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Technical Support for Integrated Community Energy Solutions

Task 2
Development of Cost Benefit Information and Business Case for Integrated Community Energy Solutions

Draft Report

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Submitted by

FVB
ENERGY INC

222 South Ninth St., Suite 825
Minneapolis MN, 55402
Phone 612-338-4489

Contents

Executive Summary

The Metropolitan Washington Council of Governments (COG) recently launched a new initiative in the region to advance district energy systems (DES), combined heat & power (CHP), and microgrids. This report:

- Describes these clean energy technology options;
- Provides generalized costs and benefits, including capital and operating costs, power-related benefits, energy efficiency benefits and environment benefits;
- Summarizes challenges that can constrain the implementation of these systems; and
- Describes alternative models for ownership and operation of these systems.

Technologies

District energy systems deliver hot water, steam or chilled water from a central plant(s) to multiple buildings via a network of pipes to meet thermal end uses: space heating, domestic hot water, air conditioning or industrial process heating or cooling. DE systems can use a wide variety of energy sources including CHP.

CHP systems use the same energy source to simultaneously produce useful thermal energy and electricity or mechanical power in an integrated system. A variety of technologies can be used for CHP, including reciprocating engines, combustion turbines, steam turbines, organic rankine cycle turbines and fuel cells.

Microgrids are small-scale electricity distribution systems that link and coordinate multiple distributed energy resources (DERs) into a network serving some or all of the energy needs of one or more users located in close proximity, which can operate connected to the traditional centralized electric grid or autonomously from it, in an intentional island mode.

Costs and Benefits

It cannot be overstressed that the generalized characterization of technologies (including efficiencies and costs) in this report should not be applied to specific cases without a case-specific evaluation of loads, densities, fuel and electricity costs and other case-specific circumstances.

The report presents generalized economics for 8 district energy system scenarios, with the following sources used for baseload heating and cooling capacity:

1. Natural gas chillers and electric centrifugal chillers
2. Reciprocating engine CHP and absorption chillers
3. Gas turbine CHP and absorption chillers
4. Combined cycle CHP and absorption chillers
5. Biomass boiler and absorption chillers
6. Ground source heat pumps
7. Industrial waste heat recovery and electric chillers
8. Solar heating and electric chillers

Baseload heating capacity is sized to provide 50% of the peak heating load, which supplies 86% of the annual heating energy. Absorption chiller capacity is sized to use the heat output of CHP or the biomass boiler. All district energy scenarios assumed medium-temperature hot water distribution, chilled water distribution and thermal energy storage that is used seasonally for chilled water storage and hot water storage.

District energy costs are then compared with building-scale systems using natural gas boilers and electric centrifugal chillers.

The economic analysis concludes that:

- District energy natural gas boilers, electric chillers and thermal storage (typically the initial step in developing a (DES) can provide modest cost advantages over conventional hydronic building technologies, especially if low-cost financing is available.
- CHP is not cost-competitive where electricity is inexpensive ($0.06 per kWh) but can cost-effective in areas with high power costs if the excess electricity not needed by the district energy plant can be sold to the grid.
- Biomass is not cost-effective at the scale of DES modeled.
- Ground source heat pumps and solar district heating are unlikely to be cost-effective.
- Industrial waste heat recovery is potentially cost-effective but truly requires a site-specific analysis.

The impact of DES varies depending on the particular scenario, but generally provides significant reductions in total fossil fuel consumption, greenhouse gases and regulated pollutants. These calculations include both direct consumption by the district energy plant or the building system and indirect consumption in the power grid resulting from electricity purchased from the grid.

District energy provides significant reductions in peak grid power demand, generally in excess of 25% compared with conventional approaches. With CHP, the peak power demand reduction ranges from 150% to 250%, as the CHP facility, which is sized based on the heating load, makes a large net contribution to the grid during the summer.

Implementation Challenges

Development of a DES requires interactive progress on a range of fronts, including: market assessment; stakeholder communication; technical design; economic analysis; securing the revenue stream with customer contracts; permitting; risk analysis; and financial structuring and analysis.

Ownership and Operation Models

Ownership structures have a significant impact on the options available for funding and financing the development of the system. There are many different models of ownership and operation with no single preferred model; the ultimate structure should be tailored to the goals of the major stakeholders. Key considerations in the assessment of models should include:

- Access to a range of project financing sources, including state and federal grants, tax credits, subsidized financing tools and cost-effective market-based financing.
- Risk mitigation in construction and operation of the system that can address energy costs and price stability, as well as changing environmental parameters.
- Flexibility to accommodate future expansions of the district energy system while supporting development and sustainability agenda.

Introduction

Background

The Metropolitan Washington Council of Governments (COG) recently launched a new initiative in the region to advance district energy utilities, combined heat & power (CHP), and microgrids. These technologies are defined below. Deployment of these technologies in the region has the potential to:

- cut emissions of both criteria pollutants and greenhouse gases;
- reduce peak power demand;
- enhance energy security;
- reduce energy cost volatility; and
- strengthen the local economy by spending more energy dollars locally.

Definitions

Although there are no universally accepted definitions of the following interrelated and overlapping terms, the meaning of these terms as used in this report are as follows.

District Energy (DE)

District energy systems deliver hot water, steam or chilled water from a central plant(s) to multiple buildings via a network of pipes to meet thermal end uses: space heating, domestic hot water, air conditioning or industrial process heating or cooling. DE systems can use a wide variety of energy sources including CHP.

Combined heat and power (CHP)

CHP systems use the same energy source to simultaneously produce useful thermal energy and electricity or mechanical power in an integrated system. A variety of technologies can be used for CHP, including reciprocating engines, combustion turbines, steam turbines, organic rankine cycle turbines and fuel cells.

Microgrids

Microgrids are small-scale electricity distribution systems that link and coordinate multiple distributed energy resources (DERs) into a network serving some or all of the energy needs of one or more users located in close proximity, which can operate connected to the traditional centralized electric grid or autonomously from it, in an intentional island mode.

Integrated Community Energy Solutions (ICES)

ICES is a general term for a cross-cutting set of community systems that emphasize synergy between multiple sectors, such as energy supply and distribution, housing and buildings, transportation, industry, water, wastewater and solid waste management. ICES may or may not include DE or CHP systems.

Community Energy Systems (CES)

A CES is an integrated approach to supplying community energy requirements from renewable energy or high-efficiency sources. This term is generally synonymous with DE.

Focus of This Report

Community energy is an enormous topic, covering many end-uses, technologies, levels of government and policy issues. This project does not address every strand of this complex web. The effort is focused on district energy, CHP and microgrids. Technologies such as electric vehicles, non-CHP renewable power generation (wind, photovoltaic, etc.) are not part of the scope of this project.

It cannot be overstressed that the generalized characterization of technologies (including efficiencies and costs) in this report should not be applied to specific cases without a case-specific evaluation of loads, densities, fuel and electricity costs and other case-specific circumstances.

Organization of This Report

The deliverable of this task is a report on the business case for various approaches available for Integrated Community Energy Solutions, with a primary focus on district energy, microgrids, and CHP. There are four major elements in this report:

- Overview of Clean Energy Technology Options -- Overview of key clean technology options, including a description, graphic illustrations, and example cases from the US and internationally.

- Costs and Benefits -- Generalized overview of the costs and benefit of the clean energy options, including: capital costs, operating costs and total costs; power-related benefits; energy efficiency benefits; and environment benefits.

- Implementation Challenges – Description of major challenges that can constrain the implementation of integrated community energy systems.

- Ownership and Operation Models – Description of the advantages and disadvantages of different community energy system ownership and operation models.

Overview of Clean Energy Technology Options

This section describes a range of technologies relevant to district energy systems, combined heat and power (CHP) and microgrids.

District Energy Systems Overview

District energy systems produce hot water, steam and/or chilled water at a central plant for distribution through underground pipes to buildings connected to the system to provide space heating, air conditioning, domestic hot water and/or industrial process energy. Although steam has historically been common in the U.S.A., hot water is generally the preferred heat transfer fluid in new heating systems.

There are three major elements in a district energy system:

- Plants – equipment to produce hot water and chilled water, located at one or more locations.
- Distribution -- buried pipes to distribute hot water and chilled water. There would be four pipes (hot water supply and return, and chilled water supply and return).
- Building connections – the interface between the distribution systems and the building heating and cooling systems.

Options for production of hot water and chilled water are addressed in the subsequent sections. In this overview section it is useful to address some key principles in selecting energy sources, including temperature parameters and the selection of resources for meeting “base load” (required most hours of the year) and “peaking load” (required only during the coldest heating days or warmest cooling days).

Baseload and Peaking Load

In designing district heating systems, diagrams such as Figure 1 are important tools. This “load duration curve” chart shows the numbers of annual hours when the total district heating load is at or above a given percentage of the peak load, and is based on detailed climate data.[1] This is a generalized load duration curve assuming a mix of commercial, institutional and residential consumers in the Washington DC climate; the curve for any specific system may be different.

With this information we can make sound decisions about how much of which types of resources we want to deploy for a district energy system. In most locations higher levels of heating (or cooling) load occur for very few hours per year. Consequently, we tend to install the most efficient capacity (which often has a relatively high capital cost) to meet the “base load”, which in this diagram is shown at 50% or less of the peak load. It is notable that this base load (indicated in orange) comprises 86% of the annual energy based on the load duration curve for Washington DC.

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[1] American Society of Heating, Refrigeration and Air-conditioning Engineers, ASHRAE Fundamentals.

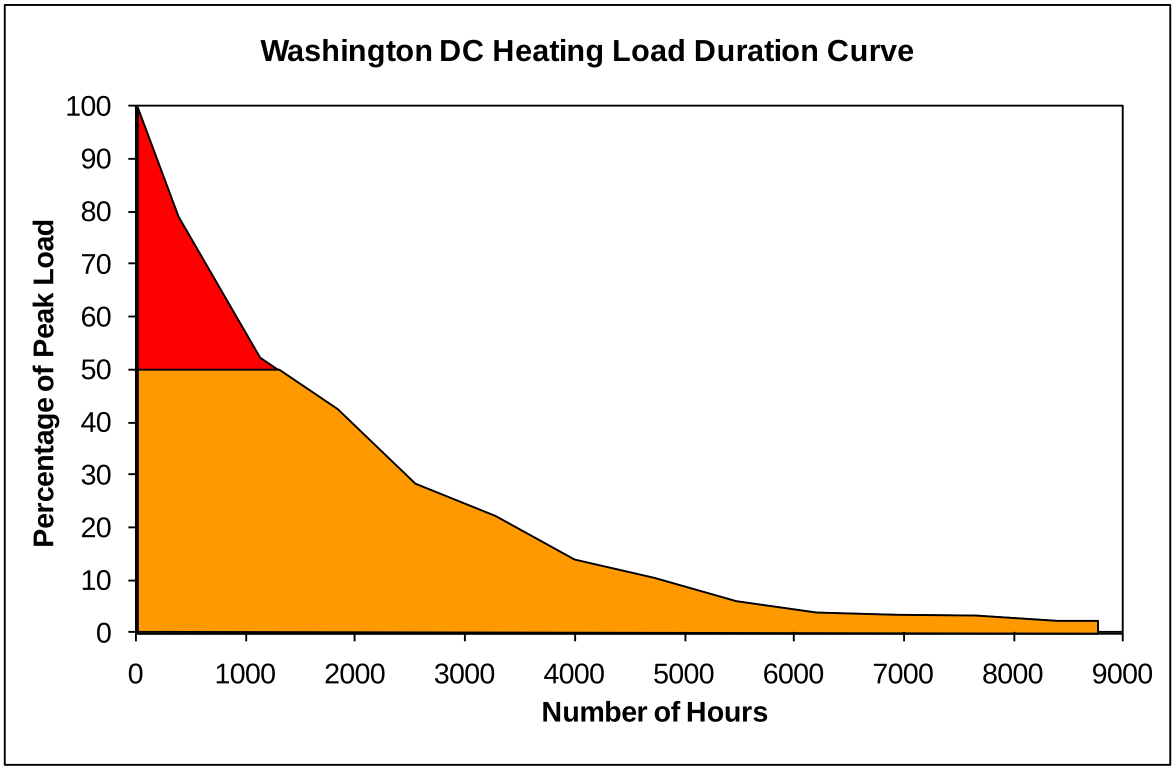

Figure 1. Generalized District Heating Load Duration Curve, Washington DC

Some technologies, such as CHP, become less efficient when operated at loads significantly below their design capacity. Therefore, in the analysis we made the conservative simplifying assumption that if only district heating is being supplied, the district heating requirements during warmer weather (May – September) are met with the same systems used for peaking and back-up (generally boilers fired with natural gas). For example, in Figure 2 the area shown in orange indicates the annual heating energy provided by gas engine CHP (69% of total energy), with the red areas showing when natural gas boilers would be used (31%).

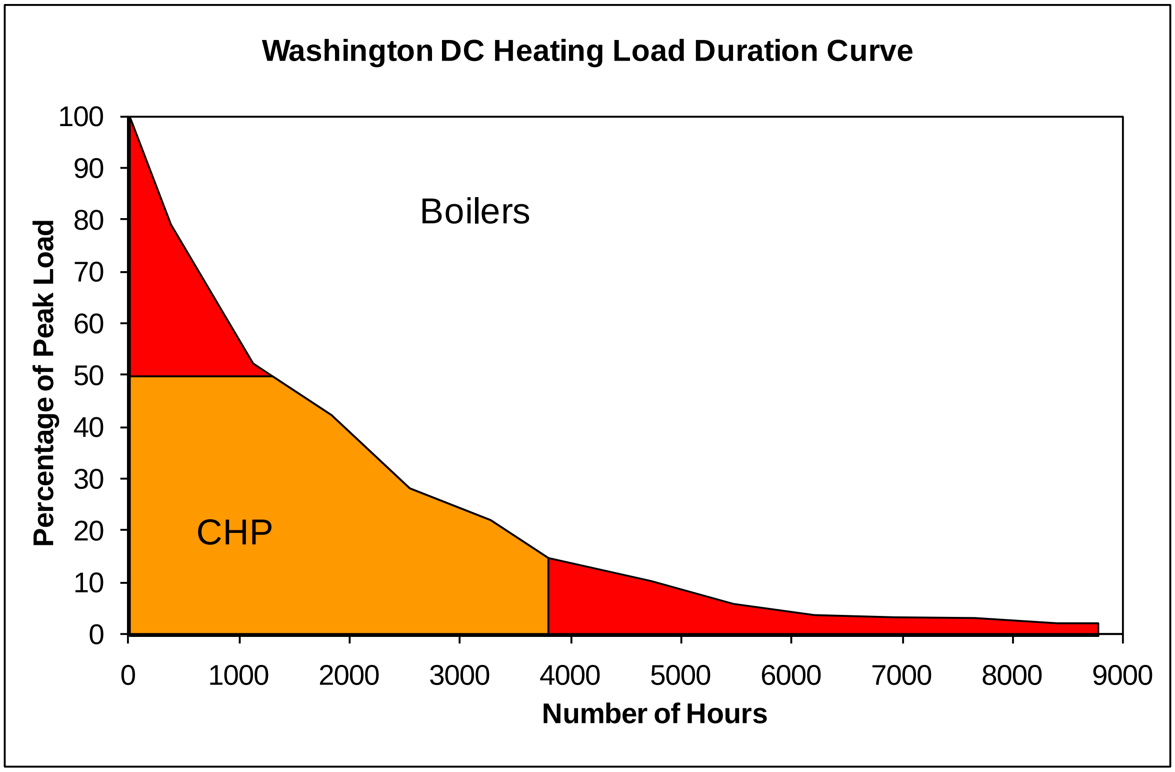

Figure 2. Heating Load Duration Curve for Washington DC Showing Gas Engine CHP and Gas Boiler Operation for Peaking and Low Loads

A similar exercise occurs in selecting resources for district cooling, as illustrated in Figure 3. In this curve, the horizontal line shows the amount of peak cooling load that could be supplied with absorption chillers using waste heat from CHP. Although providing only 16% of the peak cooling capacity, CHP could supply 52% of the annual cooling energy. With summertime use of CHP heat, the CHP facility can be operated year-round.

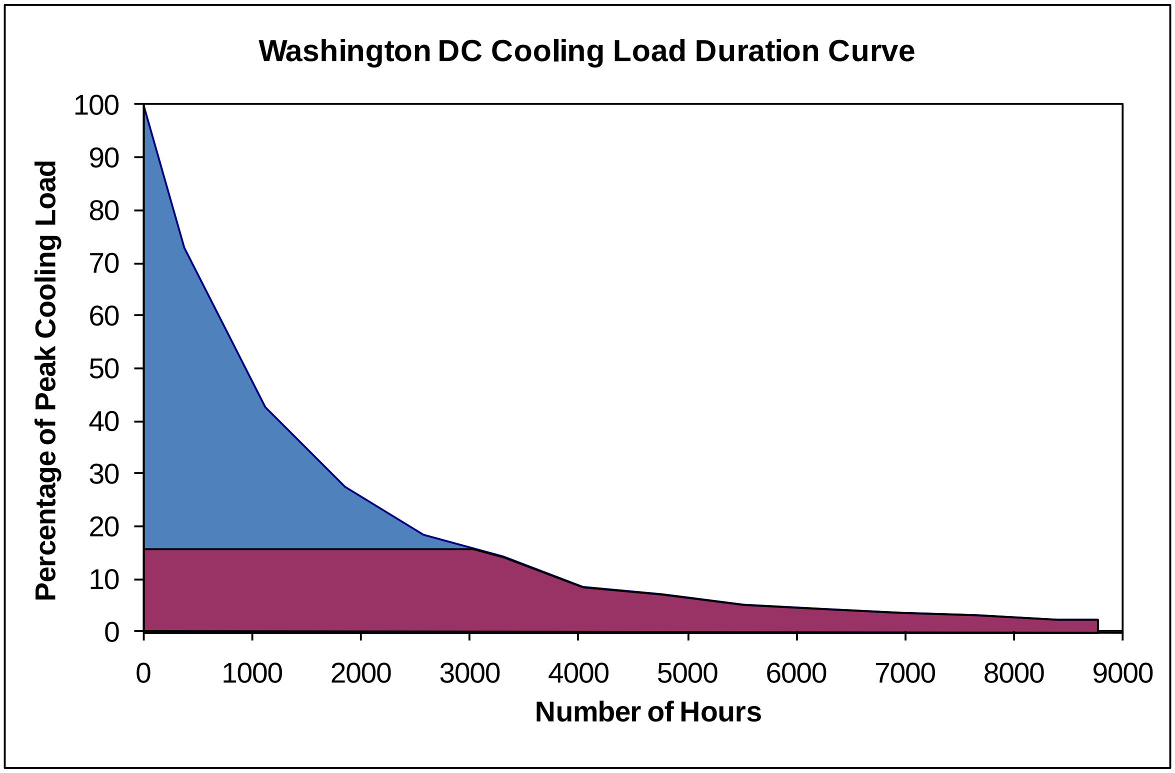

Figure 3. Cooling Load Duration Curve for Washington DC

Temperature Considerations

Selecting the supply and return temperatures for district heating and cooling is a critical design decision. In simple terms, operating district heating systems at higher temperatures can help reduce the size and thus capital cost of distribution pipes. As shown in Figure 4, by dropping the district heating temperatures, it is possible to pick up a range of waste heat sources, such as chiller condenser heat, reciprocating engine jacket water or industrial process energy. Lower temperatures also open up the potential to access renewable resources such as geothermal (there are many more sources of low-temperature geothermal as compared with high-temperature) and cost-effective solar (flat-plate solar collectors are relative inexpensive compared with parabolic trough or other high-temperature solar technologies used for solar power generation).

The highest district heating temperatures and the lowest district cooling temperatures are only required during the coldest and hottest weather, respectively. For most of the year, the district system can be operated at lower hot water or higher chilled water temperatures. In the later analyses in Costs and Benefits chapter of this report, we assume:

- District heating supply/return temperatures of 250/160°F (on the coldest day;
- District cooling supply/return temperatures of 40/58°F on the hottest day;
- Base load heating resources are supplied at supply/return temperatures of 212/160°F;
- Base load cooling resources are supplied at supply/return temperatures of 44/58°F;
- For peak heating conditions, natural gas boilers are used to meet peak temperature and energy requirements.

- For peak cooling conditions, electric centrifugal chillers are used to meet peak temperature and energy requirements.

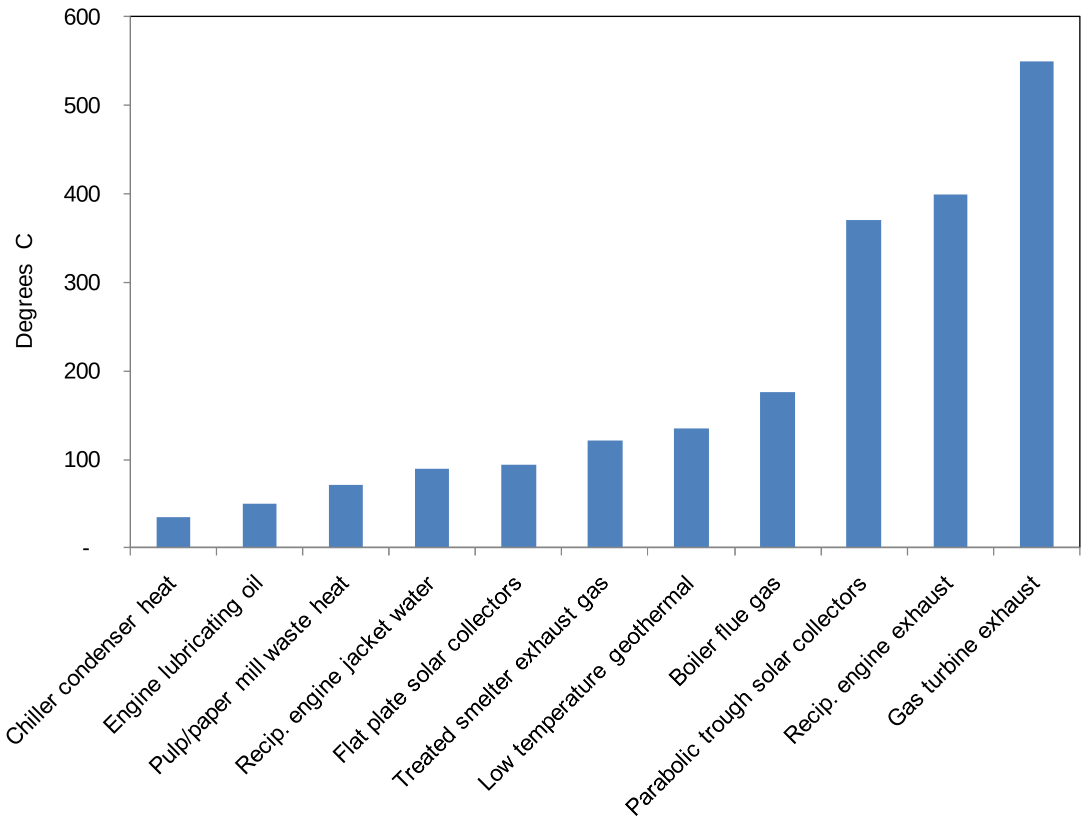

Figure 4. Temperatures of Potential Heat Sources [2]

Distribution Systems

Hot water distribution systems are typically constructed of pre-insulated steel pipe surrounded by polyurethane insulation, with a polyethylene water vapor jacket applied over the insulation, as illustrated in Figure 5. These piping systems are designed for hot water service up to 250°F. The same type of pipe is generally used for district cooling applications also, but with less (or, in some cases, no) insulation. These distribution systems are generally installed with an integrated leak detection system that is built into the pre-fabricated pipe sections.

These piping systems can efficiently transmit heat over long distances. For example, the heat transmission pipe shown in Figure 6 moves industrial waste heat 14 miles to a district heating system in Sweden.

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[2] Spurr, M., Why Energy Policy Will Get You into Hot Water, International District Energy Association, District Energy Magazine, Fourth Quarter 2010.

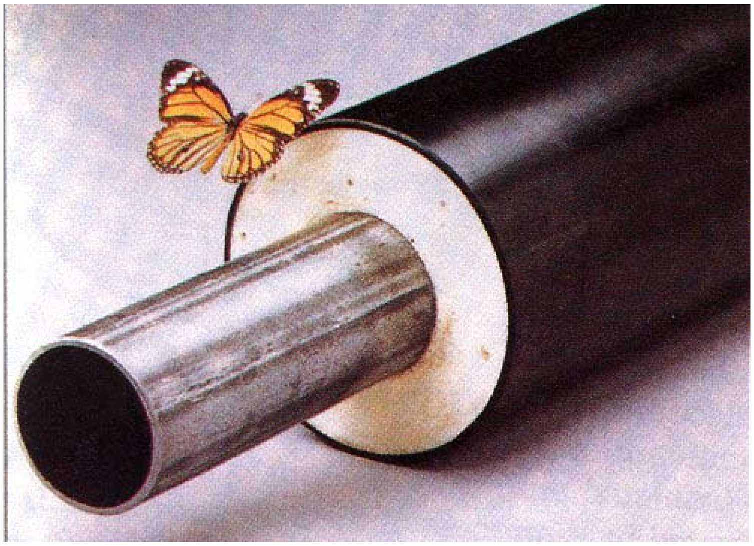

Figure 5. Pre-insulated Steel Pipe Typically Used in District Heating Systems

Figure 6. Long Distance Heat Transmission

Thermal losses and pumping energy in district heating piping systems will vary depending on length and size of pipes, flow, temperatures, soil condition and insulation. A recent study analyzed heat losses and pumping energy for three "intensities" of district heating systems, as summarized in Table 1. [3]In our analysis, we conservatively modelled "typical" and "low density" district heating systems using the data from Table 1 for "medium density" and "low density systems, respectively.

District Heating System Density	**Annual delivered energy (MMBtu/trench foot)**	**Annual distribution loss**
Low density	3.1	12.4%
Medium density	8.5	4.7%
High density	15.6	1.9%

Table 1. District Heating System Distribution System Efficiencies

District cooling thermal losses are lower because there is less differential between the district system temperature and ambient temperatures. On the other hand, district cooling pumping energy is about 4 times higher than district heating per delivered kWh of thermal energy because more water is pumped per delivered unit of thermal energy.

Building Energy Transfer Stations

Energy is transferred from the district energy distribution system to the building heating or cooling system in one of two ways. In direct systems the district supply water is circulated directly through the customer's radiators or air-handling equipment. In indirect systems the distribution system and the building systems are isolated from each other, with heat exchangers used to transfer heat between the two systems. Figure 7 shows a typical heat exchanger, which is a very compact device.

Most district heating systems use indirect connections. In district cooling systems a direct connection is most common, but this can vary depending on the system supply pressures at the building location, the condition of the building equipment and the height of the building.

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[3] VTT Technical Research Centre of Finland, FVB Sverige ab, BRE Building Research Establishment Limited, BB Energiteknik (2011), District heating for energy efficient building areas, International Energy Agency Programme of Research, Development and Demonstration on District Heating and Cooling including the integration of CHP, Annex IX, 8-DHC-11-02.

Figure 7. Heat Exchanger Used to Transfer Thermal Energy to Building System

Combined Heat and Power (CHP)

In electric-only power plants, most of the energy input to the plant ends up as waste heat. In simple cycle gas turbines all of the energy in the exhaust gases is wasted. Power plants using a steam turbine (either steam turbine or gas turbine combined cycle plants) condense the steam exiting from the turbine. This creates a vacuum on the exit end of the steam cycle, thus increasing the torque and power output of the steam turbine. However, most of the energy then ends up in the condenser cooling system (using cooling towers which put the heat into the air, or dissipating the heat in a body of water such as a river). Reciprocating engines lose heat through the exhaust gas, engine cooling jacket, lubricating oil and other systems.

With each of these power generation technologies adapted for CHP, much or all of the waste heat can be recovered for heating or for conversion to cooling using absorption chillers or steam turbine chillers.

Steam turbine power plants are the most common type of plant in the world today. Any type of fuel can be burned in a boiler to make steam, which drives a steam turbine which in turn spins a generator. The capital cost of steam turbine plants are higher than other alternatives, but the ability to burn lower-cost solid fuels (e.g., biomass) can make steam turbine plants cost-effective.

Gas turbines, often called combustion turbines, are basically like jet engines (in fact, many commercial systems are so-called “aero-derivatives,” i.e., they are directly evolved from aircraft engines). Natural gas is combusted, and the hot gases drive a turbine which in turn spins a generator. The exhaust gas coming out of the turbine is very hot (850-1000°F), and can be directed to a heat recovery boiler to generate steam or hot water for thermal purposes or for generation of additional electricity. A "combined cycle" gas turbine system uses the steam generated by the heat recovery boiler to turn a steam turbine-generator. In a combined cycle plant, the heat recoverable for district energy thermal uses is in the steam exhausted from the steam turbine that would otherwise be dissipated in the cooling towers.

In gas engine CHP, a generator is attached to the shaft of an internal combustion engine (like a truck engine). Heat is recovered when the hot exhaust gas is cooled in a heat recovery boiler. Heat can also be recovered from the engine cooling water and oil lubrication system. In addition, heat can be recovered from other devices (turbocharger and intercooler). Both gaseous and liquid fuels can be used in reciprocating engines. In the analysis, we model use of natural gas and biogas.

The efficiency of a given CHP facility depends on many case-specific factors, including equipment characteristics, temperature of recovered thermal energy, ambient temperature conditions and part-load operation. Table 2 summarizes the efficiency assumptions for the analysis for a range of CHP technology types and sizes. These assumptions are representative for the technology, assuming:

- district heating temperature conditions presented earlier in this section;
- ambient temperature conditions of 60°F;
- operation at 30% of capacity or above.

Organic rankine cycle (ORC) is a technology for generating power that is similar to steam turbine except that the working fluid is a volatile organic fluid, such as iso-pentane, rather than steam. The major advantage is that these fluids can be used below a temperature of 750°F, so a variety of waste heat sources can be used. ORC is also frequently used in very small biomass-fired CHP systems.

		Efficiency (Higher Heating Value)		
CHP Technology	**Size (MWe)**	**Power**	**Heat**	**Total**
Gas engine CHP	3	36%	38%	74%
Simple cycle gas turbine	10	29%	47%	76%
Combined cycle gas turbine	20	40%	37%	76%
Steam turbine	30	22%	56%	78%
Organic rankine cycle	1.5	15%	67%	83%

Table 2. Combined Heat and Power Efficiency Assumption [4]

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[4] Energy and Environmental Analysis (2008), CHP Technology Characterization, prepared for the U.S. Environmental Protection Agency, and Spurr, M. and Larsson, I. (1996), Integrating District Cooling with Combined Heat and Power, International Energy Agency Programme of Research, Development and Demonstration on District Heating and Cooling including the integration of CHP, Report 1996:N1, ISBN 90-72130-87-1.

Biomass

Biomass is any organic material, and can include urban waste wood, forest industry mill residues, forest harvesting residues, agricultural residues, and organic portions of municipal solid waste or energy crops. As distinguished from biogas, which is produced through gasification of this material, the term "biomass" refers to direct combustion of these organic materials.

Figure 8 shows the 25 Megawatt electric (MW_e) CHP plant operated by District Energy St. Paul. This facility uses urban waste wood (tree trimmings, unusable pallets, etc.) to provide electricity, hot water and chilled water for downtown St. Paul. Figure 9 shows the harvesting of woody biomass which is otherwise unusable after logging.

Figure 8. Biomass CHP Plant in Downtown St. Paul, Minnesota, USA

Figure 9. Harvesting of Woody Biomass

Increasing interest in biomass is driven by advances in technology, environmental benefits, energy supply and price stability, and the potential for significant spin-off employment in fuel procurement and processing. Using biomass for energy also can eliminate a disposal problem and create income. Residues from wood processors can be diverted from landfills or incineration.

Biomass is generally considered GHG neutral. Biomass emits the GHG carbon dioxide (and sometimes methane, a very powerful GHG) when it decays or is combusted. However, during its growth, living biomass absorbs CO_2 from the atmosphere by photosynthesis, so the net GHG effect of the biomass is neutral. By using biomass, GHG emissions from fossil fuel are eliminated.

Biogas

Biogas is a renewable fuel produced from organic matter such as sewage sludge, organic solid waste, animal manure, crop residue or other organic materials. Biogas is formed through a process known as anaerobic digestion, where bacteria degrade biological material in the absence of oxygen and release methane. Anaerobic digestion is carried out in a number of steps and can use almost any organic material as a substrate.

Biogas may be produced intentionally or as a by-product of other processes (e.g., methane produce in a landfill). In the latter case, the harvesting of biogas is an important role in waste management because methane is a huge contributor in global warming, far greater a larger threat than carbon dioxide. Figure 10 shows a biogas production facility in Linköping, Sweden. In this case, the biogas is used to fuel buses and cars.

Biogas can be consumed as is, or can be upgraded (by removing carbon dioxide, trace contaminants, and any hydrogen sulphide) to “pipeline quality”. If the impurities in biogas are removed, it is considered renewable natural gas or bio-methane and can be distributed to customers via the natural gas grid.

Figure 10. Biogas Production Facility in Linköping, Sweden

Solar Thermal

Relatively low-cost solar technology -- flat-plate collectors – can be used to harvest solar energy for district heating. Figure 11 shows the solar installation in Marstal, Denmark, which provides 30% of total annual district heating requirements. Denmark currently has more than 1.24 million square feet of solar collectors installed in conjunction with district heating systems. In the U.S.A., District Energy St. Paul has begun operation of a 3.4 MMBtu/hour solar thermal system integrated with a hot water district heating system.

Figure 11. Solar Thermal Array for District Heating in Marstal, Denmark

Industrial Waste Heat

There are many sources of surplus heat from industrial processes that is not hot enough for the industrial process but is sufficient for heating buildings. For example, Gothenburg Sweden derives only 4% of the heat for its district heating system from fossil fuels. 30% comes from industrial waste heat from refineries and other industries, 27% is from municipal waste, 19% from CHP, 5% from wastewater heat pumps and 15% from biomass and other renewable sources. (See Figure 12.)

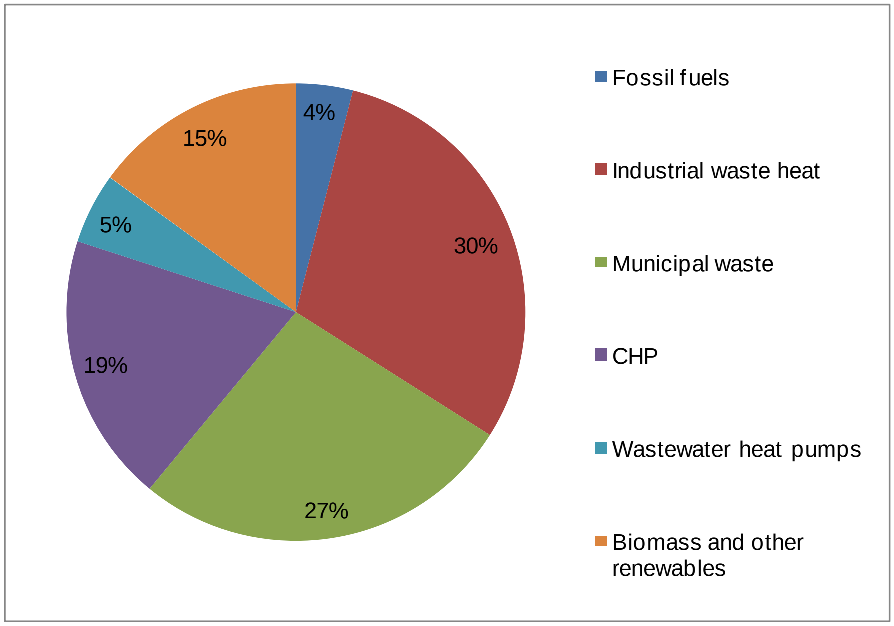

Figure 12. Energy Sources for District Heating in Gothenburg, Sweden[5]

Heat Pumps

Heat Pumps Generally

Heat pumps are devices that move heat from air or water at a lower temperature to air or water at a higher temperature. Heat pumps effectively reverse the natural process of heat flowing from a higher temperature source (air or water) to a lower temperature sink (air or water). Typically, this is accomplished with a mechanical device such as a compressor, usually powered with electricity.

There are a variety of types of heat pumps. When an air-to-air heat pump is used for heating, it is like an air conditioner working in reverse:

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[5] Göteborg Energi (2009), Göteborg Energi's District Energy System", Application for Global District Energy Climate Awards.

- The heat source is outdoor air, with a temperature lower than the desired indoor air; and
- The heat is increased in temperature and released to the indoor air.

Heat pumps can be designed to provide heating only; heating or cooling, as required; or heating and cooling simultaneously.

Heat pumps can use a variety of water sources as the heat sink (cooling) or heat source (heating), for example surface water (sea water or lake water) or sewage effluent. Significant implementation of heat pumps using seawater, lake water or sewage effluent occurred in Sweden in the 1980s with the availability of surplus electricity capacity from nuclear plants. During this period a number of large heat pumps, up to 190 MMBtu/hour, were installed. In the 1990's some of the heat pumps were adapted to simultaneously supply district heating from the heat pump condenser and district cooling from the heat pump evaporator for those times of the year (spring, fall and winter) when both heating and cooling are required.

Ground Source Heat Pump

Heat pump systems can tap the relatively consistent temperature of the ground for heating and cooling. For example, water can be pumped from a well, circulated through the heat pump for heating and injected (after being cooled through the heat pumps) into a second well. The second well can then be used as a source of chilled water for a reversed process, in which the heat pump is used to provide air conditioning. Alternatively, water can be circulated through the ground in vertical boreholes or horizontal trenches to heat or cool it.

The efficiency of heat pumps is measured in Coefficient of Performance, which is the ratio of heat (or cooling) output to electric energy input. Heat pump efficiency depends on many case-specific variables. However, for the assumed low-temperature hot water district heating system on which the Costs and Benefits analysis is based, a representative annual COP value for ground source heat pumps in heating applications is 3.2 and for cooling 4.2.

Gas Boilers

Boilers, usually fuelled with natural gas, are used to provide additional heat during peak demand periods and during low-load periods when the baseload heat resource, such as CHP, may not be able to run as efficiently. In addition, gas boilers provide back-up capacity for times when the baseload production facilities are undergoing maintenance.

Natural gas boilers are often the first step in developing a district heating system. Relatively inexpensive, these boilers may provide all heating requirements in the early stages of system growth. As the load grows, it becomes economically feasible to install more sustainable technologies (which usually have a higher capital cost but lower operating costs), such as CHP, biomass or waste heat recovery.

New gas-fired boilers can achieve efficiencies of 80-85% on a Higher Heating Value (HHV) basis, although lower efficiencies on a seasonal average basis can result if the boiler is operated at widely varying loads. (HHV includes the latent heat of vaporization of water vapor in the combustion gases.) Condensing boilers, which recover the latent heat of vaporization, can achieve efficiencies over 90% under optimum conditions.

Electric Chillers

Electric chillers use a motor to compress refrigerant vapor, which then condenses to a higher pressure and consequently releases heat. This "condenser heat" is then released, generally to the air through a device called a cooling tower. The refrigerant condensate is expanded through a valve to a lower pressure; as it expands it picks up heat from the space being air conditioned, thereby evaporating and returning to its original condition to begin the cycle anew.

New district energy plant electric centrifugal chiller systems operated at a good load factor have a total annual system COP of 4.4, including power to drive the compressor as well as auxiliaries such as cooling tower, condenser pump and chiller pump. In a district cooling system it is typically easier to operate chillers at optimal load factors to achieve high efficiencies.

Absorption Chillers

The absorption cycle uses heat to generate cooling, using two media: a refrigerant and an absorbent. Water/lithium bromide and ammonia/water are the most common refrigerant/absorbent media pairs, but other pairs can be used. In the absorption cycle, the refrigerant "flashes" from a liquid to a vapor in a device called an evaporator because the pressure in the evaporator is very low. In the process of evaporating, the refrigerant absorbs heat from the district cooling water. The vaporized refrigerant has a chemical affinity for the absorbent, so it is drawn to be absorbed by the absorbent and in the process becoming a liquid again, intermixed with the absorbent. Heat is an essential part of this process, because it boils the refrigerant/absorbent mix and separates these two fluids to begin the process again.

A typical absorption chiller system has a heat COP of 0.60 (1.0 kW of heat input to each 0.60 kW of cooling output) and an electrical COP of 14.1 (1.0 kW of power to run auxiliaries per 14.1 kW of cooling produced).

Deep Water Cooling

Deep water cooling is a technology that uses cold water drawn from deep sources such as lakes, seas, or underground aquifers to provide cooling to buildings. There are a number of district cooling systems utilizing deep water cooling throughout the world, particularly in Sweden. There are at least 7 deep water cooling systems in Sweden. Examples include:

- Stockholm, where the Baltic Sea is used in combination with heat pumps to supply over 85,000 tons of cooling for downtown Stockholm.
- Södertälje, with a 17,000 ton district cooling system at Lake Mälaren supplying a pharmaceutical plant and other commercial customers. Figure 13 shows the installation of polyethylene pipe in Lake Mälaren.
- Sollentuna, a 1,100 ton district cooling system that includes aquifer storage. During the winter, cold sea water from a bay of the Baltic Sea is stored in the aquifer to reduce the warmer temperature of the sea water during summer. (See Figure 14.)

In North America, deep water cooling technology is used to air-condition the Cornell University campus and downtown Toronto. A similar system is being developed for Honolulu. The Toronto deep water cooling system will use a fresh water source, and is designed to use part or all of the water drawn from the water source as potable water after the cooling energy has been extracted from it. Generally, however, deep water cooling systems return all of the water back to the source after cooling energy is extracted. Water is returned to the water source at shallow depths where the water is warmer to lessen or eliminate the impact of warm water rejection on the local ecosystem.

Typically, a separate, closed chilled water distribution loop, which is isolated from the open deep water source loop, carries chilled water to buildings for cooling use. Often, the temperature of the chilled water supply in this closed loop is reduced further with electric chillers at times of peak cooling use.

The efficiency of a given deep water cooling system depends on case-specific factors. Based on experience from the Stockholm, Toronto and Cornell systems, a representative COP for such systems is 24, i.e. for every 1 kW of electricity used, 24 kW of cooling is produced.

Figure 13. Installation of Polyethylene Pipe for Deep Water Cooling from Lake Mälaren, Sweden

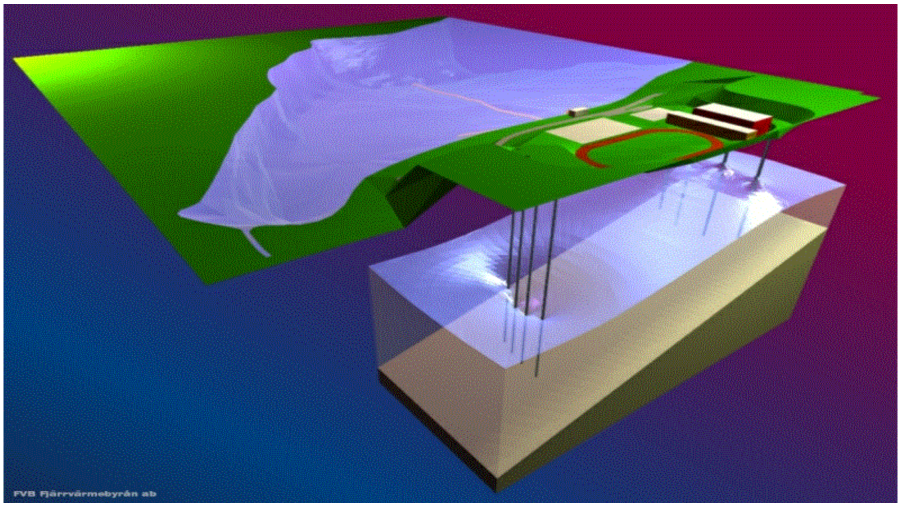

Figure 14. Illustration of the Aquifer Storage System Used for Seasonal Storage of Cooling Energy in Sollentuna, Sweden

Thermal Storage

Thermal storage can be an important strategy for reducing peak power demand, and optimizing the integration of CHP or waste heat recovery with district heating or district cooling. Hot water storage is commonly used in European district heating systems, facilitating a maximum production of hot water from renewable or waste heat sources when those sources are available, then using this stored energy when required, thereby maximizing use of sustainable energy sources. Figure 15 shows a hot water thermal storage tank, usually called an accumulator.

Figure 15. Hot Water Accumulator

In the U.S., thermal storage is generally limited to cooling systems based on energy price factors. Thermal storage systems are designed to be recharged on a cyclical basis (usually daily) and fulfill one or more of the following purposes:

- **Increase system capacity**. Demand for heating, cooling, or power is seldom constant over time, and the excess generation available during low demand periods can be used to charge the energy storage system in order to increase capacity during high demand periods. For example, cooling storage allows a district cooling system to install less chiller capacity and to use the installed capacity at a higher load factor.

- **Enable dispatch of CHP plants**. CHP plants are generally operated to meet the demands of the connected thermal load, which often results in excess electric generation during periods of low electric use. By incorporating thermal energy storage, the plant need not be operated continuously and can be dispatched within some limits.

- **Shift energy purchases to low demand/low cost periods**. Cooling storage allows a district cooling system to shift electricity demand from costly daytime on-peak periods to lower-cost nighttime periods.

- **Increase system reliability**. Thermal storage increases the flexibility and reliability of district cooling by ensuring that there is a readily available source of cooling which can be supplied to users with only a minimal requirement for pumping energy.

Cool storage can be provided through storage of chilled water, ice or ice slurry. Chilled water is the most common form of cool storage, using concrete or steel tanks to store chilled water generated with any type of conventional chiller. Chilled water is typically stored between 40°F to 44°F in one large or several tanks located above ground or below ground.

Where space is available for chilled water storage, the economies of scale for this technology can provide significant economic advantages over ice storage. Under normal conditions a chilled water storage tank is always filled with water. During discharge, cold water is pumped from the bottom of the tank and warm return water is supplied in the top. Due to the different densities for water at different temperatures a stable stratification can be obtained.

Ice generation and storage is a well-developed technology, and allows storage in a more compact space -- often a key issue in urban environments. The volume required for ice storage is 15 to 25 percent of the space required by chilled water storage for the same energy storage capacity. Ice storage also provides an opportunity to reduce the temperature of cooling distribution and therefore reduce distribution system and building system capital costs. These advantages must be weighed against higher capital and operating costs for ice-making equipment compared to water chillers. The average capital costs of ice storage are about twice those of chilled water storage, and the energy requirements are higher by about one third.[6]

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[6] ASHRAE Transactions 1995, V. 101, Pt. 2, "ASHRAE RP-766: Study of Operational Experience with Thermal Energy Storage Systems," as noted in "Energy and Economic Implications of Combining District Cooling and Thermal

Microgrids

Microgrids are small-scale electricity distribution networks that link distributed power generation facilities to one or more users located in close proximity. New technologies are making it possible to create microgrids that effectively operate either independently ("islanded") or in conjunction with a broader power grid ("macrogrid"). Islanding would typically occur if a disruptive event arises in the macrogrid, such as short circuits, voltage fluctuations or service interruptions. This provides microgrid customers with levels of power quality and reliability that are usually better than with the local utility.

There are a range of potential economic benefits of microgrids. In addition to the potential energy savings from CHP or other distributed generation, costs related to purchase of electricity transmission and distribution (T&D) services may be reduced. Further, with power generation close to the loads, T&D losses can be reduced. Microgrids have the potential to capture economic value by participating in power demand response markets, and by offering enhanced power quality and reliability. Further, they may enable the local power utility to defer T&D capacity investments.

A recent study[7] found that most microgrids are 10 MW or less, although some are as big as 40 MW.

There are a variety of ownership and operational models for implementing microgrids. Companies such as Pareto Energy design, own and operate microgrids systems which include power generation facilities as well as electrical distribution infrastructure. The reported capital cost of its microgrid systems is approximately $3 million per MW.[8] Pareto is now developing a microgrid for Howard University, easing pressure on the stressed Pepco substation serving the University.

An alternative approach is planned by San Diego Gas and Electric Company (SDGEC) in a "Beach Cities" demonstration project in Borrego Springs, CA. In this project, the microgrid system will be "unbundled," i.e. the distribution system will be owned by SDGEC but the generation facilities will be owned by customers or a third party.

Some universities, such as Cornell, operate their own microgrids, i.e. they own and operate the campus electrical distribution system, which is fed by both on-campus generation as well as utility power.

Storage," Andrepont, Kooy and Winters, 10th Annual Cooling Conference, International District Energy Association, October 1995.

[7] "Microgrids: An Assessment of the Value, Opportunities and Barriers to Deployment in New York State," Center for Energy, Marine Transportation and Public Policy at Columbia University, for the New York State Energy Research and Development Authority, Sept. 2010.

[8] "Power Play," Washington Business Journal, Sept. 24-30, 2010.

Costs and Benefits

Introduction

This chapter presents a generalized overview of the costs and benefit of the clean energy options, including: capital costs, operating costs and total costs; power-related benefits; energy efficiency benefits; and environment benefits. It cannot be overstressed that the generalized characterization of technologies (including efficiencies and costs) in this report should not be applied to specific cases without a case-specific evaluation of loads, densities, fuel and electricity costs and other case-specific circumstances.

Among the many variables, the costs of fuel and electricity are key cost/benefit drivers. Further, theses costs, particularly electricity, can vary significantly within the COG region and from customer to customer. Therefore, in the economic analysis we have run sensitivities with this variable.

Parameters for Generalized System

Loads

In the prior chapter the concept of heating and cooling load duration curves was presented, with illustration of such curves for a generalized district energy system in the Washington DC climate. This generalized system is assumed to serve a mixed use development composed of the mix of building space shown in Table 3.

Energy load characteristics for the generalized customer base are shown in Table 4. Note that the peak demands account for load diversity, i.e., the fact that not all customers have a peak demand at the same time.

Office	4.5
Residential	3.0
Retail	1.5
Hotel	1.0
Total	10.0

Table 3. Assumed District Energy System Customer Base by Building Type (million square feet)

Heating

Peak heating demand (MMBtu/hr)	139
Annual heating energy (MMBtu)	275,205

Cooling

Peak cooling demand (tons)	13,802
Annual cooling energy (ton-hrs)	27,613,103

Electricity (excluding thermal production)

Peak power demand (MW)	26
Annual electrical energy (MWh)	140,580

Table 4. Assumed Peak Demand and Annual Energy Consumption for Heating, Cooling and Electricity (Excluding Electricity for Thermal Energy Production)

Distribution Systems

The district energy system is assumed to have a heating load density of 11.5 MMBtu of annual delivered heat per trench foot of distribution. This is in-between the "medium" and "high" density in Table 1. For this hypothetical system there would be 24,000 trench feet of distribution. The distribution system would consist of four pipes: heating supply, heating return, cooling supply and cooling return. The largest heating pipe (coming out of the plant) would probably be 16 inches in diameter, with the largest cooling pipe probably 30 inches.

The piping is assumed to be pre-insulated steel pipe as described above under "Distribution Systems".

Building Interface

Buildings are assumed to interface with the district heating system indirectly, using a heat exchanger as described above under "Building Energy Transfer Stations". We assume that 35% of the cooling system connections are indirect and 65% are direct (no heat exchanger).

Operating Costs

Key operating cost assumptions for the district energy system are summarized in Table 5. As noted above, electricity costs can vary significantly within the COG region depending on the local utility's tariffs and a particular customer's load pattern. It is assumed that the district energy system achieves electricity cost savings with the incorporation of thermal energy storage, which reduces peak power demand and peak power costs. Natural gas costs can vary significantly based on broad market forces, as illustrated in Figure 16, which shows average U.S. natural gas prices for the commercial and industrial sectors. Further, natural gas prices can vary depending on the particular tariff or purchase contract under which the gas is procured.

Costs		District Energy System Base Case	District Energy System High Elec.
Natural gas	/MMBtu	$ 6.00	
Biomass	/MMBtu	$ 4.00	
Electricity	/kWh	$ 0.050	$ 0.100
Water	/1000 gal.	$ 3.68	
Sewer	/1000 gal.	$ 8.51	
Water treatment chemicals	/1000 gal.	$ 0.85	

Revenues			
Sale of excess power	/kWh	$ 0.025	$ 0.040

Table 5. District Energy System Operating Cost and Non-Thermal Revenue Assumptions

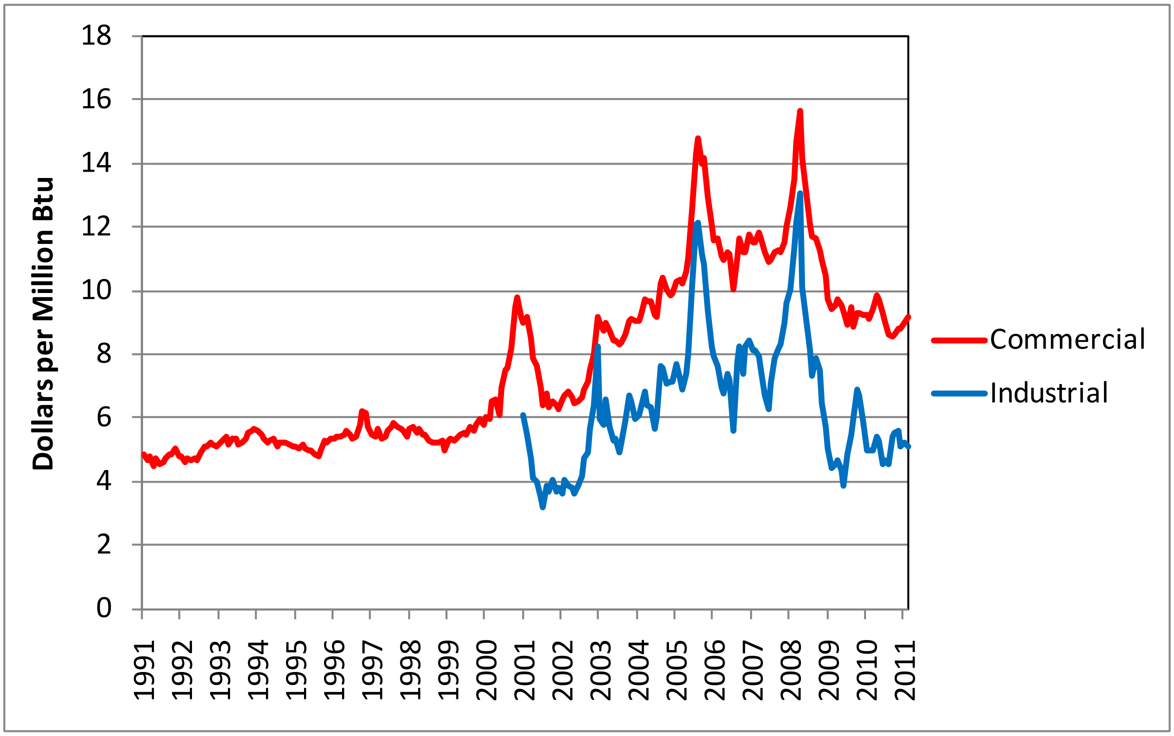

Figure 16. Average U.S. Natural Gas Prices for Commercial Customers (1991-2011) and Industrial Customers (2001-2011)[9]

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[9] *U.S. Energy Information Administration, Annual Energy Outlook 2011*

Costs of Community Energy Technology Options

Community Energy Technology Scenarios

Technology types and capacities for 8 community energy technology scenarios are summarized in Table 6. Baseload heating capacity is sized to provide 50% of the peak heating load. Absorption chiller capacity is sized to use the heat output of CHP or the biomass boiler. The thermal energy storage tank is used primarily for chilled water storage, but during winter it is switched to hot water storage. Sufficient redundant capacity is assumed in order to provide "n+1" capacity, i.e., peak demand can be met even if the largest unit is out of service.

Capital Costs

Generalized capital costs are summarized in Table 7. These estimates include all costs, such as land acquisition, plant building, civil costs, all mechanical and electrical equipment, all distribution systems including service lines, and all costs for the Energy Transfer Stations (ETS) connecting the district systems to the building HVAC systems. In this simplified economic analysis, we assume that all capital costs are incurred in one step.

Annual Costs

The operations of each system are summarized in Table 8, Table 9 and Table 10.

- Table 8 summarizes annual operations for the heating system, including heat produced from each component of the plant, energy conversion efficiencies, input fuels and electricity, and (for CHP) electricity produced. CHP fuel input and electricity output is attributed pro-rata to heating operations based on the share of CHP heat output that is used for heating.
- Table 9 summarizes annual operations for the cooling system, including cooling energy produced from each component of the plant, energy conversion efficiencies, input fuels and electricity, and (for CHP) electricity produced. CHP fuel input and electricity output is attributed pro-rata to cooling operations based on the share of CHP heat output that is converted to cooling energy via absorption chillers.
- Table 10 summarizes peak power demand conditions as well as tallying total annual fuel and electricity consumption.

Table 11 summarizes two sets of assumptions for capital amortization. The "market" scenario reflects a fully private sector approach. The "low cost" scenario assumes that low-cost debt can be obtained and that equity investors accept a relatively low rate of return on equity based on very tight customer contracts and/or other means of high assurance that revenues will be realized.

Table 12 summarizes operation and maintenance cost assumptions, including labor, maintenance and supplies.

Table 13 shows annual costs including base case gas and electricity costs and "market" amortization of capital. Note that this simplified economic analysis does not account for ramp-up of capacity and loads; in effect, the analysis is based on the assumption that the full system in constructed in one step and that service to the full customer base occurs in the first year of operation. Excess CHP electricity not required for district energy systems operations is assumed to be sold to the grid for $0.035 per kWh under base case assumptions and $0.070 per kWh for the High energy price assumption.

	1	2	3	4	5	6	7	8
	Boilers & Chillers	**Engine CHP**	**Turbine CHP**	**Combined Cycle CHP**	**Biomass Boiler**	**Ground source heat pumps**	**Waste heat recovery**	**Solar**
District Heating								
Natural gas boilers								
Capacity/unit (MMBtu/hr)	30	30	24	22	22	22	22	22
# of units	6	3	4	6	6	6	6	6
Capacity (MMBtu/hr)	180	90	96	132	132	132	132	132
CHP								
Type		Engine	Turbine	Com. Cycle				
Fuel		Nat. Gas	Nat. Gas	Nat. Gas				
Power capacity/unit (MW)	0	7.5	6.7	23.5		0	0	0
Power to heat ratio	1.00	1.04	0.62	1.09		1.00	1.00	1.00
Thermal capacity/unit (MMBtu/hr)	-	24.61	36.88	73.58		-	-	-
# of units	0	3	2	1		0	0	0
Power capacity (MW)	0.0	22.5	13.4	23.5		0.0	0.0	0.0
Thermal capacity (MMBtu/hr)	-	74	74	74		-	-	-
Other thermal capacity (MMBtu/hr)								
Biomass boiler					72			
Ground source heat pumps	0	0	0	0	0	72	0	0
Industrial waste heat recovery	0	0	0	0	0	0	72	0
Solar	0	0	0	0	0	0	0	72
Hot water storage	-	14	14	14	14	14	14	14
Total thermal capacity (MMBtu/hr)								
All units	180	178	184	220	219	219	219	219
Minus largest unit	150	154	147	146	146	146	146	146
District Cooling								
Electric centrifugal chillers								
Capacity/unit (tons)	1,775	1,775	1,775	1,775	1,775	1,775	1,775	1,775
# of units	8	6	6	6	6	6	8	8
Capacity (tons)	14,198	10,648	10,648	10,648	10,648	10,648	14,198	14,198
Absorption chillers								
Capacity/unit (tons)	-	1,846	1,844	1,840	1,840	-	-	-
# of units	-	2	2	2	2	-	-	-
Capacity (tons)	-	3,692	3,688	3,679	3,679	-	-	-
Thermal energy storage								
Capacity (tons)	1,775	1,775	1,775	1,775	1,775	1,775	1,775	1,775
Ground source heat pumps								
capacity (tons)	-	-	-	-	-	4,643	-	-
Total capacity (tons)								
All units	15,972	16,115	16,111	16,102	16,102	17,066	15,972	15,972
Minus largest unit	14,198	14,340	14,336	14,327	14,327	15,291	14,198	14,198
Power generation								
Total capacity (MW)								
All units	-	23	13	24	-	-	-	-
Minus largest unit	-	15	7	-	-	-	-	-

Table 6. District Energy Technology Scenarios

	1	2	3	4	5	6	7	8
	Boilers & Chillers	**Engine CHP**	**Turbine CHP**	**Combined Cycle CHP**	**Biomass Boiler**	**Ground source heat pumps**	**Waste heat recovery**	**Solar**
Capital Costs (million $)								
PLANT								
Land purchase	$ 4.4	$ 9.2	$ 7.1	$ 9.3	$ 8.1	$ 7.0	$ 6.0	$ 6.0
Heating Plant								
Natural gas boilers	$ 9.0	$ 4.5	$ 4.8	$ 6.6	$ 6.6	$ 6.6	$ 6.6	$ 6.6
Biomass boilers	$ -	$ -	$ -	$ -	$ 25.3	$ -	$ -	$ -
Industrial waste heat recovery	$ -	$ -	$ -	$ -	$ -	$ -	$ 6.5	$ -
Solar	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ 43.5
Cooling Plant								
Electric centrifugal chillers	$ 29.8	$ 22.4	$ 22.4	$ 22.4	$ 22.4	$ 22.4	$ 29.8	$ 29.8
Absorption chillers	$ -	$ 8.9	$ 8.9	$ 8.8	$ 8.8	$ -	$ -	$ -
CHP Plant	$ -	$ 29.3	$ 22.8	$ 29.4	$ -	$ -	$ -	$ -
Thermal energy storage	$ 1.4	$ 1.4	$ 1.4	$ 1.4	$ 1.4	$ 1.4	$ 1.4	$ 1.4
Ground source heat pumps	$ -	$ -	$ -	$ -	$ -	$ 30.2	$ -	$ -
Total plant	$ 44.7	$ 75.6	$ 67.3	$ 77.9	$ 72.6	$ 67.5	$ 50.3	$ 87.3
DISTRIBUTION								
Heating	$ 6.7	$ 6.7	$ 6.7	$ 6.7	$ 6.7	$ 6.7	$ 6.7	$ 6.7
Cooling	$ 10.5	$ 10.5	$ 10.5	$ 10.5	$ 10.5	$ 10.5	$ 10.5	$ 10.5
Total distribution	$ 17.2	$ 17.2	$ 17.2	$ 17.2	$ 17.2	$ 17.2	$ 17.2	$ 17.2
ENERGY TRANSFER STATIONS (ETS)								
Heating energy transfer stations	$ 1.9	$ 1.9	$ 1.9	$ 1.9	$ 1.9	$ 1.9	$ 1.9	$ 1.9
Cooling energy transfer stations	$ 3.7	$ 3.7	$ 3.7	$ 3.7	$ 3.7	$ 3.7	$ 3.7	$ 3.7
Total ETS	$ 5.7	$ 5.7	$ 5.7	$ 5.7	$ 5.7	$ 5.7	$ 5.7	$ 5.7
TOTAL	$ 67.6	$ 98.4	$ 90.2	$ 100.8	$ 95.5	$ 90.4	$ 73.2	$ 110.1
Capital Costs by Thermal Service (million $)								
Heating	$ 19.6	$ 38.9	$ 33.5	$ 41.2	$ 18.7	$ 37.8	$ 24.3	$ 61.3
Cooling	$ 47.9	$ 59.5	$ 56.6	$ 59.6	$ 76.9	$ 52.6	$ 48.9	$ 48.9
Total	$ 67.6	$ 98.4	$ 90.2	$ 100.8	$ 95.5	$ 90.4	$ 73.2	$ 110.1

Table 7. Generalized District Energy System Capital Costs

			1	2	3	4	5	6	7	8
DISTRICT ENERGY SYSTEM			**Boilers & Chillers**	**Engine CHP**	**Turbine CHP**	**Combined Cycle CHP**	**Biomass Boiler**	**Ground source heat pumps**	**Waste heat recovery**	**Solar**
BASELOAD HEATING SOURCES										
% of annual heating energy supplied by baseload resource			100%	86%	86%	86%	86%	73%	57%	26%
% of annual cooling energy supplied by baseload resource			100%	52%	52%	52%	52%	74%	100%	100%
Baseload Boilers										
Annual energy	Produced annual heating energy	MMBtu	288,868							
Fuel input	Boiler efficiency		85%							
	Annual natural gas fuel consumption	MMBtu	339,845							
CHP										
Annual energy	Produced heating energy from CHP for heating	MMBtu		247,759	247,759	247,759				
	Produced heating energy from CHP used for cooling	MMBtu		256,056	256,056	256,056				
	Produced cooling energy from CHP	ton-hrs		12,802,788	12,802,788	12,802,788				
Annual energy	Equivalent Full Load Hours (EFLH)	hours		6,823	6,830	6,847				
	Electricity output	MWH		153,521	91,522	160,902				
Fuel input	Power generation heat rate	Btu/kWhe		9,111	11,778	8,556				
	Annual fuel consumption	MMBtu		1,398,747	1,077,928	1,376,605				
Biomass Boiler										
Annual energy	Produced heat for heating	MMBtu					247,759			
	Produced heat for cooling	MMBtu					256,056			
Fuel input	Boiler efficiency						65%			
	Annual natural biomass fuel consumption	MMBtu					775,100			
Heat Pumps										
Annual energy	Produced annual heating energy	MMBtu						210,595		
	Delivered annual heating energy	MMBtu						200,634		
COPs	Heating COP							3.2		
Energy input	Annual electricity consumed	MWhe						19,282		
Baseload Heat Exchangers or Solar Energy										
Annual energy	Produced annual heating energy	MMBtu							165,166	73,955
	Waste heat transmission pumping energy	MWH							826	
PEAKING HEAT SOURCES										
Annual produced heating energy supplied by peaking resources		MMBtu		41,109	41,109	41,109	41,109	78,273	123,702	214,913
Peaking boiler efficiency				82%	82%	82%	82%	82%	82%	82%
Annual fuel consumption		MMBtu		50,133	50,133	50,133	50,133	95,455	150,856	262,089

Table 8. District Energy Systems Annual Operations -- Heating

			1	**2**	**3**	**4**	**5**	**6**	**7**	**8**
			Boilers & Chillers	**Engine CHP**	**Turbine CHP**	**Combined Cycle CHP**	**Biomass Boiler**	**Ground source heat pumps**	**Waste heat recovery**	**Solar**
BASELOAD COOLING SOURCES										
Electric Centrifugal Chillers										
Annual energy	Produced annual cooling energy (inc. to TES)	ton-hrs	28,838,750						28,838,750	28,838,750
	Delivered annual cooling energy (inc. to TES)	ton-hrs	27,613,103						27,613,103	27,613,103
COP	Electricity COP		4.40						4.40	4.40
Energy input	Annual electricity consumed	MWH	22,065						22,065	22,065
Absorption Chiller Systems										
Annual energy	Produced annual cooling energy	ton-hrs		12,802,788	12,802,788	12,802,788	12,802,788			
	Delivered annual cooling energy	ton-hrs		12,258,669	12,258,669	12,258,669	12,258,669			
COPs	Thermal COP			0.60	0.60	0.60	0.60			
	Electricity COP			14.10	14.10	14.10	14.10			
Energy input	Annual heat consumed for driving energy	MMBtu		256,056	256,056	256,056	256,056			
	Annual electricity consumed	MWH		3,192	3,192	3,192	3,192			
Heat Pump Cooling										
Annual energy	Produced annual cooling energy	ton-hrs						21,423,656		
	Delivered annual cooling energy	ton-hrs						20,513,151		
COP	Electricity COP							4.2		
Energy input	Annual electricity consumed	MWH						17,934		
Total Baseload Cooling Energy Produced		ton-hrs	28,838,750	12,802,788	12,802,788	12,802,788	12,802,788	21,423,656	28,838,750	28,838,750
PEAKING COOLING SOURCES										
Annual produced cooling energy supplied by peaking resources		ton-hrs		16,035,963	16,035,963	16,035,963	16,035,963	7,415,094	-	-
Electricity COP				4.0	4.0	4.0	4.0	4.0		
Annual electricity consumed		MWH		14,095	14,095	14,095	14,095	6,518		

Table 9. District Energy System Annual Operations -- Cooling

		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**
		Boilers & Chillers	**Engine CHP**	**Turbine CHP**	**Combined Cycle CHP**	**Biomass Boiler**	**Ground source heat pumps**	**Waste heat recovery**	**Solar**
SUMMER PEAK OPERATIONS									
Cooling production (tons)									
Electric centrifugal chillers		12,423	8,731	8,735	8,744	8,744	7,780	12,423	12,423
Absorption chillers			3,692	3,688	3,679	3,679			
Heat pumps							4,643		
Thermal storage		1,775	1,775	1,775	1,775	1,775	1,775	1,775	1,775
Total		14,198	14,198	14,198	14,198	14,198	14,198	14,198	14,198
Net summer peak power demand (MW)									
Electric centrifugal chiller systems		7.1	5.0	5.0	5.0	5.0	4.5	7.1	7.1
Absorption chiller systems		-	0.9	0.9	0.9	0.9			
Heat pump systems							3.9		
Distribution pumping and plant house		0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8
CHP		-	(22.5)	(13.4)	(23.5)	-	-	-	-
Total		8.0	(15.7)	(6.6)	(16.7)	6.8	9.2	8.0	8.0
ANNUAL DISTRIBUTION PUMPING ENERGY									
Heating distribution	MWH	664	664	664	664	664	664	664	664
Cooling distribution	MWH	2,163	2,163	2,163	2,163	2,163	2,163	2,163	2,163
Total	MWH	2,827	2,827	2,827	2,827	2,827	2,827	2,827	2,827
TOTAL FUEL AND ELECTRICITY CONSUMPTION									
Natural gas fuel consumption (MMBtu)	MMBtu	339,845	1,448,881	1,128,061	1,426,738	50,133	95,455	150,856	262,089
Biomass fuel consumption (MMBtu)						775,100			
Heating electricity consumption	MWH	664	664	664	664	664	19,947	1,490	664
Cooling electricity consumption	MWH	24,228	19,451	19,451	19,451	19,451	26,615	24,228	24,228
Electricity production and consumption									
Consumption	MWH	24,892	20,115	20,115	20,115	20,115	46,562	24,892	24,892
Production	MWhe	-	153,521	91,522	160,902	-	-	-	-
Net Consumption	MWhe	24,892	(133,406)	(71,407)	(140,787)	20,115	46,562	24,892	24,892

Table 10. District Energy Systems Annual Operations -- Peak Power Demand and Annual Fuel and Electricity Consumption

	Market	Low Cost
Debt/equity ratio	0.60	0.70
Debt interest rate	7.0%	4.0%
Equity hurdle rate	15.0%	12.0%
Weighted average cost of capital	10.2%	6.4%
Term	20	20
Capital recovery factor	0.1191	0.0900

Table 11. Capital Amortization Assumptions

	1	2	3	4	5	6	7	8
	Boilers & Chillers	**Engine CHP**	**Turbine CHP**	**Combined Cycle CHP**	**Biomass Boiler**	**Ground source heat pumps**	**Waste heat recovery**	**Solar**
Labor (FTE)	7.0	8.0	8.0	10.0	14.0	8.0	7.0	7.0
Labor rate ($/FTE)	$ 90,000	$ 90,000	$ 90,000	$ 90,000	$ 90,000	$ 90,000	$ 90,000	$ 90,000
CHP maintenance costs ($/MWHe)	$ -	$ 11.00	$ 10.00	$ 8.00	$ -	$ -	$ -	$ -
Boiler maintenance costs (% of capital)	2.0%	2.0%	2.0%	2.0%	2.0%	2.0%	2.0%	2.0%
Waste heat recovery maintenance costs (% of capital)	1.5%	1.5%	1.5%	1.5%	1.5%	1.5%	1.5%	1.5%
Solar maintenance costs (% of capital)	0.5%	0.5%	0.5%	0.5%	0.5%	0.5%	0.5%	0.5%
Electric chiller maintanance costs ($/ton/yr)	$ 25.00	$ 25.00	$ 25.00	$ 25.00	$ 25.00	$ 25.00	$ 25.00	$ 25.00
Absorption chiller maintanance costs ($/ton/yr)	$ 25.00	$ 25.00	$ 25.00	$ 25.00	$ 25.00	$ 25.00	$ 25.00	$ 25.00
Thermal storage maintenance costs (% of capital)	1.25%	1.25%	1.25%	1.25%	1.25%	1.25%	1.25%	1.25%
Ground source heat pump ($/ton/yr)	$ 25.00	$ 25.00	$ 25.00	$ 25.00	$ 25.00	$ 25.00	$ 25.00	$ 25.00
Water/sewer ($/gal.)	$ 12.19	$ 12.19	$ 12.19	$ 12.19	$ 12.19	$ 12.19	$ 12.19	$ 12.19
Water treatment chemicals ($/gal.)	$ 0.85	$ 0.85	$ 0.85	$ 0.85	$ 0.85	$ 0.85	$ 0.85	$ 0.85
Distribution system maintenance costs (% of capital)	1.00%	1.00%	1.00%	1.00%	1.00%	1.00%	1.00%	1.00%
ETS maintenance costs (% of capital)	1.00%	1.00%	1.00%	1.00%	1.00%	1.00%	1.00%	1.00%

Table 12. Operation and Maintenance Cost Assumptions

	1	2	3	4	5	6	7	8
	Boilers & Chillers	**Engine CHP**	**Turbine CHP**	**Combined Cycle CHP**	**Biomass Boiler**	**Ground source heat pumps**	**Waste heat recovery**	**Solar**
<u>Annual Costs (million $)</u>								
District Heating								
Non-thermal revenue		$ (2.64)	$ (1.58)	$ (2.77)				
Capital amortization	$ 2.34	$ 4.64	$ 3.99	$ 4.90	$ 2.22	$ 4.50	$ 2.90	$ 7.30
Natural gas	$ 2.04	$ 4.43	$ 3.48	$ 4.36	$ 0.30	$ 0.57	$ 0.91	$ 1.39
Biomass					$ 2.35			
Purchased electricity	$ 0.03				$ 0.03	$ 1.00	$ 0.07	$ 0.03
Maintenance	$ 0.18	$ 0.97	$ 0.60	$ 0.82	$ 0.69	$ 0.24	$ 0.28	$ 0.40
Labor	$ 0.25	$ 0.29	$ 0.29	$ 0.36	$ 0.50	$ 0.29	$ 0.25	$ 0.25
Total	$ 4.84	$ 7.68	$ 6.79	$ 7.67	$ 6.10	$ 6.61	$ 4.41	$ 9.38
District Cooling								
Non-thermal revenue		$ (2.73)	$ (1.63)	$ (2.86)	$ -			
Capital amortization	$ 5.71	$ 7.08	$ 6.74	$ 7.09	$ 9.15	$ 6.26	$ 5.82	$ 5.82
Natural gas		$ 4.27	$ 3.29	$ 4.20	$ -			
Biomass					$ 2.42			
Purchased electricity	$ 1.24				$ 0.97	$ 1.33	$ 1.24	$ 1.24
Maintenance	$ 0.52	$ 1.38	$ 0.99	$ 1.18	$ 0.52	$ 0.49	$ 0.52	$ 0.52
Water/sewer/chemicals	$ 0.94	$ 1.32	$ 1.32	$ 1.32	$ 1.32	$ 0.94	$ 0.94	$ 0.94
Labor	$ 0.38	$ 0.43	$ 0.43	$ 0.54	$ 0.76	$ 0.43	$ 0.38	$ 0.38
Total	$ 8.78	$ 11.75	$ 11.13	$ 11.46	$ 15.14	$ 9.45	$ 8.89	$ 8.89
<u>Average Cost of Delivered Energy</u>								
District Heating ($/MMBtu)	$ 17.59	$ 27.92	$ 24.66	$ 27.89	$ 22.16	$ 24.01	$ 16.03	$ 34.07
District Cooling ($/ton-hr)	$ 0.30	$ 0.41	$ 0.39	$ 0.40	$ 0.53	$ 0.33	$ 0.31	$ 0.31

Table 13. Annual Costs for District Energy Scenarios With Base Case Assumptions

Self-Generation of Heating and Cooling

Costs for “self-generation” of heating and cooling using building-scale natural gas boiler systems and electric centrifugal chiller systems are estimated in Table 14. These estimates cover capital and operating costs for systems to serve all load served by the district energy systems analyzed above. These costs include all mechanical, electrical and civil costs, including construction of building space for the boiler and chiller systems. Capital amortization assumptions are the same as the “market” assumption in Table 11. Other assumptions and calculations for the self-generation analysis are summarized in Table 15.

Natural gas boilers and electric centrifugal chillers require a hydronic HVAC system (i.e., heating and cooling energy is distributed from the building plant equipment to terminal equipment or air handlers within the building). There are a range of alternative HVAC approaches, such as electric resistance heating and direct expansion cooling. These systems have lower capital costs compared with boilers and chillers, but have higher operating costs and higher indirect GHG emissions.

ANNUAL COSTS (MILLION $)	
Heating	
Capital amortization	$ 1.72
Natural gas	$ 2.85
Maintenance	$ 0.29
Labor	$ 0.50
Total	$ 5.36
Cooling	
Capital amortization	$ 6.93
Electricity	$ 1.42
Maintenance	$ 0.70
Water/sewer/chemicals	$ 0.19
Labor	$ 0.63
Total	$ 9.87
Total Annual Costs (million $)	
Natural gas	$ 2.85
Electricity	$ 1.42
Boiler maintenance	$ 0.29
Electric chiller maintenance	$ 0.70
Labor	$ 1.13
Water/sewer	$ 0.07
Water treatment chemicals	$ 0.12
Total Operating Costs	$ 6.58
Capital amortization	$ 8.65
Total Annual Costs	$ 15.23
AVERAGE COST/UNIT OF ENERGY	
Heating ($/MMBtu)	$ 19.49
Cooling ($/ton-hr)	$ 0.34

Table 14. Estimated Costs for Self-Generation of Heating and Cooling Using Natural Gas Boilers and Electric Centrifugal Chillers(Base Case Assumptions for Electricity Price)

AGGREGATE LOADS	
Heating Demand (MMBtu/hr)	
Diversified peak demand	140
Undiversified peak demand	165
Heating Energy (MMBtu)	275,205
Cooling Demand (tons)	
Diversified peak demand	13,800
Undiversified peak demand	17,250
Cooling Energy (ton-hrs)	27,613,103
INSTALLED CAPACITY	
Natural gas boilers (MMBtu/hr)	222
Electric centrifugal chillers (tons)	23,288
CAPITAL COSTS (MILLION $)	
Natural gas boiler systems	$ 14.5
Electric centrifugal chiller systems	$ 58.2
Total	$ 72.7
OPERATING COSTS	
Operating Cost Factors	
Boiler efficiency (seasonal average)	82%
Chiller system COP (seasonal average)	4.1
Labor FTE	
Heating FTE per 1 MMBtu/hr capacity	0.025
Cooling FTE per 1000 tons of capacity	0.300
FTE requirements	
Heating	5.6
Cooling	7.0
Total	12.5
Labor rate ($/FTE)	$ 90,000
Boiler maintenance costs (% of capital)	2%
Electric chiller maintanance costs ($/ton/yr)	$ 30.00
Cooling make-up water consumption (gal/ton-hr	$ 2.50
Water/sewer ($/gal.)	$ 12.19
Water treatment chemicals ($/gal.)	$ 0.85

Table 15. Assumptions and Calculations for Self-Generation Estimates

Comparing District Energy Costs to Self-Generation Costs

The generalized costs of each district energy technology scenario were then compared with generalized self-generation costs. Sensitivity analyses were prepared for major input variables including the costs of electricity and natural gas, financing costs and valuation of GHG emissions. Input variables for each scenario are shown in Table 16.

	District Energy Electricity and Gas Prices			Building Electricity and Gas Prices		
	Purchased Electricity $/kWh)	Sale of Excess Electricity ($/kWh)	Natural Gas ($/MMBtu)	Purchased Electricity $/kWh)	Natural Gas ($/MMBtu)	Financing (Weighted Average Cost of Capital)
1	$ 0.050	$ 0.025	$ 6.00	$ 0.060	$ 8.50	10.2%
2	$ 0.100	$ 0.040	$ 6.00	$ 0.120	$ 8.50	10.2%
3	$ 0.050	$ 0.025	$ 6.00	$ 0.060	$ 8.50	6.4%
4	$ 0.100	$ 0.040	$ 6.00	$ 0.120	$ 8.50	6.4%
1CO2	$ 0.050	$ 0.025	$ 6.00	$ 0.060	$ 8.50	10.2%
2CO2	$ 0.100	$ 0.040	$ 6.00	$ 0.120	$ 8.50	10.2%
3CO2	$ 0.050	$ 0.025	$ 6.00	$ 0.060	$ 8.50	6.4%
4CO2	$ 0.100	$ 0.040	$ 6.00	$ 0.120	$ 8.50	6.4%

Table 16. Assumptions for Sensitivity Analysis of Simplified Economic Comparison of District Energy and Conventional Building Systems

Results are summarized in Figure 17 (assuming zero value for GHG emission reductions) and Figure 18 (assuming a GHG value of $50 per metric ton of carbon dioxide equivalent).

A basic district energy technology configuration (natural gas boilers and electric centrifugal chillers) has a modest total cost advantage over conventional approaches (Figure 17). Although district energy requires the construction of hot water and chilled water distribution systems, plant capacity can be constructed and operated more cost-effectively with many small boiler and chiller installations.

Note, however, that this simplified economic analysis is based on the assumption that the entire system is built out immediately and serves the full load immediately. Realistically, built-out of the system and ramp-up of load will occur over time, which would hurt the economics.

Electricity and natural gas prices have a large impact on the cost comparison, with the economics of district energy improving as energy prices increase. This impact is especially critical for the CHP scenarios.

Cost of capital also has a strong impact on district energy economics. This effect is particularly important for the most capital-intensive scenarios, e.g. CHP, biomass and ground source heat pumps.

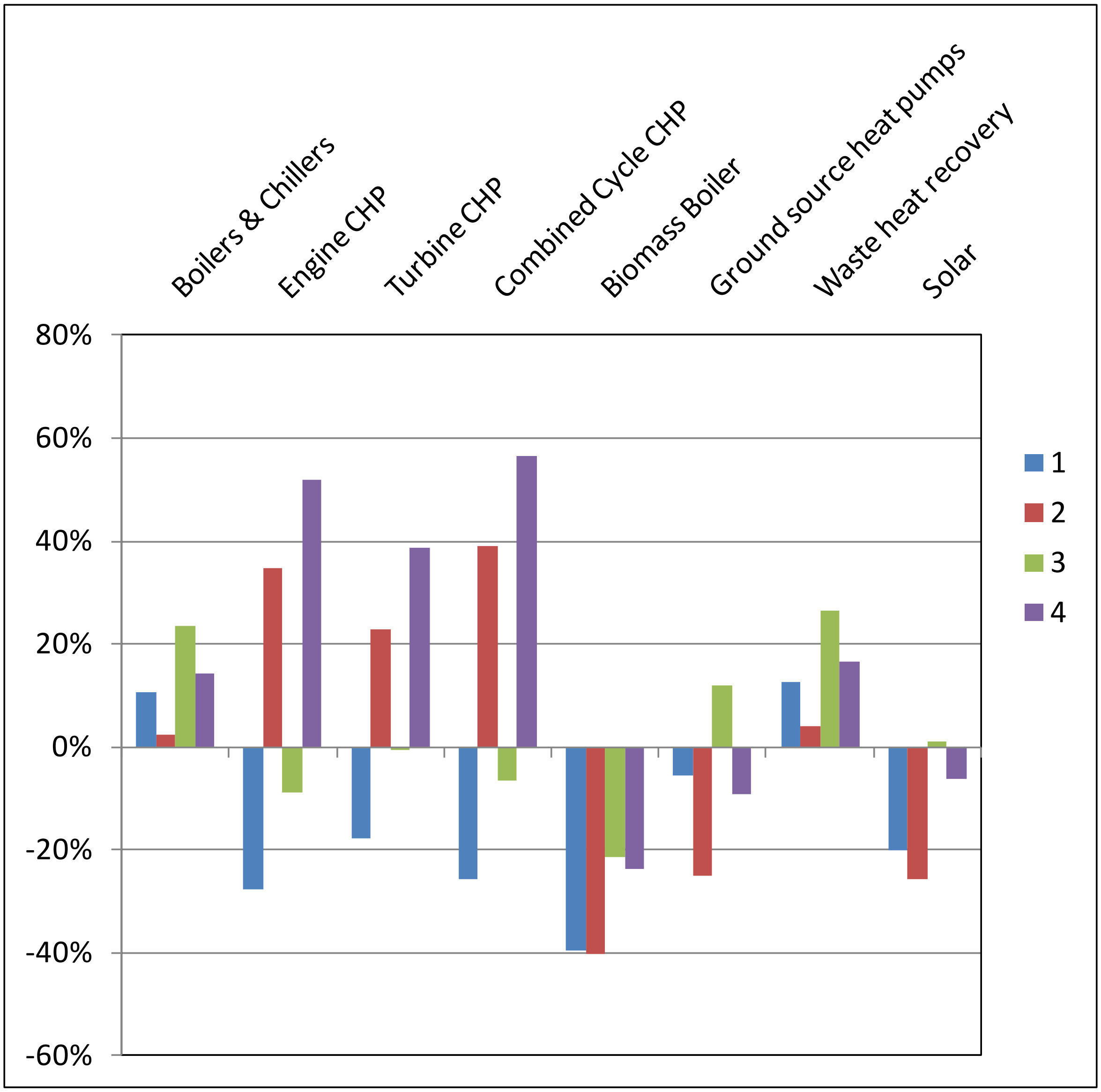


Figure 17. Percentage Total Cost Reduction with Four District Energy Scenarios Compared with Conventional Building Technologies (With Zero Value for Greenhouse Gas Emission Reductions)

In Figure 18 the same four sets of cost assumptions are applied, but it is also assumed that GHG emission reductions have a value of $50 per metric ton of carbon dioxide-equivalent.

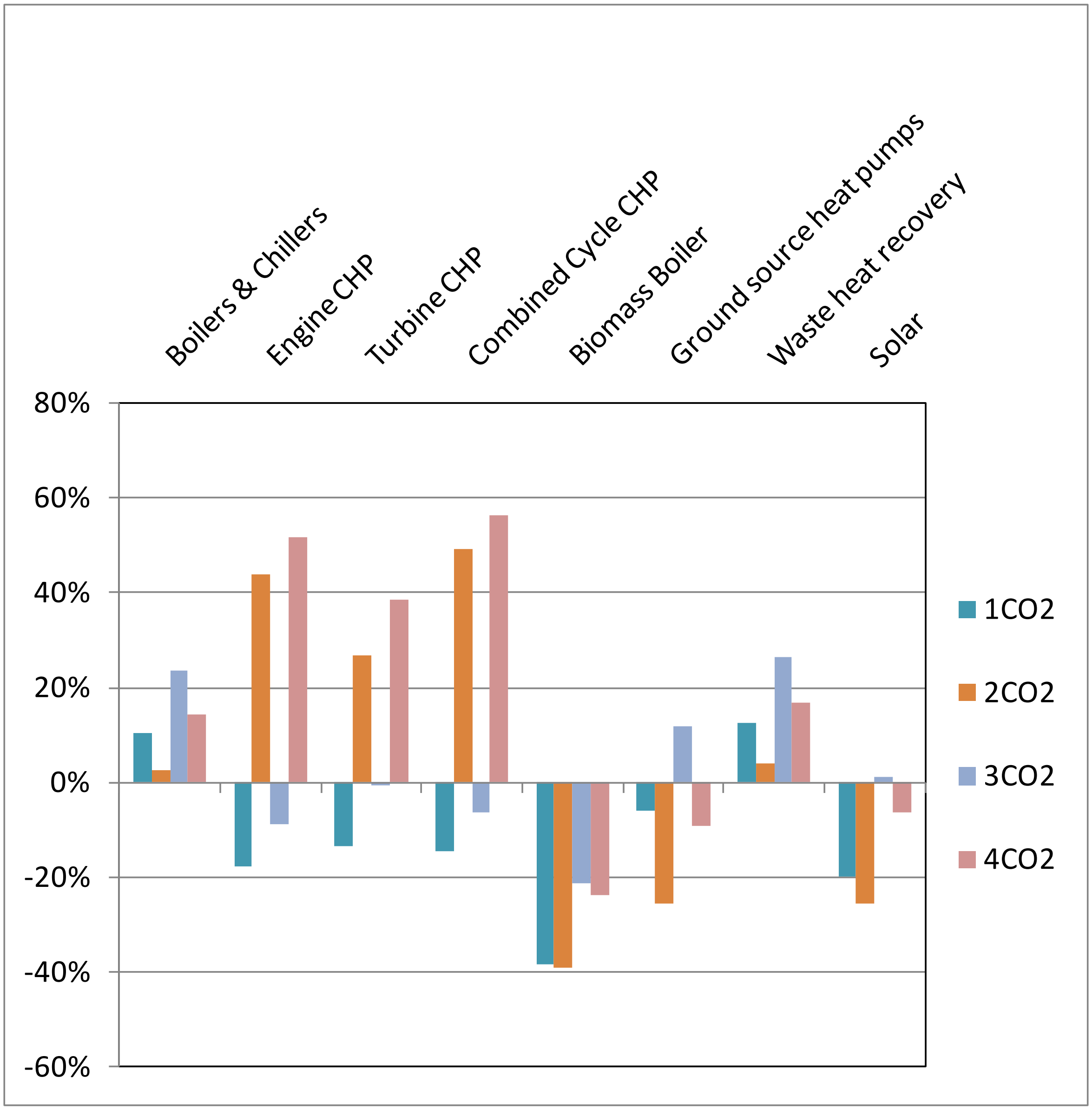


Figure 18. Percentage Total Cost Reduction with Four District Energy Scenarios Compared with Conventional Building Technologies (With $50 per Metric Ton Value for Greenhouse Gas Emission Reductions)

Customer Benefits

Architectural Flexibility

Without the need for boilers, chillers or cooling towers, architects have greater flexibility to create an attractive design, with the ***roof free of smoke stacks and cooling towers***. In addition, roof or interior space that would otherwise be dedicated to these systems can be employed for ***value-added facilities***, such as a rooftop swimming pool.

Reduced Capital Costs

District energy service ***reduces capital costs*** in comparison to installation of boiler and chiller systems in the building. The building owner will need to make minor modifications to the building system design to interface with the district system. Hydronic systems, in which heating and cooling is distributed within the building with water, are required for interface with district systems. Hydronic systems have higher capital costs than some types of building heating and cooling systems such as electric resistance heating or unitary heat pumps. However, hydronic systems are superior to these other approaches relative to quality of service and long-term operating costs.

Comfort and Safety

District energy systems provide a ***higher quality of heating and cooling service***, keeping building occupants more comfortable because industrial-grade equipment is used in the central plant and hydronic distribution is used in the building to provide a ***consistent, well-controlled source of heating and cooling***. In addition, specialist attention is focused on optimal operation and maintenance of heating and cooling systems, thus providing better temperature and humidity control than packaged HVAC equipment and, therefore, a healthier indoor environment. ***Buildings are quieter*** because there is no heavy equipment generating vibration and noise, making tenants happier and allowing them to be more productive. ***Safety concerns are eliminated*** because no fuel is being combusted in the building.

Convenience and Flexibility

From the building manager's standpoint, district energy service is easy, convenient and flexible. ***District energy service eliminates hassles*** associated with managing the equipment, labor, utilities and materials required for operating and maintaining boiler, chiller and cooling tower systems. This allows the manager to ***focus on the core business***, such as attracting and retaining tenants.

From the user's perspective, district energy service is extremely flexible. Heating and cooling energy is ***always available*** in the pipelines, thus avoiding the need to start and stop building equipment. With in-building systems, meeting heating and air-conditioning requirements at night or on weekends can be difficult and costly, particularly when the load is small. With district energy, these needs can be met easily and cost-effectively whenever they occur. The building can use as much or as little energy as needed, whenever needed, without worrying about equipment size or capacity.

Reliability

District energy is more reliable than the conventional approach because district energy systems use highly reliable industrial equipment and can cost-effectively provide ***equipment redundancy***. Staffed with ***professional operators*** around-the-clock, district energy companies are specialists with expert operations and preventive maintenance programs. According to the International District Energy Association (IDEA), most district energy systems operate at a reliability of "five nines" (99.999%).

Environment

District energy is a green technology, ***using fossil fuels more efficiently*** and providing the infrastructure for tapping ***renewable energy*** for heating and cooling. District energy systems have the ***economies of scale to implement advanced technologies*** such as combined heat and power (CHP), renewable thermal energy and thermal energy storage. In a typical power plant, more than 67% of the fuel used to generate power is lost as waste heat. CHP systems capture this heat for use in buildings.

As discussed below, district systems help building owners manage risks associated with environmental regulation.

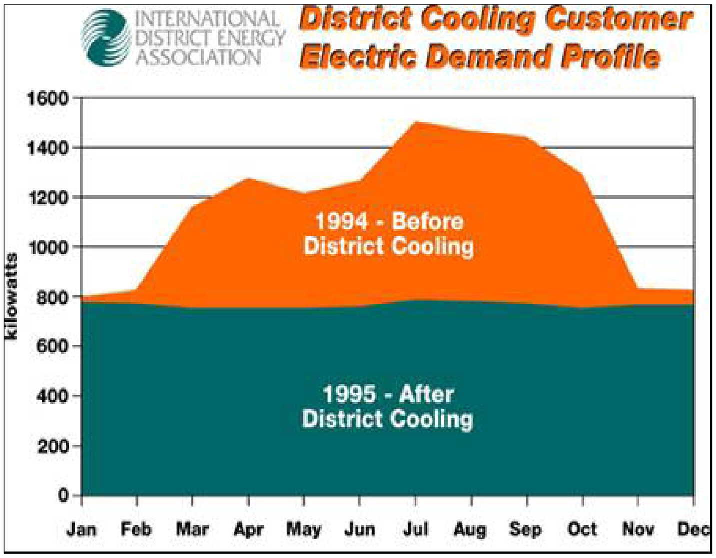
Risk Management

District energy service ***reduces capital and operating risks.*** Capital risks are reduced because no capital is tied up in the building for heating or cooling equipment. Operating risk associated with operation and maintenance of building equipment is eliminated. Costs are more predictable because more of the costs are fixed and less is spent on fuel and electricity, which can be highly volatile in price.

The inherent ***flexibility of district energy systems*** to respond to volatile energy prices and supplies, regulatory constraints and new technology opportunities is an extremely important, but difficult to quantify, benefit for customers. Some developers refer to this as ***"future-proofing"*** a building. A highly significant looming regulatory constraint is greenhouse gas (GHG) emission reduction. Although laws or regulations to limit GHG reductions are unlikely to be enacted in the current political environment, such policies are inevitable. District energy will be far better able to adapt compared with individual buildings.

District systems are well positioned to take advantage of technology, energy and pricing ***opportunities*** for the benefit of their customers. For example, in response to fluctuations in the supply or price of fuels, it is relatively easy for district systems to ***change the fuel mix*** or ***implement new technologies*** with lower costs and GHG emissions.

District cooling helps position buildings for a more competitive, higher-priced electricity market by reducing power demand. The chart at right shows the actual monthly peak demand for an Ohio office building before and after district cooling. The flat load profile will ***reduce power bills*** because peak power is more expensive.



In a ***competitive real estate market***, the ability to provide superior comfort, predictable costs, green credentials and long-term flexibility will attract and retain tenants and help maintain higher asset value.

Economics

District energy has ***fundamental cost advantages*** over multiple boilers and chillers. District systems use highly efficient equipment that can be operated at optimal levels, can use economies of scale to implement advanced technologies, and have better staff economies than many separate building systems. Further, district systems can take advantage of load diversity. "Diversity" refers to the fact that not all buildings have their peak demand for heating or cooling at the same time. This diversity enables district systems to invest in less peak capacity than would be required if all buildings installed their own equipment, yet provide superior reliability.

Typically, district energy systems charge for service through a fixed charge tied to peak demand and a variable charge for energy consumed. The relationship between a district system and its customers is a lot like the relationship between building owners and tenants. In many cases the structure of a district energy service agreement is analogous to a triple net lease: demand charges are like base rent; and operating costs are passed through.

Comparing district energy service to self-generation requires consideration of ***total capital costs and operating costs***. Capital costs include the installed cost of boilers, chillers, cooling towers, pumps, controls, electrical service and gear, engineering services and spare parts, as well as construction costs to create the space for the equipment. Operating costs include electricity, fuels, maintenance and repair, labor and administration, water, chemicals and supplies. The developer should ask whether he or she can invest marginal capital at a higher rate of return in elements of the building that are more visible and accretive to the market value of the property.

Power Grid Benefits

District energy systems serve more densely developed areas, which also tend to have high electricity demands. District cooling systems reduce peak power demand through the use of chilled water or ice thermal energy storage, which shift power demand from on-peak to off-peak periods. To the extent that heat-driven chillers are used in the district system (usually in conjunction with CHP), further reduction in peak power demand is provided. Further, district energy CHP facilities generate power in high power load areas, and can be dispatched based on real-time peak power pricing signals. For example, Princeton University cut its peak power demand from 27 MWe to 2 MWe with a combination of CHP, absorption chillers and thermal energy storage.

Reductions in peak power demand have multiple benefits. Electricity transmission and distribution losses from remote power plants are reduced, and constraints in delivery of power to high-load areas are relieved.

District energy and CHP can also play other useful roles in facilitating increased use of renewable power technologies by helping balance the power grid. As non-dispatchable renewable generation sources (such as wind and solar) increase, there will be greater needs to quickly increase or decrease other generation in response to decreases or increases in renewable power production. This other generation is likely to be relatively inefficient simple cycle (“open cycle”) gas turbines.

The carbon intensity of gas-fired power plants can be significantly reduced if the resulting waste heat is recovered. Hot water thermal storage can be used to maximize heat recovery by smoothing out the supply of heat relative to demand. Thermal storage through hot water accumulators is a common practice in district heating systems. Accumulators have been successfully deployed to facilitate use of CHP to match fluctuating power demand in a range of applications, such as in Woking and Barkantine in the United Kingdom. The European Union has concluded that there is a good potential for using CHP to back up wind turbines in a spot market for power.

Energy and Environmental Benefits

The energy and environmental impacts of each DES scenario are compared with conventional technologies in Table 17. These impacts include primary fossil energy consumption and emissions of GHG, nitrogen oxides (NOx) and sulfur dioxide (SO2). Both direct emissions (associated with fuel consumption at the district energy plant or building) and indirect emissions (associated with power plants to generate and deliver purchased electricity used by the district energy plant or building system). Power grid emissions are based on data from the U.S. Environmental Protection Agency eGRID 2010 Version 1.1 database. The factor used was the average for the two EPA regions covering the COG region.

	1	2	3	4	5	6	7	8
	Boilers & Chillers	**Engine CHP**	**Turbine CHP**	**Combined Cycle CHP**	**Biomass Boiler**	**Ground source heat pumps**	**Waste heat recovery**	**Solar**
Primary energy consumption								
Primary energy consumption factor for power grid	10,500	10,500	10,500	10,500	10,500	10,500	10,500	10,500
District energy technology primary energy consumption (MMBtu)								
Direct District Energy consumption	339,845	1,448,881	1,128,061	1,426,738	50,133	95,455	150,856	262,089
Power grid	261,371	(1,400,761)	(749,772)	(1,478,259)	211,210	488,902	261,371	261,371
Total	601,216	48,120	378,289	(51,521)	261,344	584,357	412,227	523,461
Building technology primary energy consumption								
Building systems	335,616	335,616	335,616	335,616	335,616	335,616	335,616	335,616
Power grid	254,853	254,853	254,853	254,853	254,853	254,853	254,853	254,853
Total	590,469	590,469	590,469	590,469	590,469	590,469	590,469	590,469
% reduction in primary energy consumption	-2%	92%	36%	109%	56%	1%	30%	11%
Peak power demand (MW)								
District energy scenario								
Base non-thermal production peak power	25.9	25.9	25.9	25.9	25.9	25.9	25.9	25.9
District energy system peak power	8.0	(15.7)	(6.6)	(16.7)	6.8	9.2	8.0	8.0
Total	33.9	10.2	19.3	9.2	32.7	35.1	33.9	33.9
Building technology scenario								
Base non-thermal production peak power	25.9	25.9	25.9	25.9	25.9	25.9	25.9	25.9
Building system peak power	11.7	11.7	11.7	11.7	11.7	11.7	11.7	11.7
Total	37.6	37.6	37.6	37.6	37.6	37.6	37.6	37.6
Peak power demand reduction with district energy	10%	73%	49%	76%	13%	7%	10%	10%
Greenhouse gas emissions								
Total annual GHG emissions (metric tons CO2-equivalent)								
District Energy System								
Direct	18,195	77,572	60,395	76,386	2,684	5,111	8,077	14,032
Indirect	20,635	(110,586)	(59,193)	(116,705)	16,675	38,597	20,635	20,635
Total	38,830	(33,015)	1,203	(40,319)	19,359	43,708	28,711	34,667
Building systems								
Direct	17,969	17,969	17,969	17,969	17,969	17,969	17,969	17,969
Indirect	20,120	20,120	20,120	20,120	20,120	20,120	20,120	20,120
Total	38,089	38,089	38,089	38,089	38,089	38,089	38,089	38,089
Reduction with District Energy System	(741)	71,103	36,886	78,407	18,730	(5,620)	9,377	3,422
% reduction in GHG with district energy	-2%	187%	97%	206%	49%	-15%	25%	9%
Regulated pollutant emissions (metric tons)								
Carbon dioxide								
District Energy								
Direct	18,195	77,572	60,395	76,386	2,684	5,111	8,077	14,032
Indirect	20,635	(110,586)	(59,193)	(116,705)	16,675	38,597	20,635	20,635
Total	38,830	(33,015)	1,203	(40,319)	19,359	43,708	28,711	34,667
Building Systems								
Direct	17,969	17,969	17,969	17,969	17,969	17,969	17,969	17,969
Indirect	20,120	20,120	20,120	20,120	20,120	20,120	20,120	20,120
Total	38,089	38,089	38,089	38,089	38,089	38,089	38,089	38,089
% reduction with District Energy	-2%	187%	97%	206%	49%	-15%	25%	9%
Nitrogen Oxides								
District Energy								
Direct	4.78	17.01	7.46	9.34	106.21	1.34	2.12	3.69
Indirect	15.60	(83.59)	(44.74)	(88.22)	12.60	29.18	15.60	15.60
Total	20.38	(66.58)	(37.28)	(78.88)	118.81	30.52	17.72	19.28
Building Systems								
Direct	14.01	14.01	14.01	14.01	14.01	14.01	14.01	14.01
Indirect	15.21	15.21	15.21	15.21	15.21	15.21	15.21	15.21
Total	29.22	29.22	29.22	29.22	29.22	29.22	29.22	29.22
% reduction with District Energy	30%	328%	228%	370%	-307%	-4%	39%	34%
Sulfur Dioxide								
District Energy								
Direct	-	-	-	-	7.03	-	-	-
Indirect	71.72	(384.39)	(205.75)	(405.66)	57.96	134.16	71.72	71.72
Total	71.72	(384.39)	(205.75)	(405.66)	64.99	134.16	71.72	71.72
Building Systems								
Direct	-	-	-	-	-	-	-	-
Indirect	69.94	69.94	69.94	69.94	69.94	69.94	69.94	69.94
Total	69.94	69.94	69.94	69.94	69.94	69.94	69.94	69.94
% reduction with District Energy	-3%	650%	394%	680%	7%	-92%	-3%	-3%

Table 17. Energy and Environmental Impacts of District Energy Scenarios

District energy significantly reduced peak power demand on the grid, as summarized in Table 18.

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	1	2	3	4	5	6	7	8
	Boilers & Chillers	**Engine CHP**	**Turbine CHP**	**Combined Cycle CHP**	**Biomass Boiler**	**Ground source heat pumps**	**Waste heat recovery**	**Solar**
District Energy System (MW)								
Electric centrifugal chiller systems	7.1	5.0	5.0	5.0	5.0	4.5	7.1	7.1
Absorption chiller systems	-	0.9	0.9	0.9	0.9	-	-	-
Heat pump systems	-	-	-	-	-	3.9	-	-
Distribution pumping and plant house	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8
CHP	-	(22.5)	(13.4)	(23.5)	-	-	-	-
Total	8.0	(15.7)	(6.6)	(16.7)	6.8	9.2	8.0	8.0
Building Systems (MW)	10.7	10.7	10.7	10.7	10.7	10.7	10.7	10.7
% Reduction with District Energy	25%	248%	162%	257%	36%	14%	25%	25%

Table 18. Impact of District Energy Scenarios on Net Peak Power Demand

Implementation Challenges

DES Challenges

There are a range of challenges which may inhibit the development of district energy systems, including:

Awareness, information and education

Generally, the people and organizations that could be key stakeholders in implementing a DES are not aware of the potential benefits of these systems. Even if city officials, building owners and others are aware of district energy and its benefits, they generally lack the expertise needed to facilitate implementation of these systems. Development of a new community energy system is a complex undertaking that requires support from many stakeholders including building owners, utilities, city officials, engineers and architects.

Leadership

Development of a new DES involves many institutional, technical, legal and financial issues. Successful implementation requires one or more informed, motivated public-sector 'champions' who understand the benefits of a DES and how to successfully guide its implementation and integrate stakeholder interests.

Price signals

There are no price signals for the public benefits of DES (in economists' terms: "positive externalities") such as lower greenhouse gas emissions, infrastructure flexibility, decreased price volatility, improved energy security and local economic benefits of using local resources to meet local needs. Although in some cases a DES can be economically viable based on direct current economics (ignoring externalities), it is often challenging without a wise technical plan for phased implementation, some form of financial support from the public sector, and a concerted information and education program to communicate the long-term economic, environmental and energy security benefits.

Capital costs

The large initial capital investment required is a key constraint to developing a new DES. While district energy is a proven and reliable energy service technology, its benefits are accrued over an extended period. The difficulty is 'birthing' the system, given the high initial capital costs and need to obtain sufficient customer commitments to finance the initial investment. Financing the initial feasibility and design studies and the development effort is often a key barrier, since a potential system's financial viability cannot be evaluated prior to the completion of such studies.

Land use

District energy systems work best in densely developed areas with a mix of building uses. However, North American land use development patterns – and plans and regulations governing them – do not always encourage the high thermal densities or mixed-use patterns most conducive to DES.

Lack of integrated planning

When the issues of new power plant capacity, solid waste management, environmental quality, local economic development and other critical issues are approached through integrated community energy planning, the benefits of a DES become more visible. However, decisions about these issues are generally not made in an integrated fashion in North America.

Siting

While new district energy distribution technologies can economically and efficiently transport energy over greater distances than previously possible, a DES plant must still be sited relatively close to potential users that are usually located within a densely developed area. Power plant siting processes are generally still oriented toward large centralized plants far from population centers, despite the fact that new plant technologies are far smaller and cleaner than in the past. In addition, siting can raise crippling 'not-in-my- backyard' problems.

Grid access

The overall increase in competitive pressure in power generation has both positive and negative impacts on district energy. Increasing competition will intensify the pressure to wring as much marketable energy as possible out of power plants, thereby making more valuable the 'thermal sinks' that a DES represents. On the other hand, increasing competitive pressure may make it more difficult to establish new CHP systems because of their capital-intensiveness and the time lag before these systems achieve sufficient growth to realize their full economic benefits. In an era of increasing competition in electric generation, power plant investment time frames may tend to shrink, making it more difficult to substitute capital for energy through a DES or other energy systems with high capital costs and low fuel costs.

Key Stages in System Development

Development of a DES requires interactive progress on a range of fronts, including:

- Market assessment
- Stakeholder communication
- Technical design
- Economic analysis
- Securing the revenue stream with customer contracts
- Permitting
- Financial structuring and analysis

These multiple aspects are inextricably interrelated, with progress on one aspect enabling other elements to move forward. For example:

- The recommended technical design depends on a sufficient market, economic feasibility and stakeholder support.
- The financial feasibility of the system depends on the technical design, capital and operating costs and the financial structure.
- The investment and financing path depends on the ownership structure and key contractual relationships.
- The cost of capital depends on the strength of contractual commitments for a revenue stream.
- Contracts for revenue flow depend on the economics of the system as well as a communication/education process to help customers and other stakeholders understand the full benefits of the system, including flexibility for managing long-term risks.

The bottom line is that there is inevitably an iterative nature to the process of creating a district energy system.

Stakeholder Assessment

A critical early step is to identify key stakeholders and assess stakeholder interests. It is important that early in the process the issues important to these stakeholders are identified and clearly understood. An effective education and community relations strategy will have to be developed and carefully implemented.

Market Assessment

District energy system planning must start with a solid foundation of load analysis. Our long experience in these types of studies will help establish a realistic load basis so that sufficient capacity is planned but the system is not overbuilt or the revenues overestimated. This assessment must examine both new and existing development plans and schedules, developing a breakdown of the potential customer base in the study area by building space projection, building type/usage, and development phasing. Peak demands, daily and seasonal load patterns and annual energy must be evaluated, then mapped in order to plan and size the distribution systems.

It is also important to determine the likely “Business As Usual” scenario so that the costs and benefits of the district energy scheme can be compared with the conventional approach.

Screening Analysis

In the screening analysis requires several steps. First, a site-specific inventory and mapping of current and future renewable or waste heat energy sources available to the community is conducted. Then a range of technologies for producing usable energy from the potential energy sources are identified and evaluated. The screening analysis typically addresses:

- Technical reliability
- Energy efficiency
- Water efficiency
- Environmental impacts including greenhouse gases and criteria pollutants
- Capital costs
- Operating costs

Economic and Financial Analysis

Interactive with development of the system conceptual design is an economic analysis, which typically includes:

a. Capital costs including soft costs.
b. Estimated annual operation & maintenance (O&M) costs, including but not limited to, system maintenance, management and staff, insurance (property and liability), property taxes, municipal fees, customer service costs, land rent, overheads and fuel costs.
c. Annual costs including capital amortization.

At the feasibility study stage, the rate structures and rate levels based on the cost of service and financial performance criteria must be developed. Note that the deliverables as presented above are different from the wording in the RFP.

As the technical concept and financial structure are developed, a financial proforma model must be developed, including the following elements:

- Customer Loads
- Capital Costs
- Depreciation
- Operation and Maintenance Costs
- Labor Costs
- Debt Service
- Rates and Revenues
- Cash Flow
- Net Income
- Internal Rate of Return

Environmental Benefits

Key environmental benefits should be quantified, including impacts on emissions of GHG, regulated pollutants and ozone-destroying refrigerants. This analysis should assess both the direct emissions at the district energy plant or building as well as the indirect emissions from the power plants generating power purchased by the DES or building.

To the extent possible, it is desirable to assess the potential employment impacts including not only the jobs directly created (e.g., construction workers) but also those indirectly created in the industries or services that support the project (e.g., workers in factories providing equipment and supplies). In addition, there are induced jobs created when the workers employed directly or indirectly spend their wages for such things as groceries, transportation, etc.

Permitting

Timely initiative of permit applications and successful follow-up are critical to timely initiation and completion of system construction.

Risk Analysis

A thorough risk analysis should be conducted to inform the assessment of options for Ownership and Operations. Development of a district energy system is a relatively capital-intensive undertaking. Further, capital costs are “front-loaded” because of the high costs of installing basic plant infrastructure and pipe mains in the early years – in contrast to adding customers in later years with relatively short, small-diameter pipe additions and the installation of additional chillers in the plant. Given these characteristics, a fundamental risk in development of a district energy system is lower-than-projected customer load. This may be due to a low level of success in marketing to targeted customers, or as a result of slower-than-projected build-out of development by customers and/or master developer.

Ownership and Operation Models

Key Considerations

There are many different types of entities that may seek to play an ownership and/or operational role in a DES, including local governments, universities, private for-profit companies and private non-profit companies. A district energy system's ownership and operating structure can be as critical to its success as its engineering and design. Ownership structures will often have a significant impact on the options available for funding and financing the development of the system. There are many different models of ownership and operation with no single preferred model; the ultimate structure should be tailored to the goals of the major stakeholders.

Key considerations in the assessment of models should include:

- Access to a range of project financing sources, including state and federal grants, tax credits, subsidized financing tools and cost-effective market-based financing.
- Risk mitigation in construction and operation of the system that can address energy costs and price stability, as well as changing environmental parameters.
- Flexibility to accommodate future expansions of the district energy system while supporting development and sustainability agenda.

The question of what type of entity should own and operate a district energy system begins with the understanding that there are several component parts to a district energy system---the ownership and operation of which may be separated and undertaken by different entities. In fact, ownership of the underlying assets can also be separated from the day-to-day operation of the energy system. The two components of the district system that are potentially separable for purposes of ownership and operation include:

- Generation in the form of thermal energy that is the source for providing district heating and cooling; and
- Distribution of heating and cooling services from the point of the thermal source to the point of interconnection with the district energy user, typically in the form of piping below the public street right-of-way.

It is possible that these components could have its own ownership and operating structure. For example, it would be possible for one or more private entities to own and operate the plant systems and provide thermal energy under contract to a district energy piping system that is owned by a public agency or a public-private partnership.

Range of Ownership Options

The best way to think of the options for system ownership and operation is as a range with a purely private system of ownership and operation at one end and a fully publicly owned and operated system at the other end of this continuum. A purely private system is typically most applicable where all of the property that is part of the district energy system is under one owner, such as a college campus or large hospital complex. The many different stakeholders and potential partners likely to be part of most potential systems in the COG region suggest that an entirely public owned system will not be the preferred option.

The potential participants in an ownership structure may include a the local power or natural gas utility company, a company specializing in district energy system ownership and operations, the local government, building owners in service area, or individuals or institutions that provide project equity in exchange for access to federal tax credits or the tax benefits of accelerated equipment depreciation and net operating loss deductions.

Another element of the ownership analysis is whether the ownership is structured as a not-for-profit corporation, a for-profit entity, or a joint venture that includes both for-profit and non-profit partners. Within the for-profit categories, there are also several options include a limited liability corporation, or an entity based on a cooperative utility model.

What follows is a brief description of some of the more common business structures based on a review of the literature and some examples of other district energy system in the U.S. and Canada.

Private utility model

Most multi-user district energy systems in the U.S. are owned and operated by private companies, either as stand-alone entities, or as subsidiaries of larger utility companies. In some cases, cities have sold off or privatized their district energy systems as a means to raise funds in tight budget years. The private utility model tends to be the case in larger district energy systems in larger communities such as Philadelphia, Detroit, Indianapolis, Seattle and somewhat smaller cities such as Omaha and Hartford.

Private non-profit

This approach has been used to great success in St. Paul, Minnesota. Based on positive results from feasibility studies funded by the federal and state governments in the late 1970s, a private non-profit corporation was created to develop a new hot water district heating system. Its initial board of directors included representatives of building owners, the City of St. Paul and the local electric utility, which had for decades provided district heating service via an aging district steam system. The initial project cost, including construction, financing and other expenses (not including building conversions) was $45.6 million in 1982 dollars. Funding sources included tax exempt revenue bonds and loans from the City of St. Paul and Housing and Urban Development (HUD) funds. The City played a vital role in helping the system in the early years by deferring payment of franchise fees until the young utility company reached a certain threshold of financial viability on its balance sheet. In 1992 a district chilled water system was developed to help customers respond to the phase-out of CFC refrigerants. The City played an important role in obtaining low-cost loans for construction of the system. In 2003, the district heating and cooling company partnered with Cinergy, a private utility company, to finance a 25 MW biomass CHP facility.

City-owned for-profit

Markham District Energy in Ontario is a for-profit entity that owns and operates a district energy system but the for-profit is wholly owned by the municipal government. That gives MDE the ability to take the tax advantages available to a private firm such as accelerated depreciation expenses but also finance the project using municipal sources of project financing. The system uses natural gas boilers to provide district heating and cooling to 1.8 million square feet of residential and commercial space, including office buildings for IBM and Motorola, and also cogenerates about 8 megawatts of electrical power. Based on its sole ownership, the City also operates it, has a direct role in marketing district energy services to additional users, and is able to coordinate expansion of the energy system with other public infrastructure projects.

City-owned, privately contracted

Metro Nashville District Energy System was built in 2004 to replace a waste-to-energy facility that had been in operation for 30 years but was destroyed by fire. The City of Nashville owns the facility but contracted for design and construction and also contracts for operation of the facility with Constellation Energy Source, a private energy services company. Constellation manages metering, invoicing of customers, operations and maintenance of the facility as part of a 15-year operating agreement with the City. The MNDES facility was built using tax-exempt municipal bonds that had no cost to taxpayers because the bond payments are made entirely from revenues from energy sales. The district energy system boilers and chillers use gas and electricity to provide district heating and cooling for about 50 buildings in the downtown business district at a cost estimated to be about 10 percent below market.

City-owned non-profit

Buffalo, New York recently developed a small district energy system that is based on ownership of the heating plant by the City, but ownership of the district energy distribution system by a non-profit entity. The non-profit group was granted easement rights for piping in public rights-of-way and owns and operates the piping distribution system up to the point of building inter-connection.