INTEGRAL GROUP

ENERGY SUPPLY PRIMER

Cambridge Getting to Net Zero Task Force

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1. PURPOSE OF REPORT

The Cambridge Getting to Net Zero Task Force is charged with developing a series of recommendations that, if implemented in tandem, will enable the city to become a net zero community. The net zero target implies zero greenhouse gas (GHG) emissions from building operations. Cambridge's target requires a combination of tactics, most simply described as deep reductions in operational energy use from buildings to significantly reduce consumption, coupled with investment in renewable energy resources to meet the demand. In support of the Task Force, this report is a technical backgrounder that lays out options for renewable energy supply.

This report outlines a series of renewable technologies as a means of providing a menu of options to the Task Force inform the development of recommendations. Each technology is described briefly and defined, and the relative efficacy of each is evaluated according to a set of criteria to determine applicability in a particular context, and contribution to meeting the net zero objective. Intended to be used a as a tool by the Task Force, this guide provides criteria to aid decision making, including an overview of each technology, appropriate applications, key benefits, constraints, and relative costing[1].

The technologies described in this report are:

- Solar photovoltaic
- Solar thermal
- Micro wind
- Combined heat and power
    - Incineration: municipal solid waste
    - Biomass
    - Natural Gas
- Waste heat recovery
    - Sewer heat recovery
    - Geoexchange

[1] A statewide evaluation indicated that Cambridge has poor potential for wind energy due to its intermittent and erratic nature. Large-scale wind is not included in this study as the Cambridge area does not have sufficient wind to support such a system. In addition, dense urban environments like Cambridge are not generally amenable to large scale wind installations.

2. DEFINITIONS

COSTING

When considering the cost of a particular technology, there are two factors to take into account – capital costs and operations and maintenance costs:

> **Capital cost** – the initial investment on hardware and installation

> **Operations and maintenance** (O+M) – O+M costs include labor costs plus repair and replacement of parts.

Evaluation of costing - the technologies vary significantly in both capital costs, and ongoing operations and maintenance costs. Instead of providing estimated absolute costs for a particular system, each is evaluated on a scale of relative cost. This approach aids in decision making at the outset based on a project's budget and specific priorities.

CAPITAL COST	$ Low Capital Cost	$$ Medium Capital Cost	$$$ Large Capital Cost
OPERATIONS + MAINTENANCE	$ Low Ongoing Cost	$$ Medium Ongoing Cost	$$$ Large Ongoing Cost

ENERGY

Broadly speaking there are two types of energy sources - high grade and low grade:

> High grade energy sources – can be converted into high grade forms of end use energy such as electricity or high temperature heat. Electricity and high temperature heat can be used directly in conventional buildings to meet energy demands without the need for intermediary technologies.

> Low grade energy sources – can only be converted to another form of low grade energy such as low temperature heating or cooling. Low grade energy can only be used in low temperature buildings and requires intermediary technology (such as heat pumps). As such, there are more limited applications for low grade energy sources.

3. TECHNOLOGIES

3.1 HIGH GRADE - SOLAR PHOTOVOLTAIC

OVERVIEW

Solar energy utilizes one of the few truly renewable and free energy resources: the sun. There are two primary ways to incorporate solar energy into a building or district's design: photovoltaic systems and solar thermal systems.

Photovoltaic (PV) systems convert solar radiation directly into electricity. Other than the initial PV panel manufacturing process, this energy conversion does not result in any GHG emissions, making PV systems a carbon neutral source of energy.

BEST APPLICATION

Photovoltaic panels are modular, allowing systems to be sized to meet a range of applications. Large scale applications include 'solar farms' (featured in image above) while small and medium scale systems can be installed on one or several buildings or properties to generate a local source of electricity. There is limited opportunity for ground-mounted solar farms in a dense urban environment such as Cambridge, with opportunities limited to parking lots and potentially City-owned tracts of land outside of the city's geographical boundaries. Whether systems are concentrated in a 'farm', or on one or several rooftops does not significantly impact the overall system performance. The electricity generated can be used directly by a building as it is generated, stored with batteries and used at a later date or fed into the electricity grid.

KEY BENEFITS

PV systems offer buildings and district energy systems a way to generate usable, high grade energy. Photovoltaic systems have an average lifespan of 25 years, require very little maintenance and do not have any ongoing fuel needs. All of these factors make operating a PV system relatively simple compared to high grade renewable energy systems.

CONSTRAINTS / POTENTIAL ISSUES

In broad terms the efficiency of a renewable energy technology is its ability to convert the energy content of a source into another usable form of energy; in the case of PV systems this is the conversion of solar radiation into electricity. The efficiency of photovoltaic panels is relatively low compared to other renewable technologies, with average efficiencies currently ranging from 10% to 25%[2].

In addition to this, photovoltaic panels are directional and are most efficient when directly facing the sun. Photovoltaic systems in the northern hemisphere thus operate best when facing south, so that they can receive the most sunlight throughout the entire day. It may be worth exploring the feasibility of west facing installations in Cambridge, in situations where access to a south facing surface is not viable. Existing buildings facing other directions, or with significant shading, may not be suitable for a photovoltaic system.

PV systems are also weather dependant and do not generate electricity at a constant rate. Their electricity generation is based on available sun hours and will vary both on an annual and daily basis. PV systems cannot generate electricity during the night. However, as the price of batteries falls, onsite (battery) storage of electricity is becoming more common, offering buildings a more constant supply of electricity from their PV system.

COSTING

The low efficiency of photovoltaic panels means that large panel areas are required in order to generate significant quantities of electricity. The relative capital cost of PV systems is therefore high compared to other renewable energy technologies.

To overcome this potential financial barrier, there are incentive funds available to Cambridge property owners to subsidize solar PV capital costs[3], and other approaches such as loan programs[4] and employers offering solar subsidies as an employee benefit[5] will make solar more financially accessible to many residents.

PV systems have low ongoing costs relative to other renewable energy systems. PV systems typically only require annual maintenance and testing and have no ongoing fuel costs.

Capital Cost:	$$$ Large Capital Cost
Operations + Maintenance:	$ Low Ongoing Cost

[2] Research shows that efficiency may improve significantly (to 40% or 60%, according to different sources) as soon as 2020.

[3] Incentive funds available at the time of publication of this report, August, 2014.

[4] http://www.mass.gov/eea/energy-utilities-clean-tech/renewable-energy/solar/residential-solar-loan-program.html

[5] http://thinkprogress.org/climate/2014/10/22/3582763/cheap-solar-power-employee-benefit/

3.2 HIGH GRADE - SOLAR THERMAL

OVERVIEW

Solar thermal systems also use solar energy, but instead of generating electricity they convert solar radiation into usable thermal energy. While there are many different types of solar thermal collector technology available on the market today, the principal behind each is the same. The collector harnesses the sun's energy to heat water, which is then circulated through a building to be used in space heating or domestic hot water (DHW) systems.

Vancouver Creekside Community Centre Solar Thermal Installation (Integral Group)

BEST APPLICATION

As solar thermal systems only generate thermal energy, they are best suited to buildings or district energy systems with high heating demands. Buildings that require large amounts of domestic hot water, for example swimming pools or fitness centers, are well suited to solar thermal technology.

KEY BENEFITS

Solar thermal systems are relatively efficient and are able to convert between 60% to 70% of available solar radiation to usable heating capacity. This high efficiency means solar thermal systems requiring less roof space than photovoltaic systems.

Another benefit of solar thermal technology is that it is not directional. While a system should ideally be facing south, to maximise the available sun light, its efficiency is not substantially decrease if it is facing other directions. This makes it simpler to install solar thermal systems on existing buildings.

Solar thermal systems require little maintenance and consume only small quantities of electricity in pumping energy.

CONSTRAINTS / POTENTIAL ISSUES

As a roof top system, solar thermal's overall capacity is limited by the amount of available roof space. In addition to this, as a weather-dependant technology, its generation is intermittent and varies both on a daily and annual basis. Alternate heating systems, such as fossil fuel boilers, will be needed during the winter. Another potential limiting factor is the structural capacity of the rooftop. Rooftops must be able to bear the weight of the system and accommodate system installation and maintenance.

COSTING

The relatively high efficiency of solar thermal systems, particularly when compared to PV systems, allows them to have lower initial capital costs. The systems also have low maintenance requirements and only consume small amounts of electricity for pumping. While cost effective in principle, the low cost of natural gas may be one reason that uptake of solar thermal technology in the Cambridge area is not as prolific as in other jurisdictions where alternative fuel options are relatively costly.

Capital Cost:	$ Low Capital Cost
Operations + Maintenance:	$ Low Ongoing Cost

3.3 HIGH GRADE - MICRO WIND

OVERVIEW

A wind turbine is a device that converts the force of the wind into torque acting on the rotor blades of the turbine. This torque is then used to drive a generator to produce electricity. The term ‘micro wind’ refers to small scale turbines designed to generate electricity for a single building.

Micro Wind System [http://www.lowcarboneconomy.com/Resources/NewsImages/Wind+Power+2_1235_18760800_1_0_97_300320x320.jpg]

BEST APPLICATION

Micro wind turbines are commercially available in a range of sizes. A micro wind system can be made up of a small number of larger turbines, or a large number of smaller turbines depending on the available wind profile. Although the technology is scalable, given their relatively small capacity micro wind systems are best suited to building scale applications.

KEY BENEFITS

Micro wind systems generate usable, high grade energy that can be used directly on site. Also micro wind systems do not have any ongoing fuel costs. This insulates them from potential future fuel price increases and makes it a carbon neutral energy source.

CONSTRAINTS / POTENTIAL ISSUES

The electrical output of wind turbines is dependent on the wind patterns in the area, making it an intermittent energy source. State-level and local studies show low feasibility for wind as an energy source in Cambridge due to the erratic and intermittent nature of wind energy in the area.

As a weather dependant technology, the amount of electricity generated by micro wind will vary across an hour, day and year. Their intermittent generation means that micro wind systems cannot be relied upon to meet a building's electrical demand on a day to day basis; they can be used as a supplementary technology only.

Site selection is also very important in maximising wind turbine output, making them more difficult to install on existing buildings.

COSTING

Micro wind systems have higher capital costs than other similar high grade energy generation systems. As such, they are typically installed in rural areas where there is limited access to grid electricity.

Wind turbines also contain moving parts which will require routine maintenance. As a result of this micro wind systems have higher ongoing maintenance costs than photovoltaic or solar thermal systems.

Capital Cost:	$$$ Large Capital Cost
Operations + Maintenance	$$ Medium Ongoing Cost

3.4 HIGH GRADE - COMBINE HEAT + POWER

The term 'combined heat and power' refers to a large category of systems that generate both electricity and high grade heat. These systems utilize different fuel sources and different technologies in order to do this. For the purpose of this report the technologies included shall be cogeneration and trigeneration through complete combustion and gasification, using the fuel sources of Municipal Solid Waste (MSW), biomass and natural gas.

COGENERATION VS. TRIGENERATION

Cogeneration systems are a type of heating system that simultaneously generates heat and electricity. Cogeneration can be broken down into two stages: first fuel is combusted to power a turbine that generates electricity and then, with the by-product waste heat, hot water or steam is generated for use in space heating.

Facilities with cogeneration plants receive twice the benefits from the one piece of equipment; they receive both electricity and high grade thermal energy (that would otherwise have required fossil fuels). The heating demand profile of a typical building, however, peaks in winter and dips in summer. If a cogeneration system operates year-round to generate electricity, the heat that cannot be utilized during the summer months must be rejected.

Trigeneration starts with the same steps as cogeneration (burning fuel and converting the energy to electricity and hot water), but adds on an additional cooling generating step. Instead of rejecting waste heat, it is redirected to power an absorption chiller to produce chilled water that can be used for space cooling. This is the advantage of trigeneration: it uses waste energy to meet all of a building's thermal needs year round.

COMPLETE COMBUSTION VS. GASIFICATION

Cogeneration and trigeneration can be designed using a number of different technologies. A technology that is traditionally used in cogeneration and trigeneration systems is complete combustion. In complete combustion a fuel source is burned and the heat used to generate electricity and high grade thermal energy. This can either be done through the creation of steam (in the case of MSW or biomass combustion) or directly in the case of natural gas.

Gasification is a newer, emerging technology that extracts the energy content of a fuel source without direct combustion. It subjects the fuel source to high temperatures and pressures in order to create a synthesis gas, more commonly known as syngas, and a solid waste residue. Syngas is an industrially created gas fuel that can be used in a similar manner to natural gas (i.e. burned as a part of the cogeneration or trigeneration process).

There are a number of benefits to using gasification over traditional complete combustion. Generating electricity from a syngas powered turbine is more efficient than the steam cycle used in MSW or biomass combustion. The condensed volume of syngas also makes the flue gas cleaning process associated with a syngas powered turbine simpler than that of MSW or biomass combustion.

Gasification is, however, a more complicated technology with a greater number of steps than traditional combustion. At each step there is the potential for energy loss, which makes the technology on the whole less efficient than traditional combustion. The chemical processes involved in gasification also require its fuel source to have a consistent composition. While this can be easily achieved with biomass, MSW requires a significant amount of pre-processing (such as sorting, shredding, drying and pelletization) to achieve this.

Finally, similar to natural gas, burning syngas produces GHG emissions. Whether or not electricity generated by gasification is carbon neutral therefore depends on the fuel source used.

3.5 CHP - MUNICIPAL SOLID WASTE

OVERVIEW

The term Municipal Solid Waste refers to items that the general community uses and disposes of such as product packaging, bottles, clothes or newspaper – otherwise more commonly known as garbage. All MSW has an energy content that can be converted to usable energy, though the amount of energy depends on the composition of the MSW.

For the purposes of this report, MSW will refer to non-organic, consumer waste.

Waste To Energy Facility in Sweden (Integral Group)

BEST APPLICATION

MSW Cogeneration/Trigeneration (whether through complete combustion or gasification) requires a significant amount of fuel processing and handling. A MSW cogeneration/trigeneration system is therefore best suited to district scale projects. Given the fuel handling required, MSW cogeneration/trigeneration systems are ideally located close to the end energy users.

KEY BENEFITS

As fuel for a cogeneration/trigeneration system, MSW is able to provide both electricity and high grade thermal energy to district systems. This increases the energy independence of the district by diversifying its energy sources and insulating it from potential grid/natural gas supply issues.

MSW also makes use of materials that would otherwise be disposed of in landfills. This means that MSW is one of the few fuels sources that an energy generator can be paid to receive, instead of having to pay for. When combined with modern emissions reduction technologies, waste to energy facilities can meet strict international emissions standards.

CONSTRAINTS / POTENTIAL ISSUES

Waste to energy technologies typically require MSW to be sorted before it can be used. This can be energy intensive, depending on the level of sorting and processing required. MSW sorting facilities involve multiple stages of waste handling, which requires high levels of ongoing maintenance and staffing.

The financial viability of MSW cogeneration/trigeneration also depends on the future availability of MSW. Long term contracts with municipalities will need to be entered into to guarantee a fuel supply for the life of the system. Any municipality waste programs involving the redirection of waste (through waste reduction, reuse or recycling) will need to be understood before a MSW cogeneration/trigeneration system can be designed.

Another point to consider is that MSW technologies evoke a mixed response from the public. While many of the concerns typically raised are more perceived than proven, the support of the wider community is important for district energy projects and public concerns will need to be addressed.

COSTING

As previously noted, MSW requires significant fuel processing infrastructure. If gasification technology is used, additional costs are required for the production of syngas. In either case, the ongoing operations and maintenance costs associated with MSW facilities is higher than for other renewable energy technologies.

Capital Cost:	$$$ Large Capital Cost
Operations + Maintenance:	$$$ Large Ongoing Cost

3.6 CHP - BIOMASS

OVERVIEW

Biomass refers to fuel that is derived from organic material such as wood or crops. It can include consumer, forestry and agricultural organic waste. Similar to MSW, biomass has an energy content that can be converted to usable energy in a number of ways.

For the purposes of this report the term biomass shall refer to consumer and agricultural organic waste.

UBC Biomass Plant (Integral Group)

BEST APPLICATION

As with MSW, biomass cogeneration/trigeneration can require a significant amount of fuel processing and handling (depending on the fuel type used). The scale of the fuel handling infrastructure therefore makes biomass cogeneration/trigeneration best suited to large building or district scale applications where the cogeneration/trigeneration plant is close to the end energy user.

KEY BENEFITS

There are a number of different potential sources of biomass fuel, including wood chips, hog fuel and wood pellets,, each with unique environmental implications. Waste wood products are considered a carbon neutral energy source because trees are part of a natural cycle of carbon absorption and emission. Trees naturally absorb carbon dioxide as they grow and then release it back into the atmosphere when they decay.

Another advantage of biomass cogeneration is that the system can be sized and implemented in phases. This allows the system to be built over a longer period of time, thus spreading out the capital cost and allowing employees to become accustomed to the new technology.

CONSTRAINTS / POTENTIAL ISSUES

Biomass technology is more complicated than the equivalent natural gas technology and therefore has higher maintenance and staffing requirements. It is prudent to anticipate and address concerns amongst the general public around the traffic and environmental implications of fuel transport. As mentioned above, different fuel sources have different environmental implications (e.g. the use of virgin materials versus waste material), so strict parameters around quality and source of fuel will dictate the environmental benefits of the biomass system.

COSTING

As previously noted, biomass systems typically require significant fuel pre-processing and handling. This increases both the capital costs of the system and the ongoing maintenance and operations costs.

Capital Cost:	$$$ Large Capital Cost
Operations + Maintenance	$$$ Large Ongoing Cost

3.7 CHP – NATURAL GAS

OVERVIEW

Natural Gas cogeneration/trigeneration operates under the same principles as MSW and biomass systems, but it utilizes a conventional fossil fuel (natural gas).

BEST APPLICATION

Unlike MSW and biomass systems, natural gas cogeneration/trigeneration systems do not require additional fuel handling or processing infrastructure. This allows natural gas cogeneration/trigeneration to be used in both large district scale systems and small building scale systems.

KEY BENEFITS

Natural gas cogeneration/trigeneration provides buildings and districts with electrical independence by decreasing their reliance on grid electricity. Also in Cambridge grid electricity produces approximately twice as many GHG emissions as natural gas. Using natural gas cogeneration/trigeneration as a source of electricity would therefore significantly reduce Cambridge's GHG emissions.

Natural Gas Plant
http://www.industcards.com/cc-usa-hi.htm

CONSTRAINTS / POTENTIAL ISSUES

Natural gas prices are currently lower than electricity, however prices have been known to fluctuate. Similarly, interruptions to the supply of natural gas can occur. While a natural gas CHP system does reduce a facility's reliance on grid electricity, it also increases its reliance on natural gas. Further, as the electricity supply becomes increasingly cleaner, the GHG reductions associated with CHP natural gas will diminish.

COSTING

Natural gas cogeneration/trigeneration systems utilize both a commonly available fuel source and technology. This significantly reduces the initial capital costs of the system, particularly when compared to other cogeneration/trigeneration systems. Natural gas cogeneration/trigeneration systems will require routine maintenance, however this is comparable to other traditional heating systems.

Capital Cost:	\$\$ Medium Capital Cost
Operations + Maintenance:	\$\$ Medium Ongoing Cost

3.8 LOW GRADE – WASTE HEAT RECOVERY (OVERVIEW)

There are a number of heat sources/sinks (both natural and man-made) that can be utilized to generate low grade thermal energy. These heat sources cannot generate high grade energy (i.e. electricity or high temperature water). When combined with heat pump technology, however, they can contribute to meeting a portion of a building/district's thermal energy demands.

WASTE HEAT SOURCES

Refrigeration systems must reject heat as a part of their cooling cycle. Commercial or industrial sized refrigeration systems (such as ice rink refrigeration systems or commercial cool rooms) must reject large amounts heat to maintain their indoor design conditions. This heat can be recovered and then used as a low grade heating energy source within a building in an adjacent facility. Laboratories may present an opportunity to introduce waste heat recovery systems, in cases where there is a large scale refrigeration system, for example.

DISTRIBUTION

Ambient loop systems are one way to transfer low grade heat from the waste heat source to the end user. Ambient loops transfer heated water in underground pipes from the source to distribute to buildings, relying on the constant temperature of the earth to maintain the temperature of the water. Because ambient loops distribute moderate temperature energy as opposed to chilled or hot water, no additional energy is required to maintain the temperature of the water.

COSTING

The financial feasibility of waste heat recovery systems largely depends on the system's initial capital costs. It is therefore important that the waste heat source is located close to the heating demand. The cost of trenching and installing pipework over long distances could prevent a waste heat recovery system from paying itself back within a commercially acceptable timeframe.

3.9 LOW GRADE – SEWAGE HEAT EXCHANGE

OVERVIEW

Sewage contains substantial amounts of low grade heat and represents a free, low carbon energy source. The low temperature of sewage means that it can be used as either a heat sink (to reject heat into) or as a low grade heat source. Low grade thermal energy can be extracted from sewage networks via heat exchangers to ensure there is no chance of cross contamination.

BEST APPLICATION

Sewage heat exchange requires large sewage flow rates in order to generate notable quantities of low grade energy.

This, combined with their high capital costs, means that sewage heat recovery is best suited to district scale systems.

Vancouver sewage heat recovery system during construction – (Integral Group)

KEY BENEFITS

Sewage heat exchange utilizes a free, low grade heat source that would otherwise go to waste. The system requires routine maintenance of equipment at a centralized plant, similar to traditional heating systems.

CONSTRAINTS / POTENTIAL ISSUES

Sewage heat exchange can reduce the overall temperature of sewage streams, which can have consequences for downstream waste water treatment plants. By reducing the available heat in the sewage, sewage heat recovery can also reduce the overall effectiveness of wastewater treatment processes. Wastewater treatment plants may, therefore, restrict the minimum temperature of sewage entering their facility. It is recommended to explore MWRA's system requirements prior to exploration of a sewage heat exchange system. This will correspondingly restrict the capacity of any potential sewage heat exchange system and needs to be considered in the system design.

Sewage heat exchange requires notable quantities of electricity in order to raise the low grade energy to usable temperatures. The total GHG intensity of using sewage heat exchange is therefore higher than some high grade renewable energy sources such as photovoltaics.

COSTING

The high capital costs of sewage heat exchange technology, and the civil works associated with its installation, means it is not scalable. As previously noted, sewage heat exchange relies on the use of electrically powered heat pumps. The ongoing cost of operating a sewage heat exchange system is therefore greatly affected by the price of electricity.

Capital Cost:	$$ Medium Capital Cost
Operations + Maintenance:	$$ Medium Ongoing Cost

3.10 LOW GRADE - GEOEXCHANGE

OVERVIEW

Geo-exchange systems operate in a similar manner to sewage heat exchange systems, except they use the earth as a low grade heat source/sink instead of sewage systems. Below its surface, the earth's temperature is typically between 10C and 15C year round. This stable, low temperature means the ground can be used either as a heat sink or source.

Installation of a Geoexchange System (Integral Group)

BEST APPLICATION

Geoexchange systems require significant trenching and ground works. They are therefore best suited to new buildings/district systems, and major rehabilitation projects that can accommodate significant ground works.

KEY BENEFITS

Geoexchange systems utilize a naturally occurring heat source/sink. The system also has similar maintenance requirements to a traditional heating system.

CONSTRAINTS / POTENTIAL ISSUES

Geoexchange systems must be sized correctly to avoid over drawing heat form the ground. If too much heat is drawn from the ground, there is a risk the ground could freeze and result in the development of permafrost. The development and thawing of permafrost can be potentially dangerous to surrounding building's, as it can destabilize the building's foundations.

Geoexchange systems can only provide low grade thermal energy and this requires the use of electrically powered heat pumps. Overall, geoexchange systems have a higher GHG emissions intensity than other renewable energy technologies such as photovoltaics. To reduce the GHG intensity of a geoexchange system, it could be paired with a large photovoltaic system to power the heat pumps.

COSTING

Closed loop geoexchange systems require significant excavation for initial installation, and have similar ongoing maintenance costs to traditional heating systems. It is important to note that the cost of operating and maintaining closed loop geoexchange systems is different to open loop geoexchange systems. Open loop geoexchange systems commonly experience issues relating to biological fouling, which can result in higher maintenance costs.

Capital Cost:	$$ Medium Capital Cost
Operations + Maintenance:	$$ Medium Ongoing Cost

4. SUMMARY

4.1 KEY CONSIDERATIONS

As Cambridge explores various strategies to achieve net zero, each of these technologies will likely be considered for application at various scales within a variety of contexts throughout the urban landscape. There are a number of elements to take into consideration when determining the appropriate renewable technology or solution.

COSTS + TRADE OFFS

Cost is a consideration that varies based on availability and price of technology, weighed against cost of conventional energy sources (or business as usual). As discussed in the report, there are capital costs as well as operation and maintenance costs to consider. The table below summarizes relative weightings for each of the technologies, however, there are a number of other considerations that will impact the cost and decisions around investment. For example:

> While the MSW and biomass options appear to be the most costly across the board, these options are also capable of deploying high grade energy at a large scale, and therefore may be the most appropriate choice in a district energy application, where the objective is to serve the energy needs of an entire neighborhood.

> In the case of solar PV, there are often incentives and favourable loan products available to subsidize capital costs. As such, further exploration is needed when determining the most viable technology for a specific application.

	PV	Solar Thermal	Wind	MSW	Biomass	Natural Gas	Sewage Heat Recovery	Geo-thermal
Capital Cost:	$$$	$	$$$	$$$	$$$	$$	$S	$$
O+M:	$	$	$$	$$$	$$$	$$	$$	$$

GEOGRAPHIC + CLIMATIC

There are geographically specific considerations such as Cambridge's local climate. For example, days and hours of sun need to be factored in when considering solar and wind speed and frequency when exploring turbines.

URBAN FORM + EXISTING INFRASTRUCTURE

> The city's urban form is a consideration – density of buildings may eliminate certain technologies such as solar, if shading is an issue, and on the flipside may be appropriate for district scale solutions, where a large investment in infrastructure can serve a cluster of dense buildings.

> In the case of district energy systems, an appropriate model in a small but constrained urban environment such as Cambridge might be a distributed or modular district energy system such as the system in North Vancouver[6].

> Existing infrastructure should also be taken into consideration. For example, there may be opportunities to expand or improve the efficiency of the existing Veolia steam system that generates and distributes, relatively low-emission steam recovered from natural gas driven turbines.

> There may be opportunities for low carbon energy system development beyond Cambridge's municipal boundaries, where Cambridge currently owns (or could potentially purchase) property in the surrounding region.

ENVIRONMENTAL, SOCIAL, CULTURAL + POLITICAL

Finally there are environmental, social, cultural, and political considerations. While low carbon energy sources are recommended as a tool to support environmental sustainability objectives (reduced GHG emissions), there are a set of environmental impacts associated with each technology, and these trade-offs have to be factored into the decision making process. Residents should be engaged in the decision making process where energy source choices may impact their lives, and as such, specific social, cultural, and political issues may arise that influence the choice of technologies.

[6] http://www.cnv.org/City-Services/Lonsdale-Energy