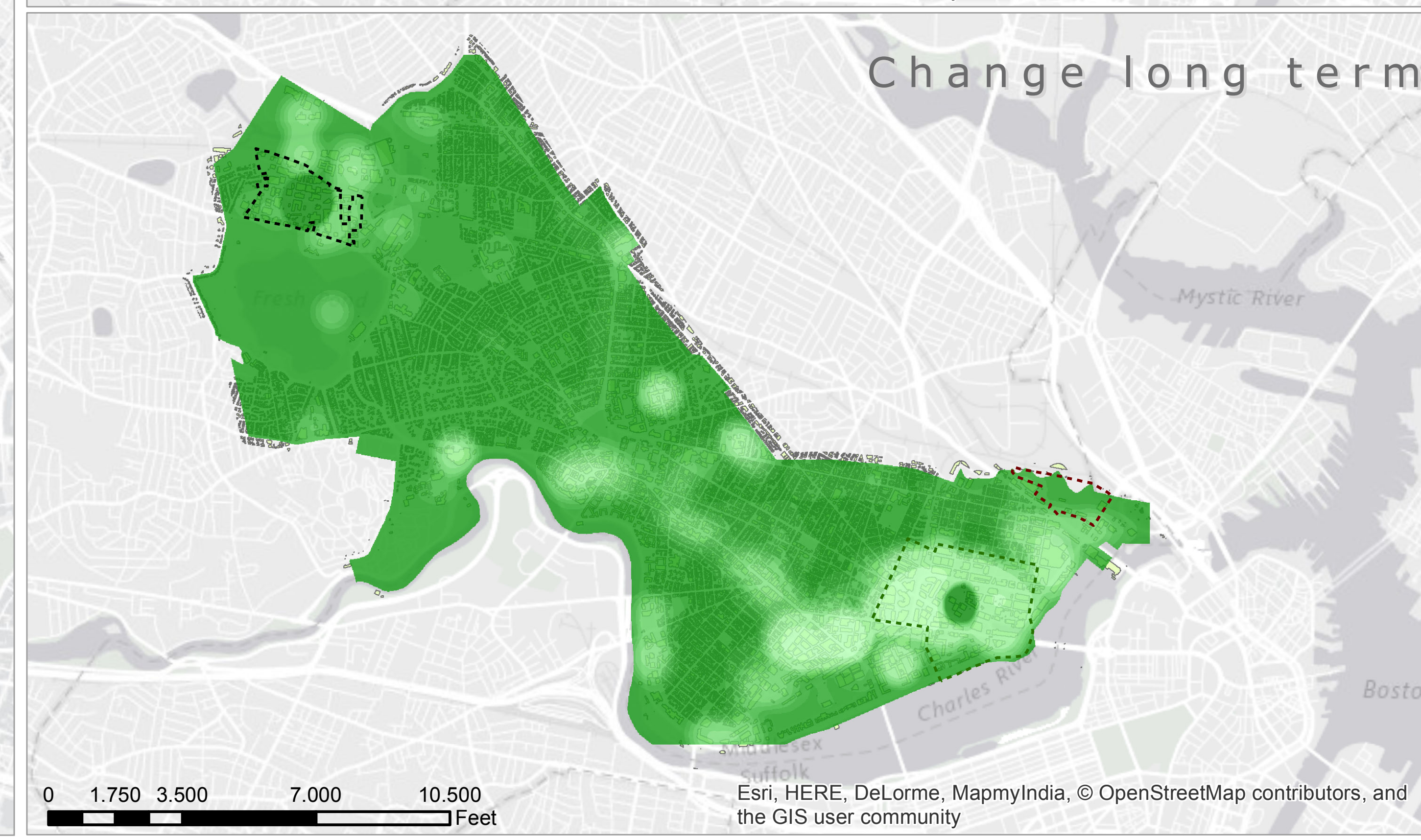
APPENDIX 3
ELECTRICITY DEMAND MAPS







Landuse parcels
Buildings
AleWife
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

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

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CITY OF CAMBRIDGE ENERGY MASTERPLANNING

Electricity demand (current, medium and long term)

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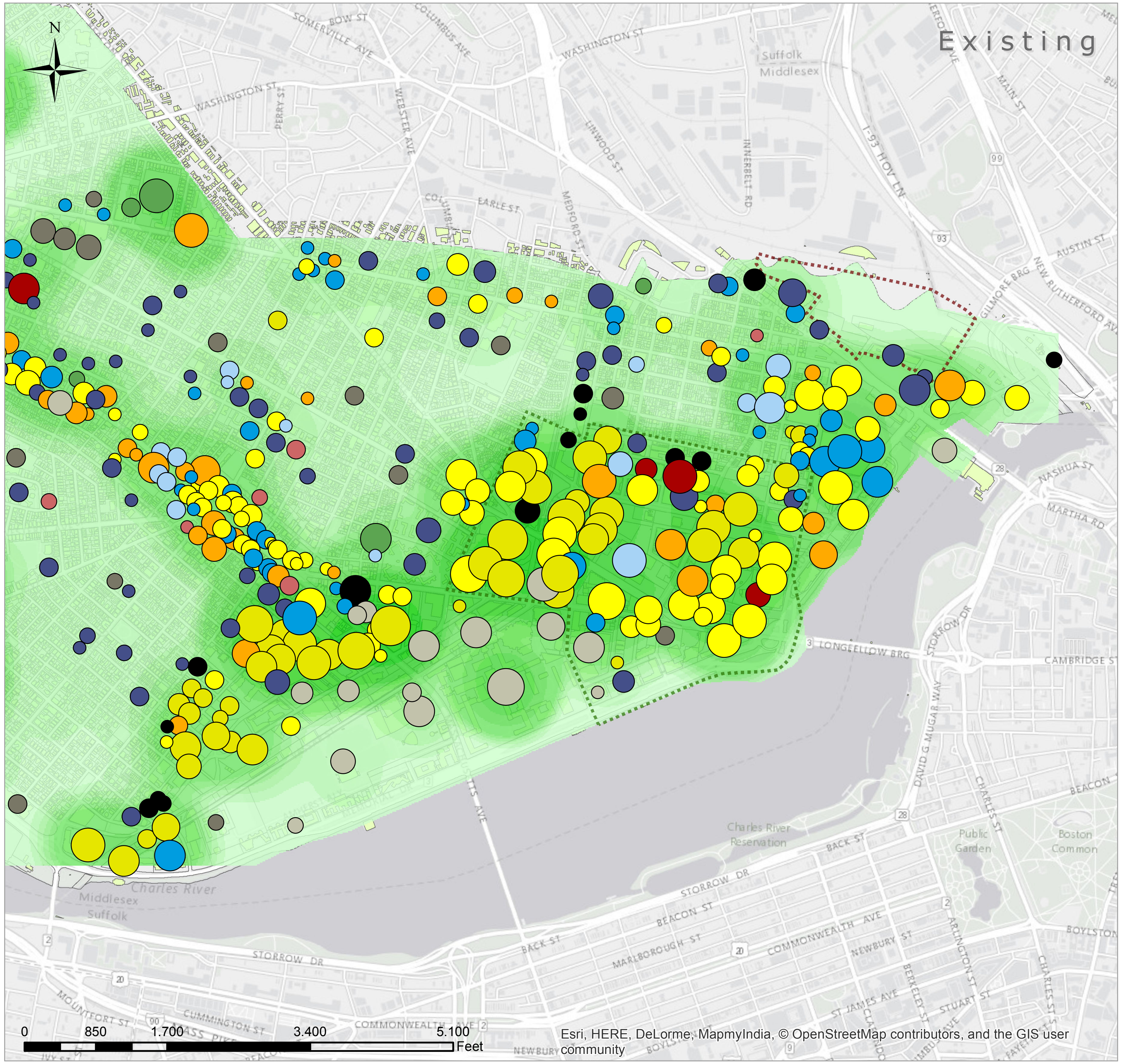

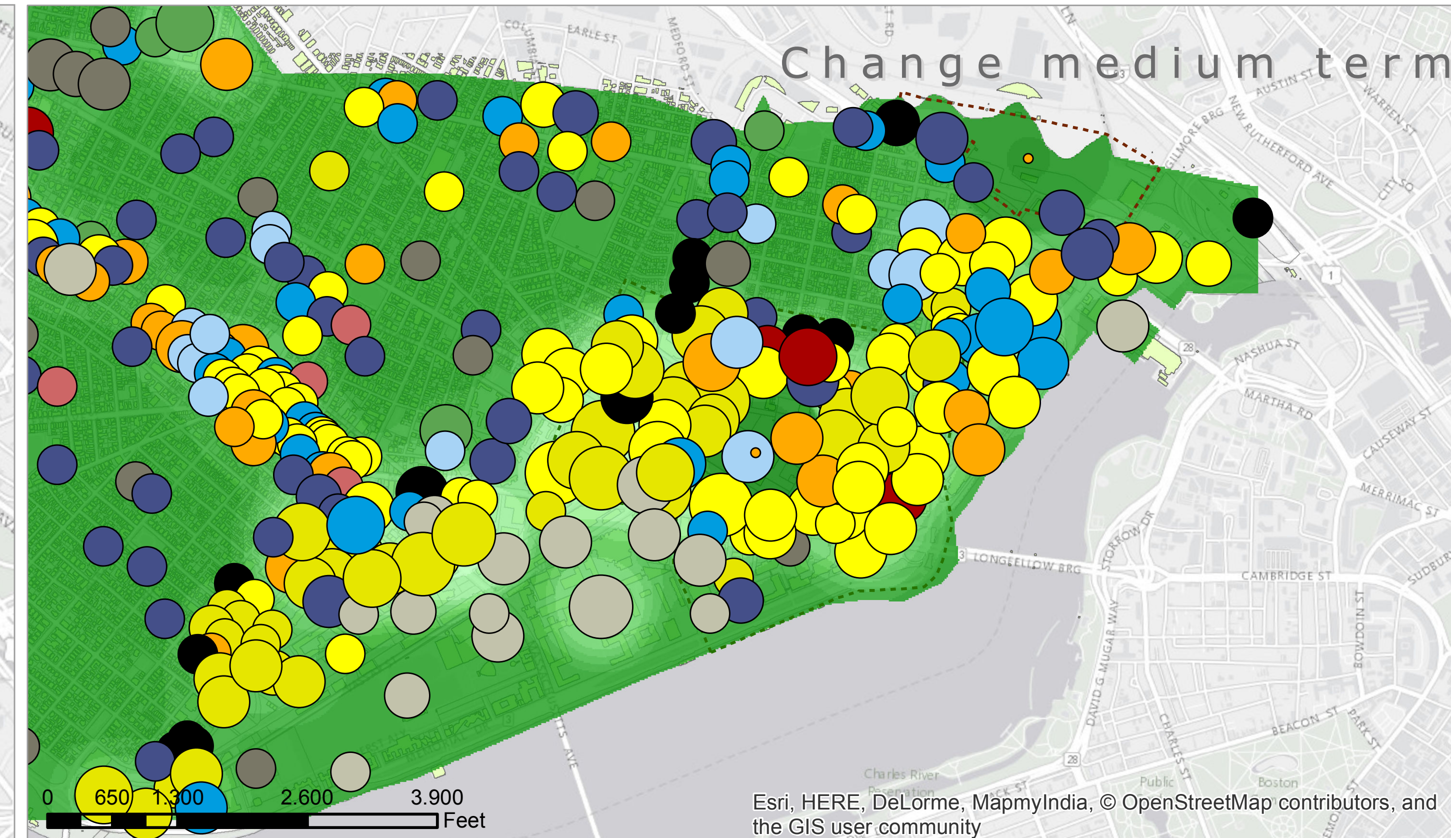

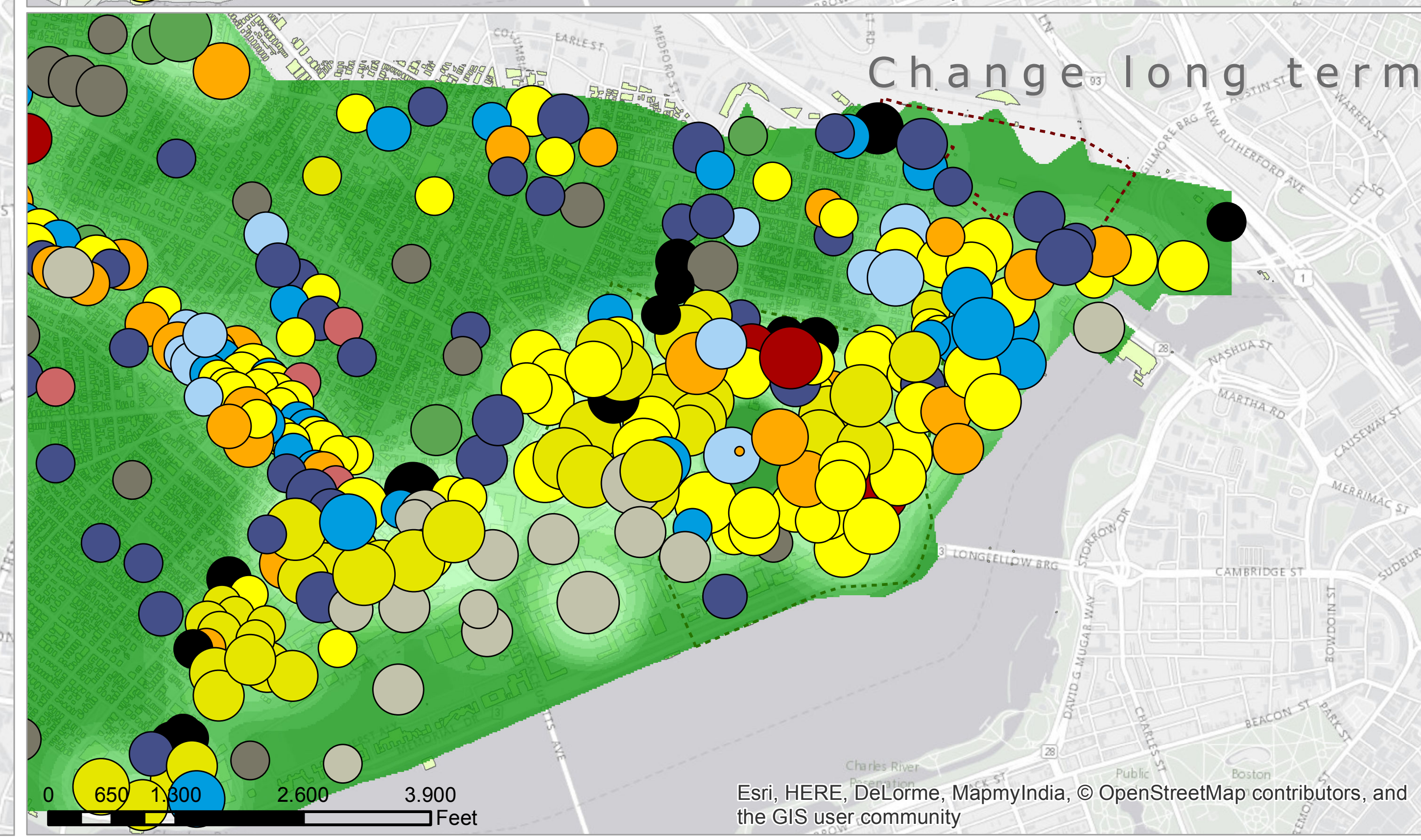

Landuse parcels
Buildings
Kendall_Square
Northpoint

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

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

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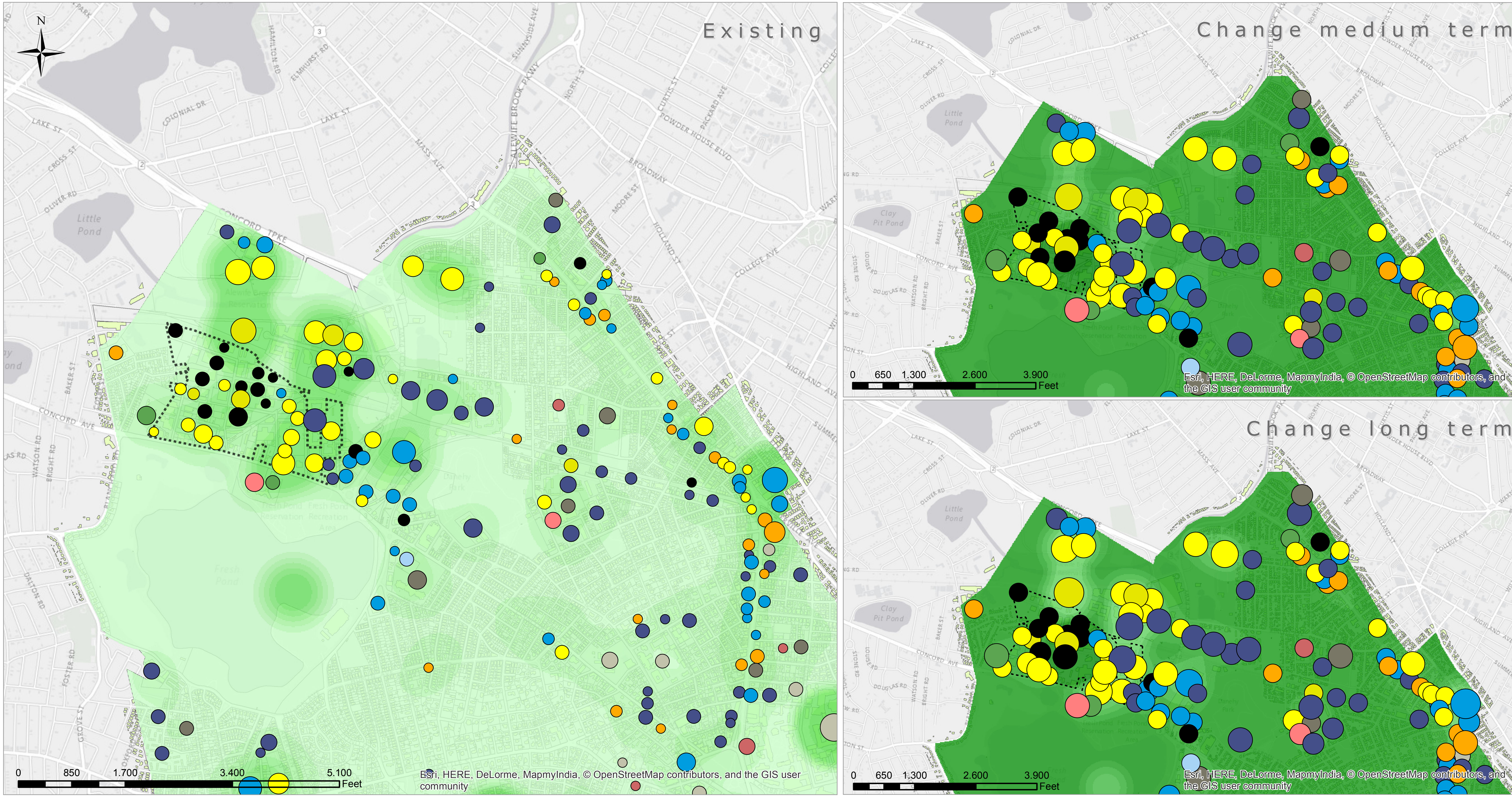

Landuse parcels
Buildings
AleWife

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

Building type
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Electricity demand above 500,000 kBTU
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- 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

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CITY OF CAMBRIDGE ENERGY MASTERPLANNING

Electricity demand (current, medium and long term)
North west city focus

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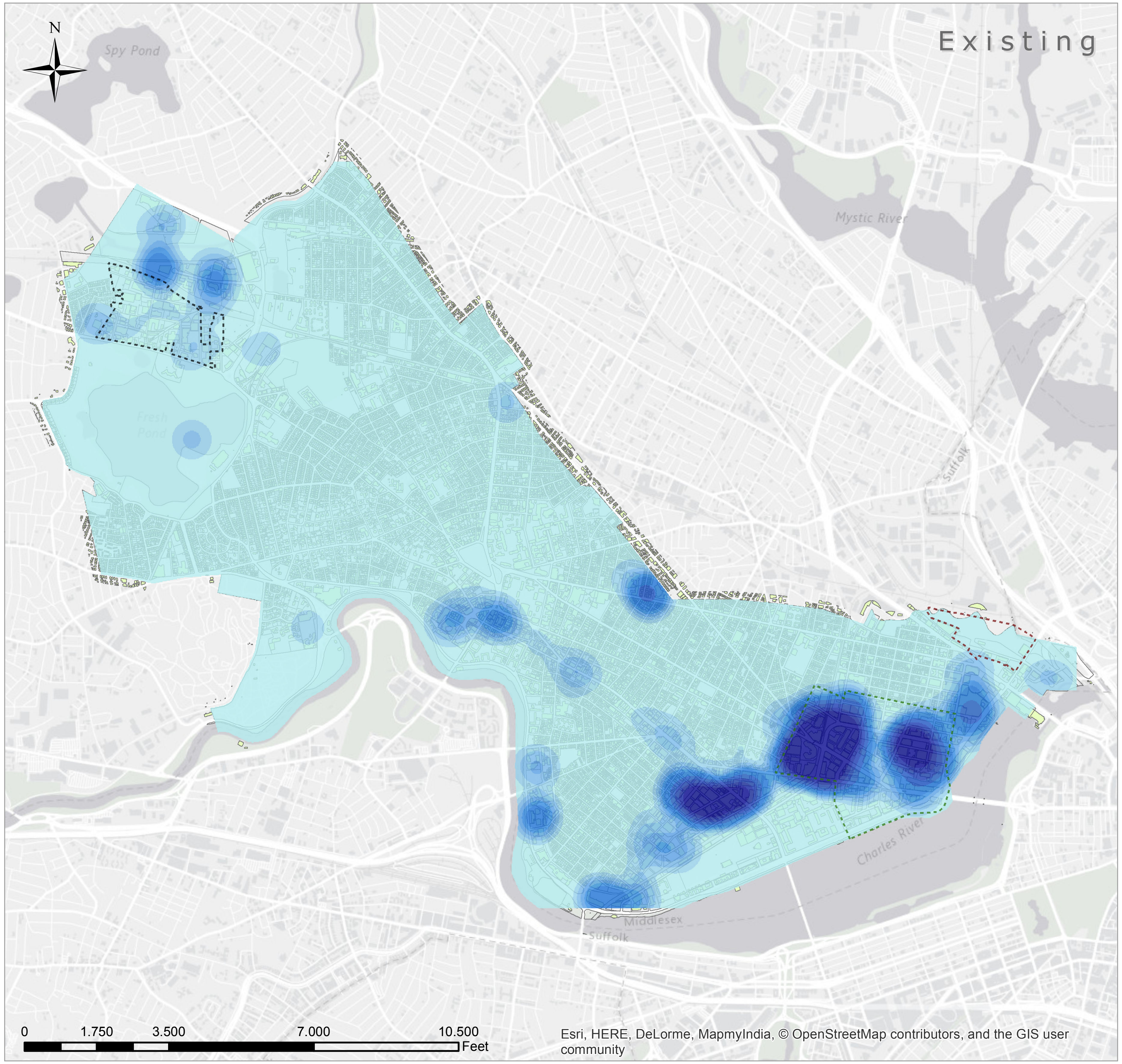
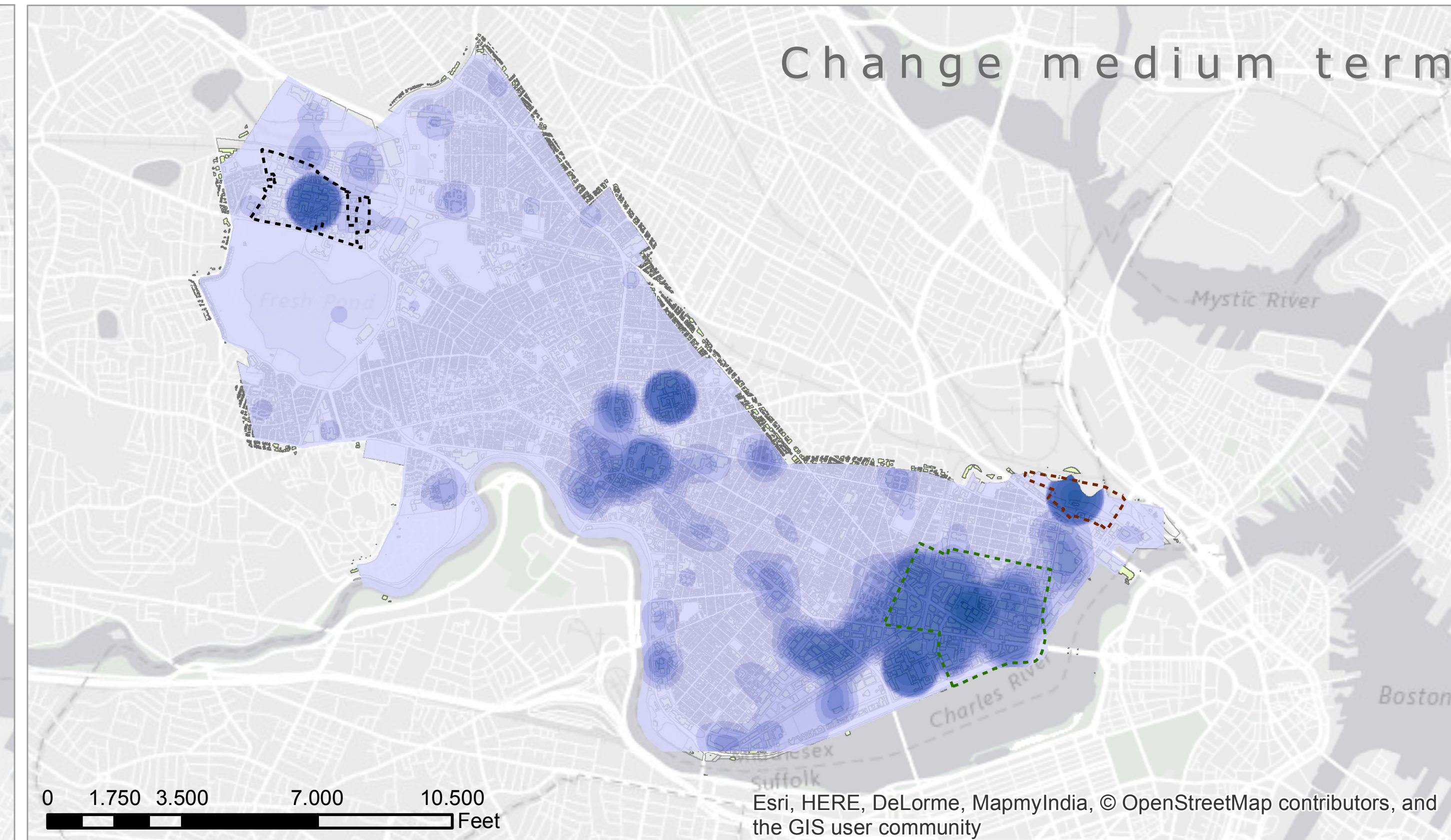
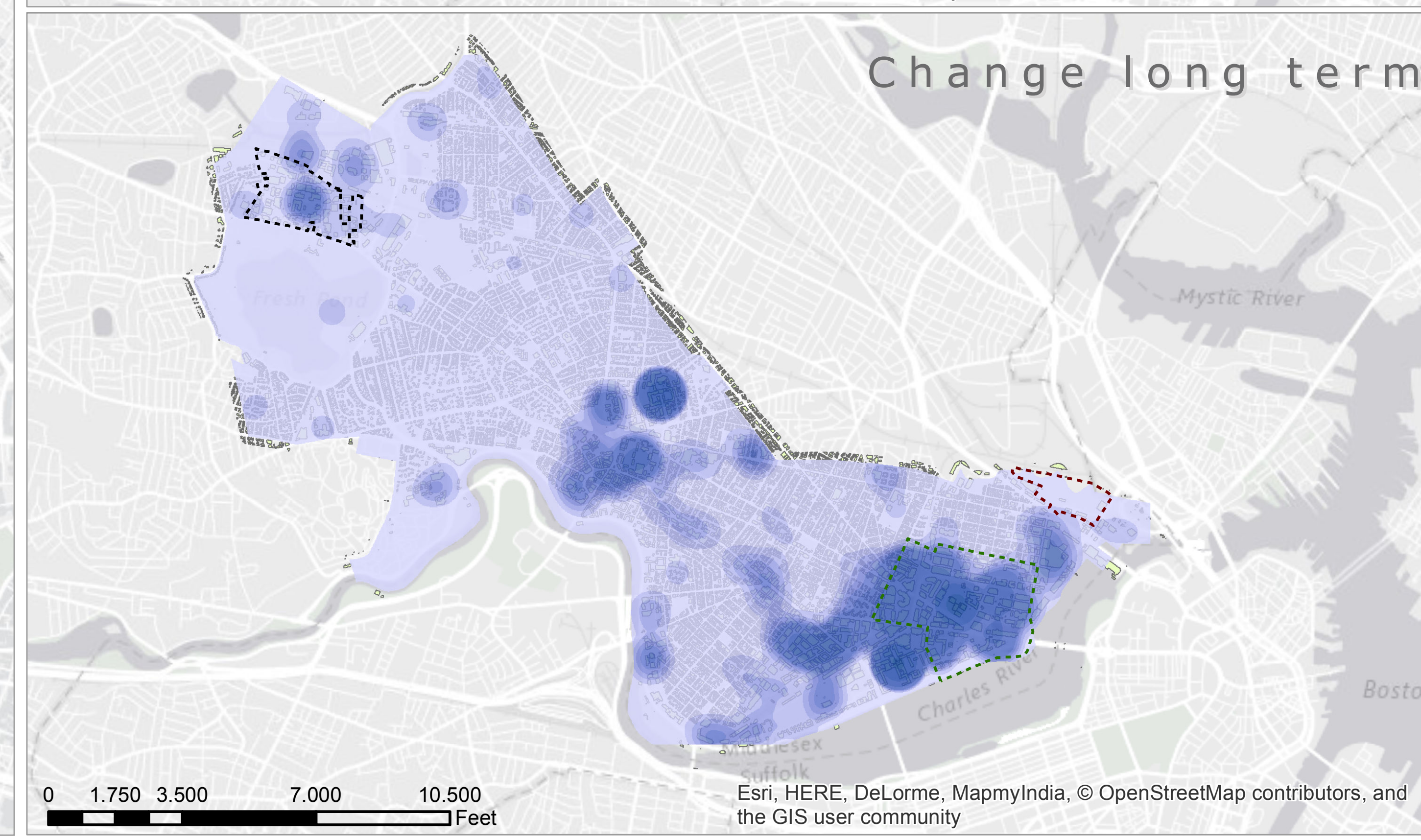
APPENDIX 4
COOLING DEMAND MAPS







- 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

Rev.	Date	Signature	Checked	Approved
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Project no. 1100025630

CITY OF CAMBRIDGE ENERGY MASTERPLANNING

Cooling demand (current, medium and long term)

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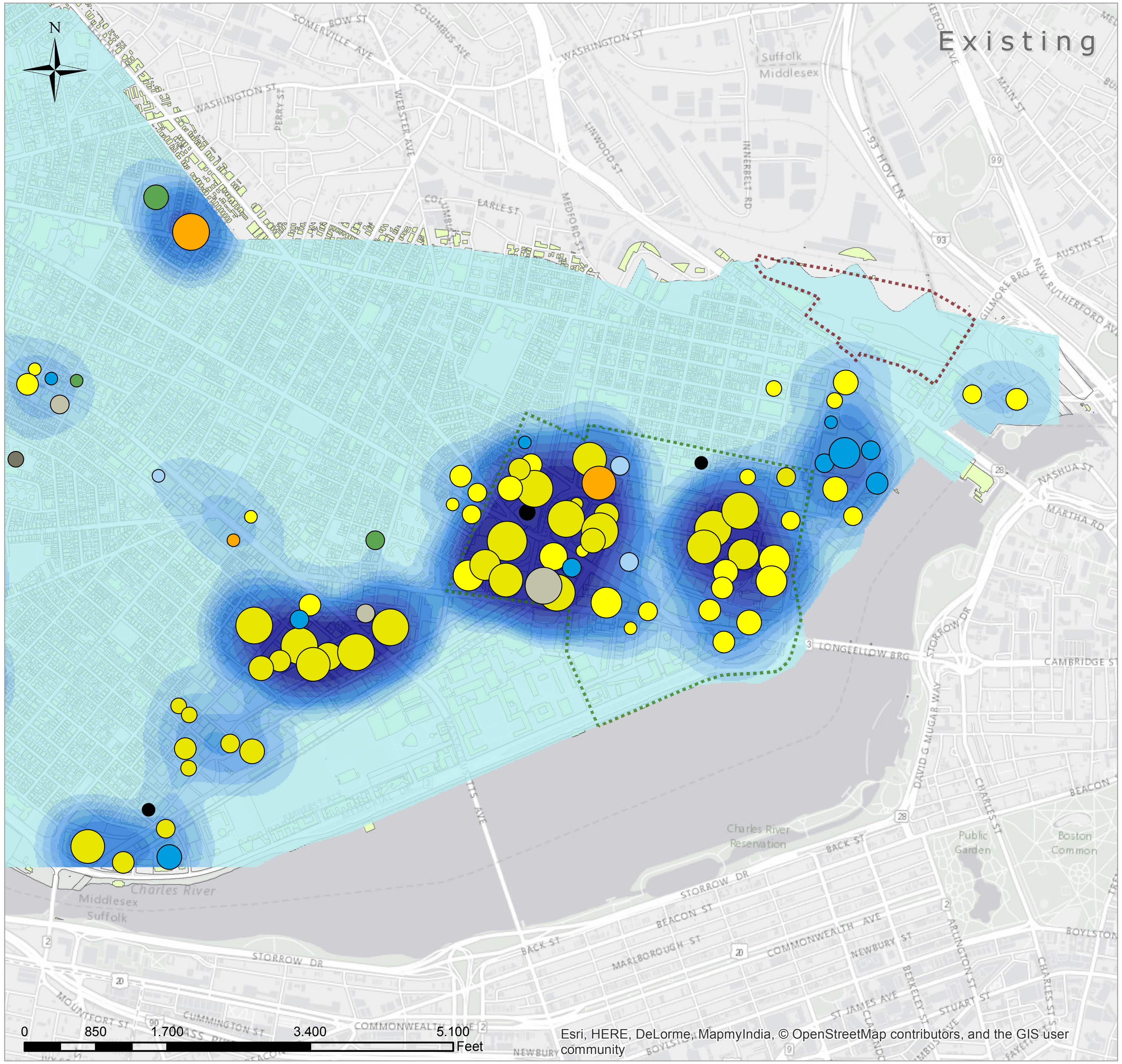

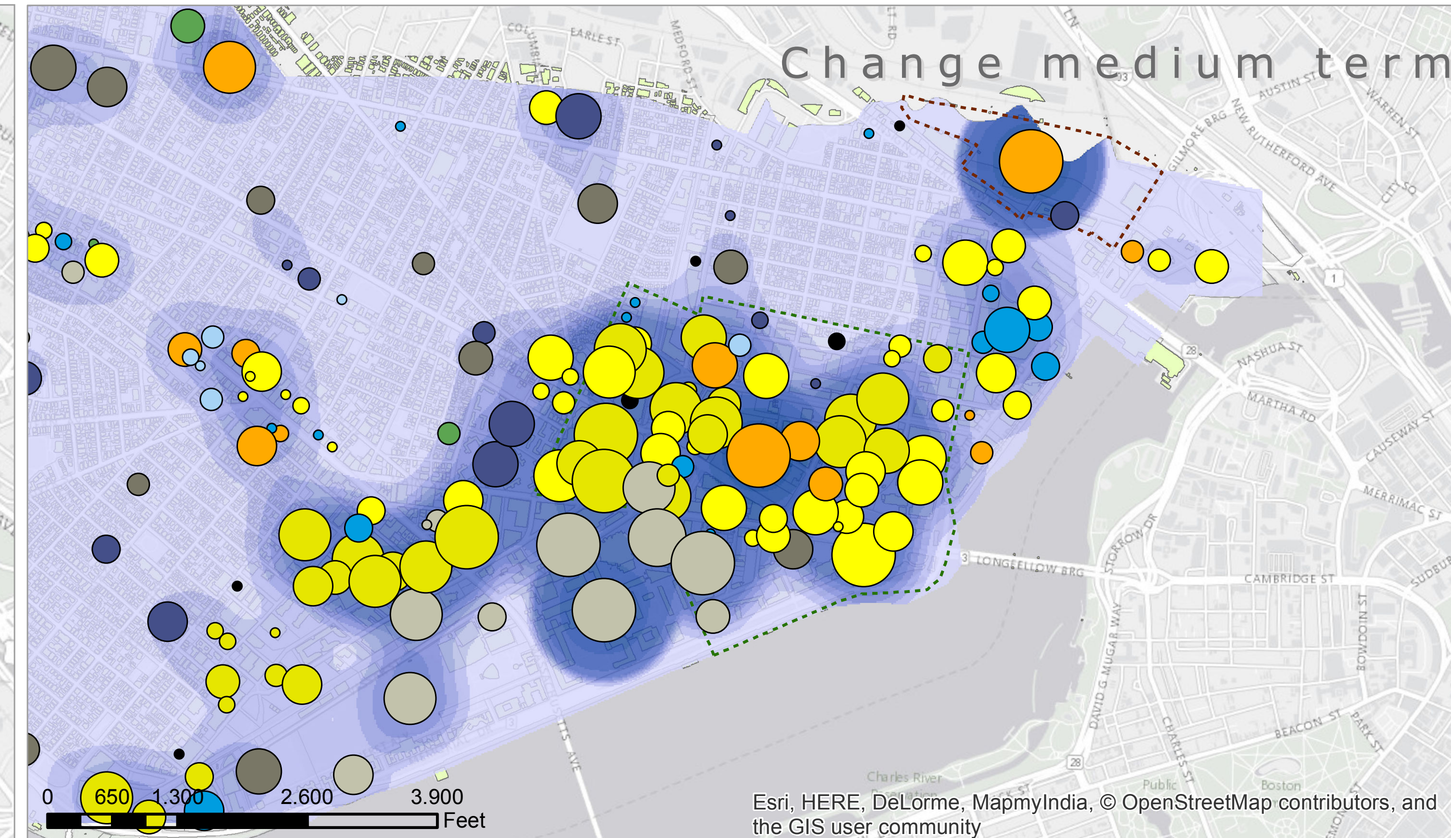

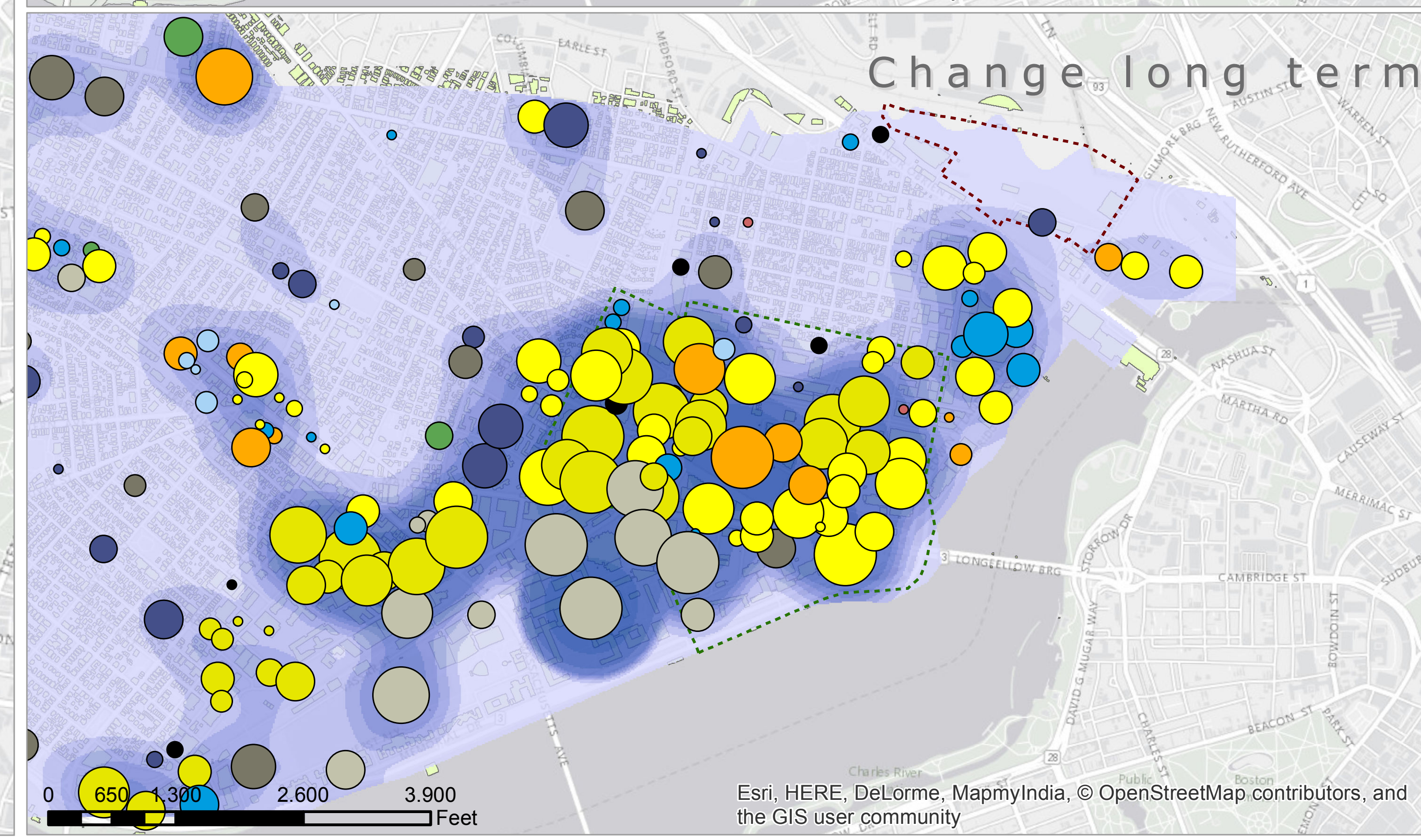

- Landuse parcels
- Buildings
- Kendall_Square
- Northpoint

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

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

Cooling demand above 500,000 kBTU

- 500,000 - 750,000
- 750,001 - 1,000,000
- 1,000,001 - 2,000,000
- 2,000,001 - 3,000,000
- 3,000,001 - 4,000,000
- 4,000,001 - 5,000,000
- 5,000,001 - 7,500,000
- 7,500,001 - 10,000,000
- 10,000,001 - 15,000,000
- > 15,000,000

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

Change by kBTU

- 0 - 250,000
- 250,001 - 500,000
- 500,001 - 750,000
- 750,001 - 1,000,000
- 1,000,001 - 1,500,000
- 1,500,001 - 2,500,000
- 2,500,001 - 4,000,000
- 4,000,001 - 6,500,000
- 6,500,001 - 8,000,000
- > 8,000,000

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CITY OF CAMBRIDGE ENERGY MASTERPLANNING

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

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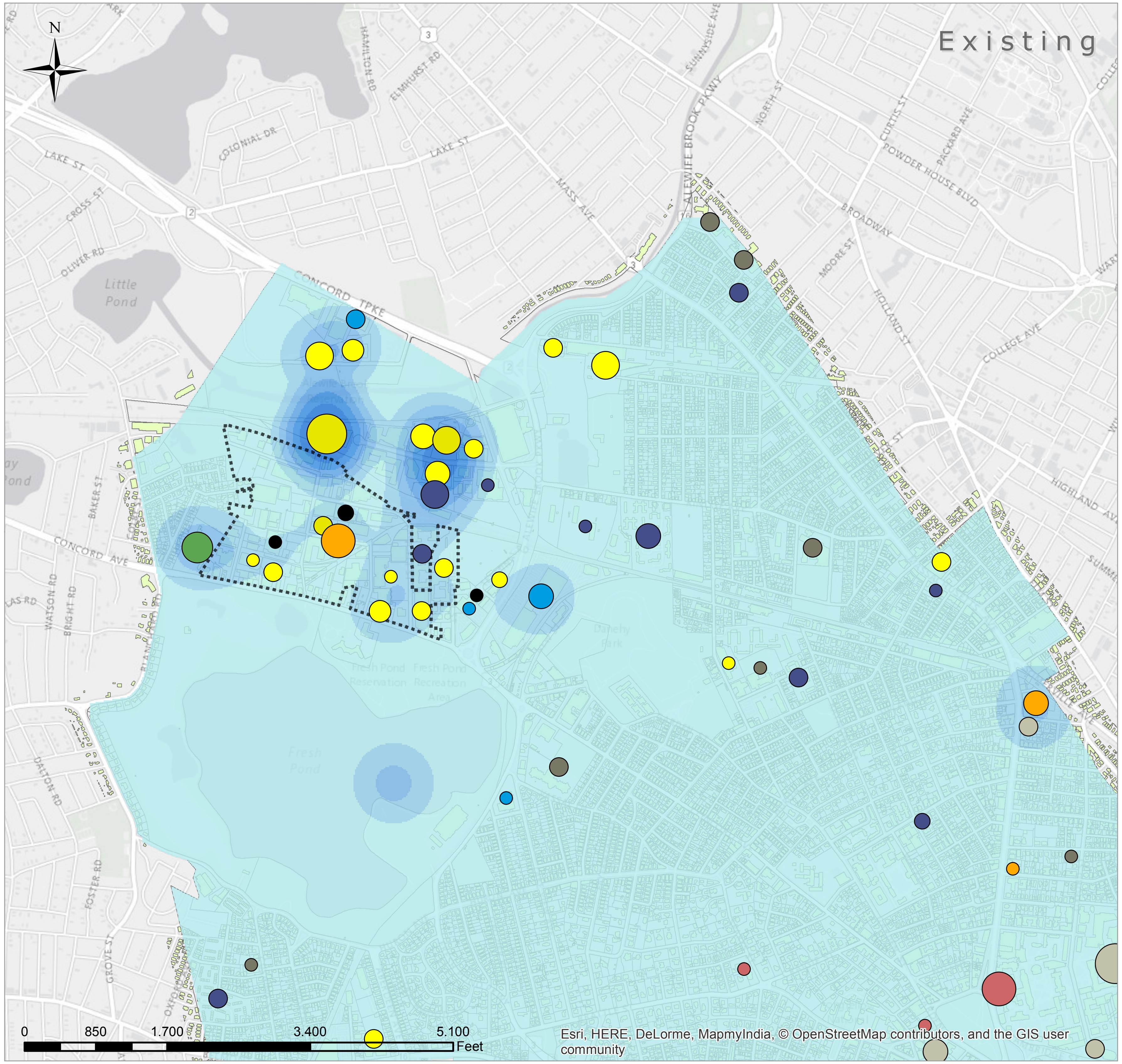
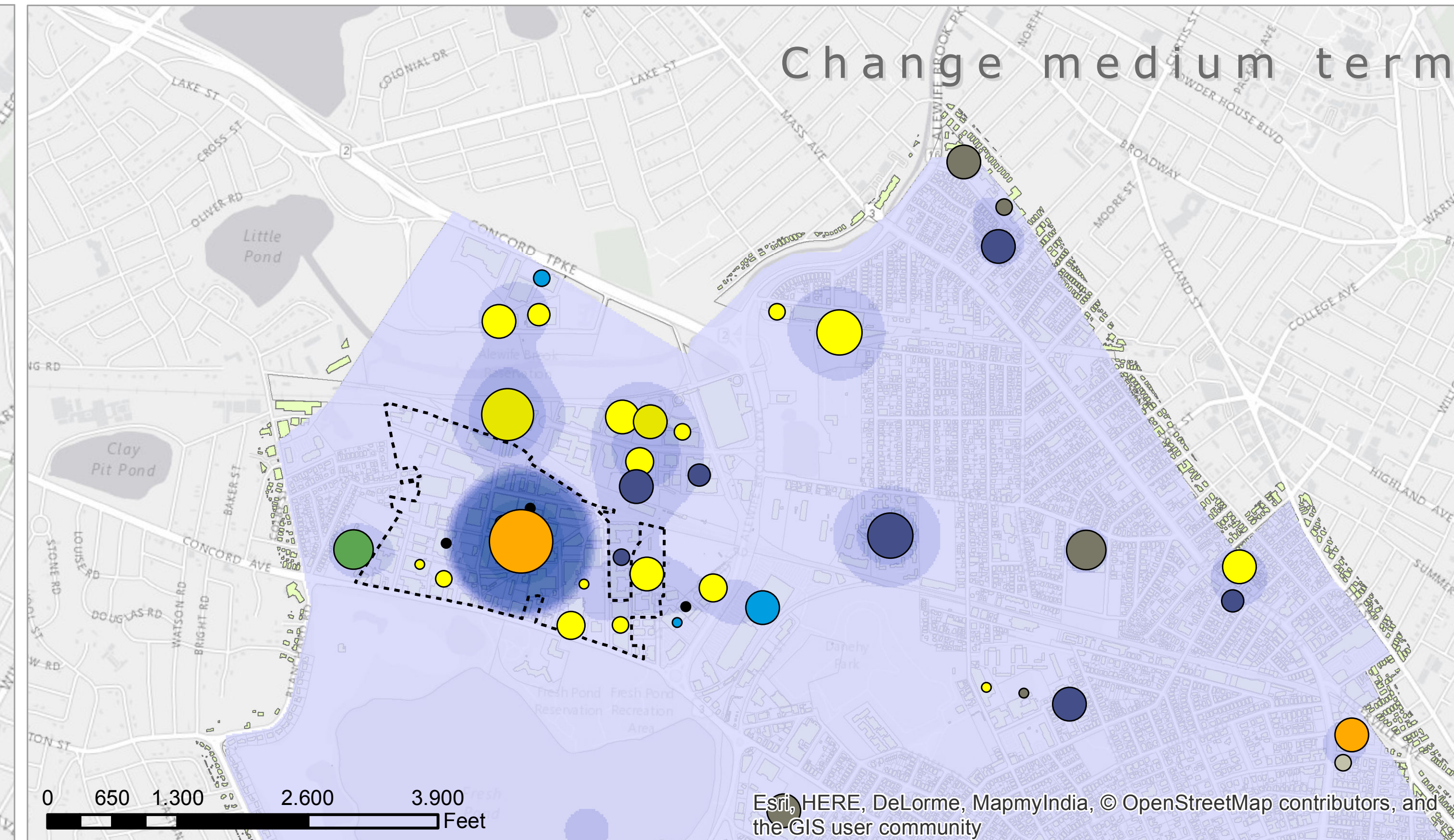
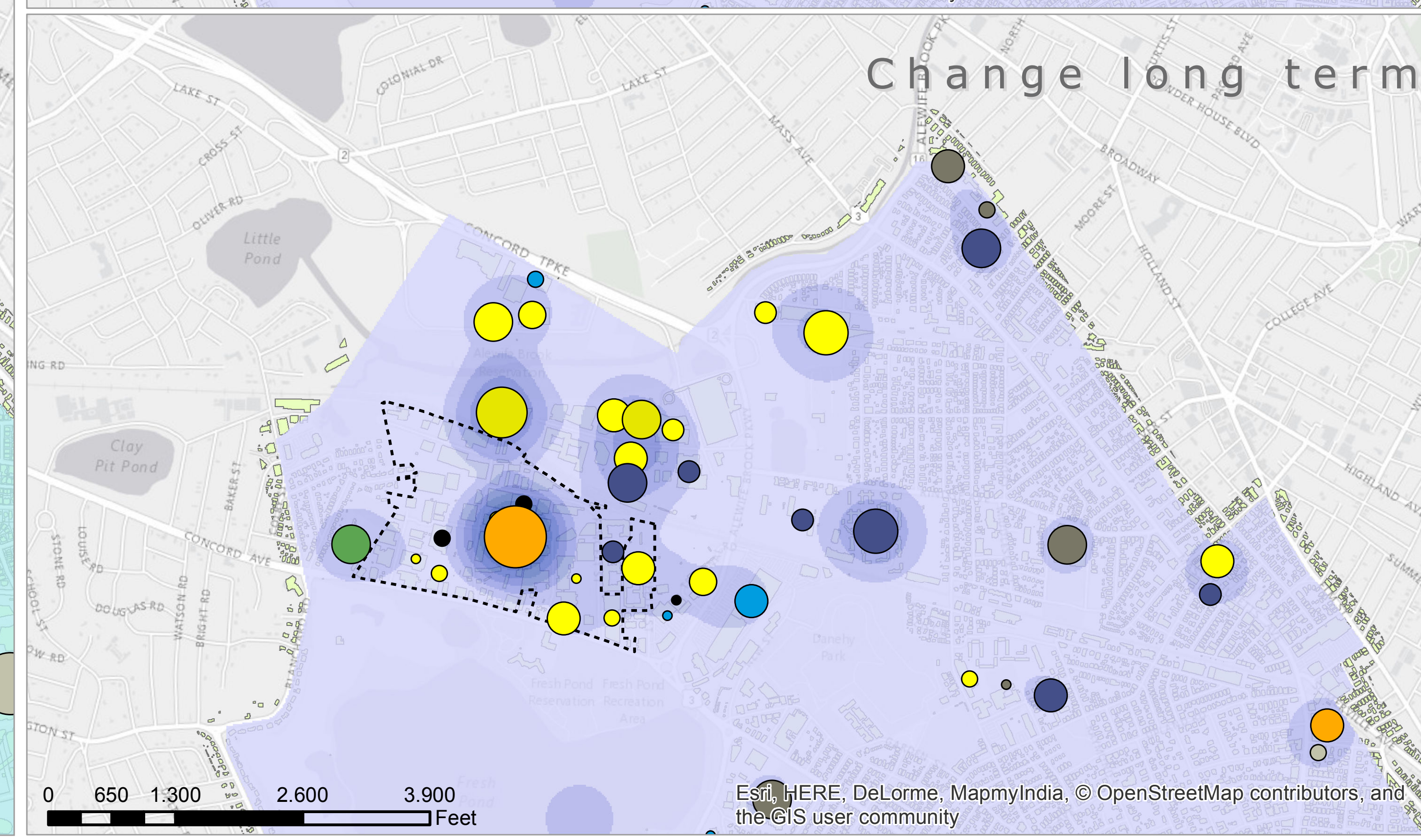






Landuse parcels
Buildings
AleWife

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

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

Cooling demand above 500,000 kBTU
- 500,000 - 750,000
- 750,001 - 1,000,000
- 1,000,001 - 2,000,000
- 2,000,001 - 3,000,000
- 3,000,001 - 4,000,000
- 4,000,001 - 5,000,000
- 5,000,001 - 7,500,000
- 7,500,001 - 10,000,000
- 10,000,001 - 15,000,000
- > 15,000,000

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

Change by kBTU
- 0 - 250,000
- 250,001 - 500,000
- 500,001 - 750,000
- 750,001 - 1,000,000
- 1,000,001 - 1,500,000
- 1,500,001 - 2,500,000
- 2,500,001 - 4,000,000
- 4,000,001 - 6,500,000
- 6,500,001 - 8,000,000
- > 8,000,000

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

Project no. 1100025630

CITY OF CAMBRIDGE ENERGY MASTERPLANNING

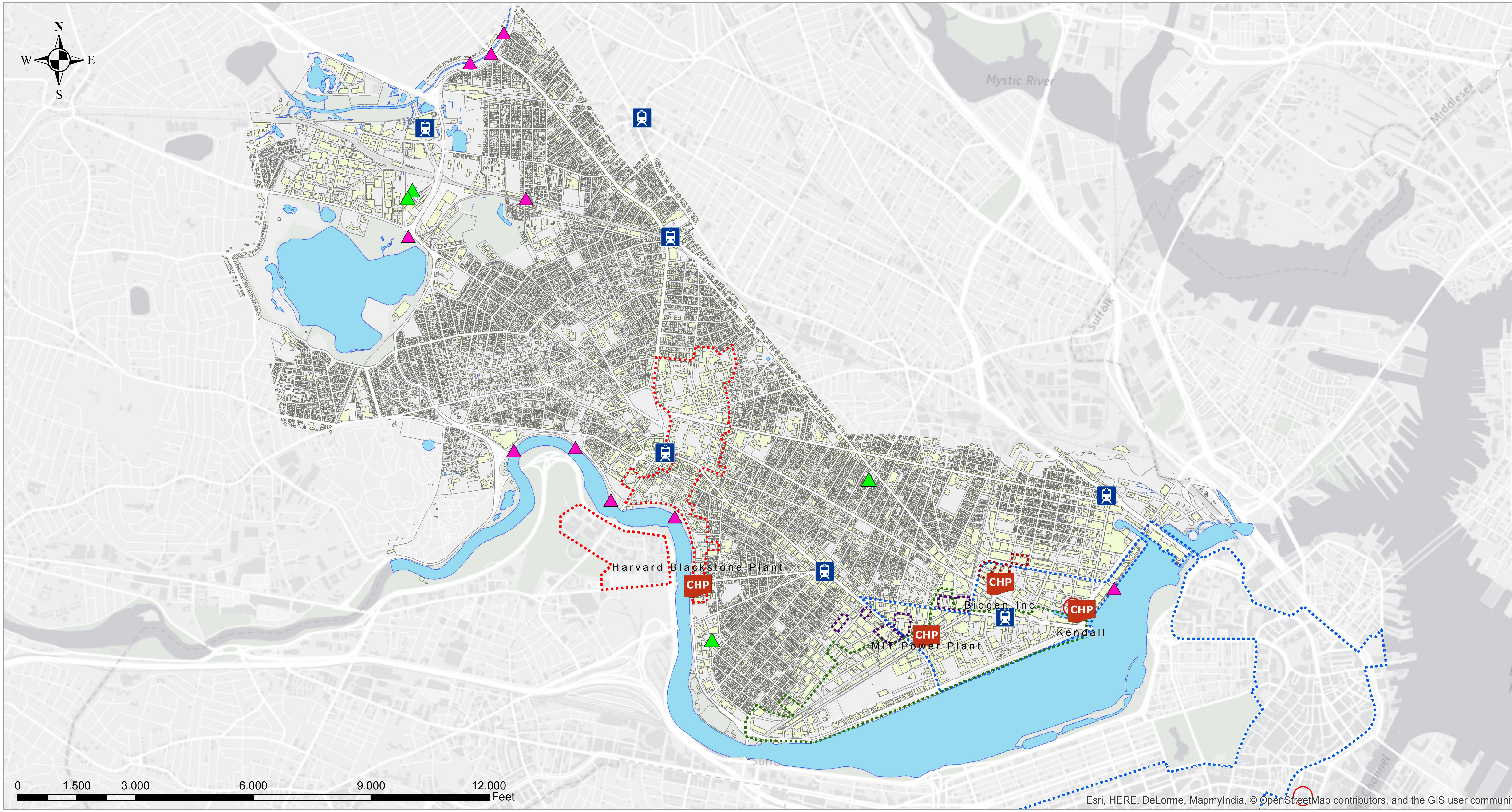
Cooling demand (current, medium and long term)
North west focus

RAMBOLL

Hannemanss Allé 53
2300 Copenhagen S
Denmark
www.ramboll.com

Cambridgema.gov

APPENDIX 5
SUPPLY ASSET MAPS



Landuse parcels

Buildings

Water Bodies with cooling potential

Harvard Steam System Area

MIT

Veolia Service Territory

BIOGEN Steam System Area

Novartis Steam System Area

CHP Combined heat and power

Steam Generating Plant

Tranformer Station

MBTA Stations

Waste Water Storage Point

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

Project no. 1100025630 Scale: 1:74000

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Hannemanss Allé 53
2300 Copenhagen S
Denmark
www.ramboll.com

CITY OF CAMBRIDGE ENERGY MASTERPLANNING

Alternative Supply sources

CambridgeMA.gov

APPENDIX 6
GOAL MAPPING FOR THE CITY OF CAMBRIDGE

GOAL MAPPING FOR CAMBRIDGE

Energy Supply Goals	Scenario Relation to 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.	

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GOAL MAPPING FOR CAMBRIDGE

Policy Goals	Scenario Relation to Goals
"net zero community" trajectory for City	
New municipal buildings achieve net zero beginning in 2020	
other new building types achieve net zero between 2022-2030	
energy efficiency retrofit regulation at time of renovation and/or sale of property	
solar ready new construction requirements	
Minimum onsite renewable energy generation requirements for new construction	
Support provision for community solar projects	
"Utility of the future" policy and model: enable energy system transformation through grid modernization, new utility revenue models, and rules which incentivize energy savings and integration of renewable energy sources.	

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GOAL MAPPING FOR CAMBRIDGE

Emission Reduction and Improved City Resiliency Goals	Scenario Relation to Goals
70% emissions reduction by 2040	
80% emissions reduction by 2050	
net zero emissions in the building sector	
decarbonizing energy supply	
Increase renewable energy generation	
Decarbonized imported electricity	
Increased local production of renewable power	
Elimination of fossil fuel heating and cooling sources	
Increase energy system resilience	

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GOAL MAPPING FOR CAMBRIDGE

City Capacity Development Goals

Technical energy system understanding

Energy policy development and implementation understanding

Energy system capital investment requirements and management

Scenario Relation to Goals

Energy Consumption Reduction Goals

Reduce energy demand

Target energy retrofit activity using BEUDO

Scenario Relation to Goals

Communication Goals

Coordinated communications and engagement with residents and key stakeholders

Scenario Relation to Goals

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