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DISTRICT ENERGY SYSTEMS IN THE UNITED STATES INFRASTRUCTURE

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ABSTRACT

District energy is already an important part of the U.S. infrastructure, but there are still potential areas of growth where district energy may help the U.S. reduce primary energy consumption and operating costs. Technology and engineering design guidelines involving district energy systems are well-established. Despite this, political and economic barriers are hindering the future growth of district energy in the United States. District energy offers many benefits such as primary energy savings and fuel flexibility, and can be coupled with other energy efficient processes such as combined heat and power to improve the overall nation's fuel efficiency. The barriers that are slowing growth of district energy should be considered a high priority in the nation's future infrastructure improvements. Barriers to growth for district energy systems in the U.S. infrastructure include slow return on investment coupled with low current and projected fuel prices, lack of short-term incentives for societal benefits, and utility regulation policies.

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ABBREVIATIONS

ABMA	American Boiler Manufacturer's Association
ASHRAE	American Society of Heating, Refrigerating, and Air-Conditioning Engineers
CHP	Combined Heat and Power
CTR	Metropolitan Copenhagen Heating Transmission Company
DEA	Danish Energy Agency
DHC	District Heating and Cooling
DOE	U.S. Department of Energy
EPA	U.S. Environmental Protection Agency
EPACT	Energy Policy Act
IDEA	International District Energy Association
IEA	International Energy Agency
PURPA	Public Utility Regulatory Policies Act of 1978

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- The rest of the AE mechanical department – Prof. Ling, Dr. Srebric, Dr. Freihaut, Dr. Treado

This thesis is dedicated to Patrick Zuza, a great friend who passed away in early March, 2013.

INTRODUCTION

This report was written to accomplish three goals:

- Outline the current state of U.S. district energy systems and address future growth capacity.
- Prove through various economic models that current district energy investment offers long-term financial benefits, especially when combined with thermal recovery processes.
- Identify barriers to future growth in district energy systems and discuss potential solutions to encourage more rapid growth.

Section 1 of this report presents information that was collected from established district energy and CHP census data from IDEA, EIA, IEA, and others. With that information, lifecycle costs were created and shown in Section 2 to analyze the performance of investments in district energy under many conditions. Finally, Section 3 of this report discusses legislative and economic barriers that are existent in the U.S. economy by analyzing how current U.S. code affects district energy. Also, a comparison is made to European economies that have high market share of district energy.

What is district energy?

District energy is a method of supplying thermal energy to multiple consumers from a central plant. Buildings connected to district energy systems are supplied heating and/or cooling energy in a similar manner as domestic water, natural gas, and electricity. In simple terms, a central thermal plant distributes thermal energy to multiple buildings via underground pipe, so that each connected building does not require thermal generation equipment. District energy systems are long-term infrastructure investments, and should not be considered simple engineering solutions.

Why is district energy important today?

Climate change, energy efficiency, and emission reduction are all timely topics. In the past few years, the U.S. and state governments have stated many energy-efficiency goals. The Energy Policy Act of 2005, for example, established energy reduction standards for both new and existing federal buildings to achieve a 30% reduction in energy use by the year 2015 (reduction is compared to energy use by the respective buildings in 2003) (DSIRE, 2012). In order to meet these goals, innovative energy-saving strategies must be employed. District energy can help the U.S. and individual states achieve these respective long-term energy goals by providing the infrastructure needed to help reduce currently wasted thermal energy evident throughout the United States.

Foreign countries have already met similar energy goals through substantial district energy investments coupled with gradual switchover to more efficient power generation strategies like combined heat and power. Scandinavian countries like Denmark, Sweden and Finland are leading nations with respect to their use of district energy, but many other countries such as Iceland and South Korea have also succeeded in meeting energy goals through district energy programs. Furthermore, future expansion of district energy systems are specifically stated in the European Union's broad energy goals:

- Expansion of district energy systems combined with combined heat and power is included in Priority 1 of their Energy 2020 document (European Commission, 2010).
- Combining district energy systems with various renewables is included in Section 2 of Energy Roadmap 2050 (European Commission, 2011).

What are the benefits of district energy?

District energy offers many benefits over traditional on-site thermal generation equipment, including:

- **Higher Overall Plant Efficiencies –** District energy systems, especially larger systems, can realize higher overall plant efficiencies than on-site thermal plants through equipment economies of scale. Larger, industrial size equipment can be installed in district energy plants, which have small efficiency advantages over equipment sized for on-site heating and cooling. For larger loads, even small efficiency savings can lead to rather large cost savings when the energy use is integrated over the entire lifetime of the equipment.

- **Better Plant and Load Matching** – Through summation of diverse thermal loads, average demand load factors can be higher for district energy systems than the individual loads themselves. Plant efficiency is more favorable when the system operates at a higher demand factor.
- **Fuel Flexibility** – The district energy industry has prided itself on reliability of services. Thornton reports that most district energy services operate at a reliability of 99.99% (Thornton, 2005). ASHRAE reports that mature district energy services operate at a reliability of 99.98% (ASHRAE, 2012). As an example, the only San Francisco utility that operated continuously without interruption during the 1989 San Francisco earthquake was the district steam system located there.
- **Cost Stability through Fuel Flexibility**– Many district energy plants are diverse in fuel input, and are flexible with the relative percentages of various fuel types to lower overall costs and emissions. See the case studies in Appendix C for examples, particularly the district energy system at University of Missouri, which has experimented with various types of locally collected biomass fuels like shredded truck tires and corn cobs. Fuel flexibility has allowed district energy costs to be stable compared to individual fuel prices.
- **More Possibilities for Renewables / Innovative Strategies** – District energy plants are in a better position than on-site thermal generation to use renewables and other energy efficient measures. Capital investments made to the large central plant of a district energy system can be recovered quicker because of scale. For example, Cornell switched to deep lake source cooling in the summer of 2000, which now saves the university 80% in annual cooling costs compared to the years prior to the system switchover. The switch cost the university close to $60 million in

construction capital, a scale which would not be affordable to smaller systems (Cornell, 2005). Another example is District Energy St. Paul, which boasts an impressive timeline of innovative system changes. Since establishment of the system in 1979, the district energy system has added chilled water thermal energy storage, a wood-chip fired CHP plant, and was the first district energy system to incorporate solar thermal (District Energy St. Paul, 2012).

- **Avoided Capital and Annual System Costs on Mechanical Equipment –** Buildings connected to district energy systems do not need installed on-site mechanical equipment for the services received through district energy. This includes boilers, chillers, cooling towers, etc. As a result, the owner can avoid capital cost and annual operation and maintenance costs for those pieces of equipment. Also, less mechanical floor space is needed, which can be designed to host other purposes. Insurance costs are lower too if the owner can avoid installing a boiler in the building.

How can the U.S. improve their use of district energy?

Parts of the U.S. have been using district energy for well over a century, but growth of district energy has been modest compared to other countries because of political and economic barriers that exist in our market structure. Today, it is important for these barriers to be recognized so they may be resolved to allow a more accelerated growth of district energy systems. The following report identifies some of these barriers and suggests possible solutions to encourage growth of district energy in the U.S. infrastructure.

SECTION 1: CURRENT STATE OF U.S. DISTRICT ENERGY

This section of the report explains where district energy is already applied in the United States infrastructure. Also, the capacity for future expansion of district energy is analyzed on a national scale.

Overview

District energy is already an important part of our nation's infrastructure. As of 2003, 67,000 buildings were served by a district heating network, totaling roughly 5.5 billion square feet of floor space (US EIA. *Commercial Buildings Energy Consumption Survey*. 2003). Figure 1 shows the member district energy networks of the International District Energy Association (IDEA) in 2009, which includes both district heating and cooling.

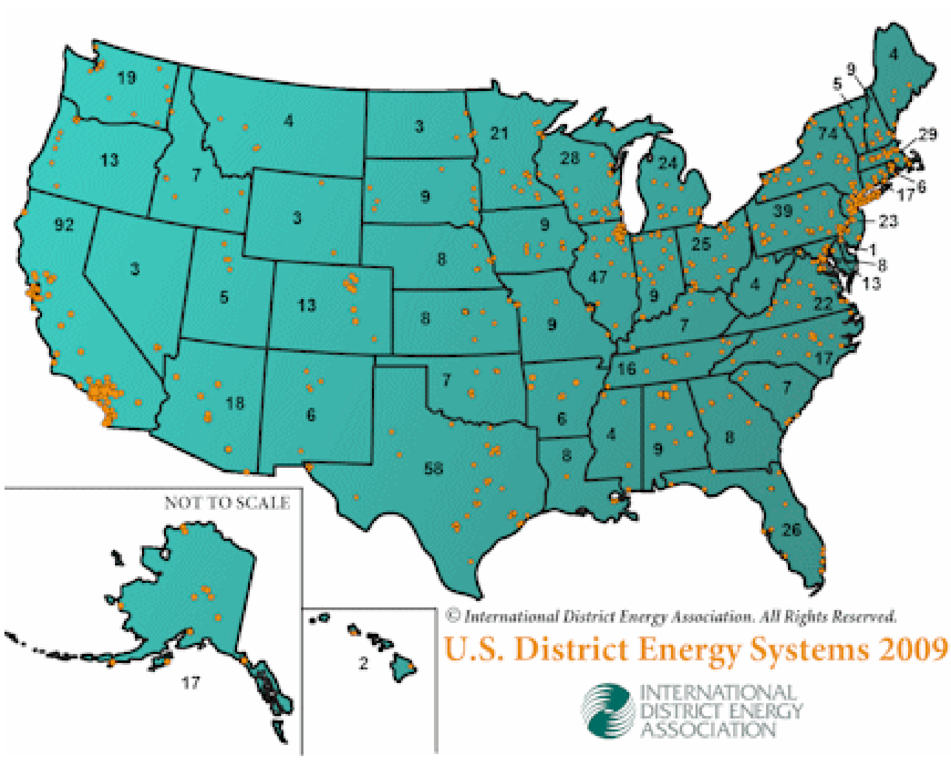

Figure 1: U.S. District Energy Systems Map, 2009 (IDEA, 2009)

The clear majority of district energy systems in the United States serve dense urban areas, university campuses, healthcare campuses, military bases, and airports. Residential and other areas of lower thermal load density were not commonly served through district energy in the past, but newer systems have begun to include some of those areas. In particular, a recent trend of hot water distribution rather than steam has helped sectors with lower heating load density feasibly connect to district heating systems. Data has shown that district energy growth has slowly increased over the past few decades, but that growth is still modest on a national perspective. Figure 2 shows a graph from IDEA of new district energy connections per year from 1990 to 2008.

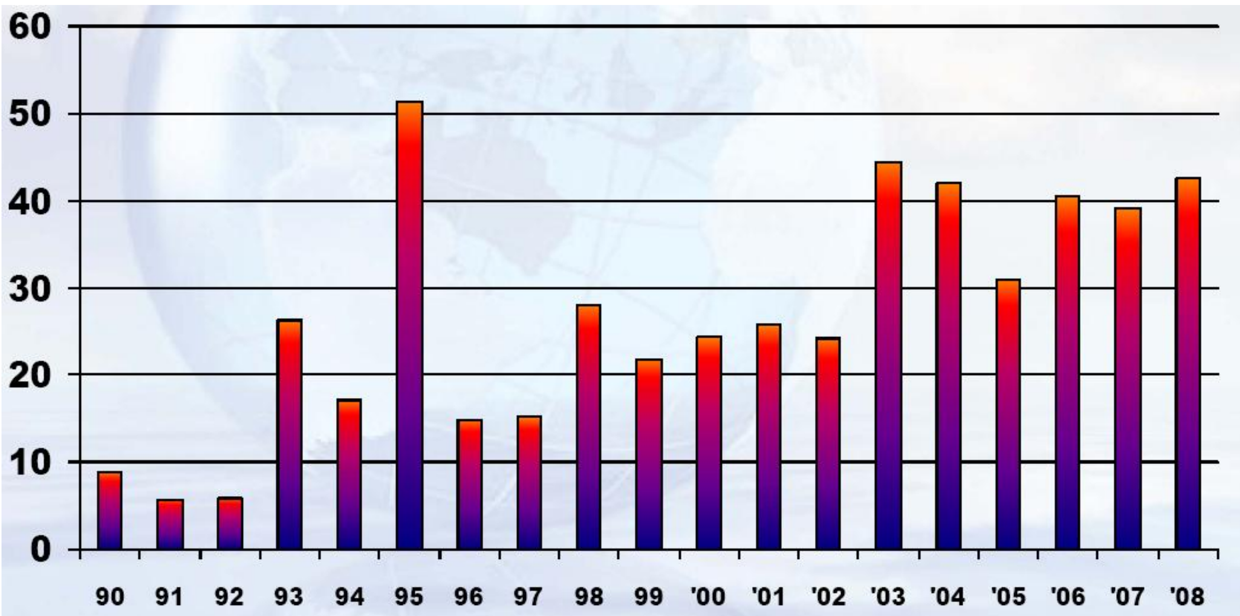

Figure 2: District Energy Growth (Million square feet of customer building space connected and committed per year) (IDEA, 2010)

Data has also shown that the sectors of recent growth in U.S. district energy match the historically served sectors. In 2010, 121 new buildings were connected to district energy systems, totaling 23 million square feet. Table 1 shows the sectors in which this new square footage was added. It is evident from Table 1 that campus institutions and downtown areas have continued to be the most successful district energy customers.

Table 1: New square feet of building space added to district energy systems in 2010 (IDEA, 2011)

Building Sector	Percentage of New Square Footage Added in 2010
School, Hospital, Institution	34%
Commercial	28%
Government	17%
Residential	9%
Hotel	9%
Other	3%

Fuel and Thermal Sources

Natural gas is the predominant primary fuel for district heating systems with slightly above 75% of the district heating fuel consumption, as shown in Figure 3.

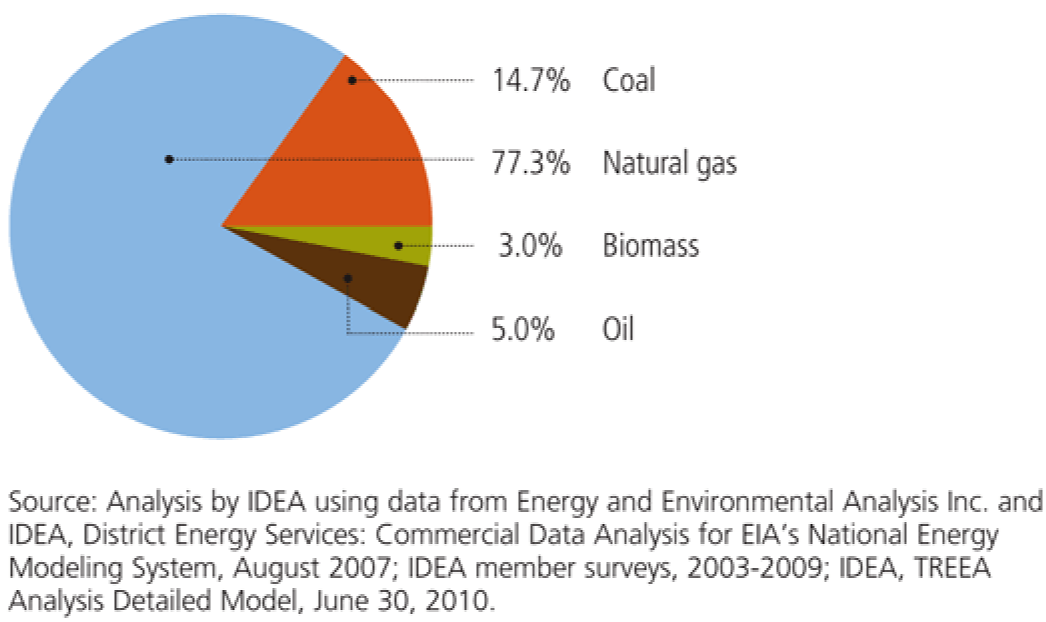

Figure 3: U.S. district heating fuel consumption by fuel type, 2005 (Spurr, 2010)

Likewise, district cooling fuel consumption is shown in Figure 4 on the next page. Site electricity and natural gas are the predominant fuels for district cooling systems.

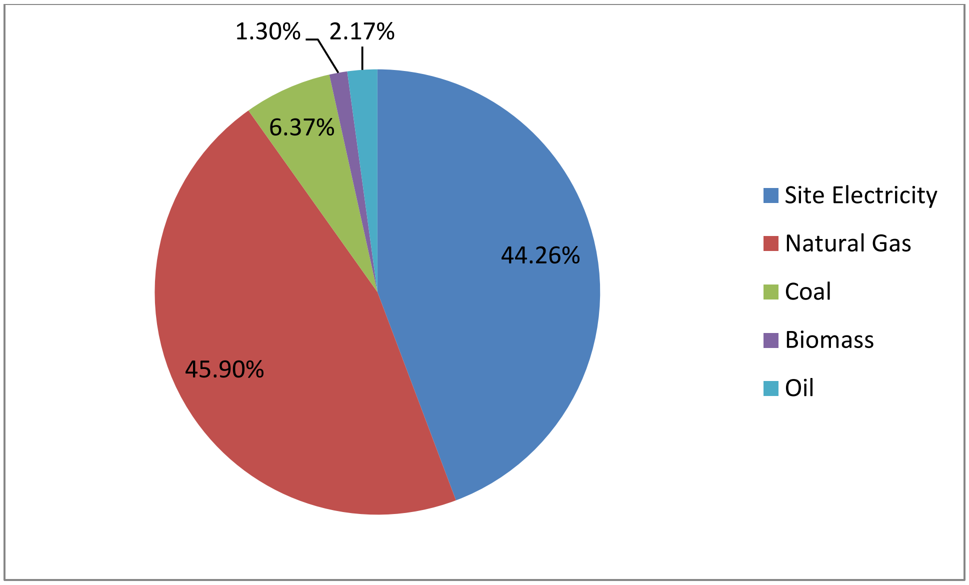

Figure 4: U.S. district cooling fuel consumption by fuel type, 2003 (US EIA, 1999)

CHP and Thermal Recovery

Historically, district energy systems have been supplied thermal energy through heating-only or cooling-only equipment. More recently, however, operators of central district energy plants have found that investment switchover to a more innovative process is reasonable considering the scale of the system. An example is the District Energy St. Paul's increased plant CHP capacity. In 2003, the utility was able to convert over 60% of the heating demand of the network to a more efficient (in terms of primary fuel) CHP process (Sherwood, 2003).

District energy systems can have the greatest societal impact by providing the infrastructure required to make use of more efficient energy processes such as combined heat and power (CHP). The U.S. has stated specific CHP growth goals for the next few decades, which can be facilitated by the growth of district energy systems. Today, the United States electric generation from CHP is around 9% of overall generation capacity (MW) and 12% of annual generation (MWh), which has remained relatively static within recent history (The International CHP/DHC Collaborative, USA, 2007). Figure 5 compares the U.S.'s market share of CHP to market shares of other nations.

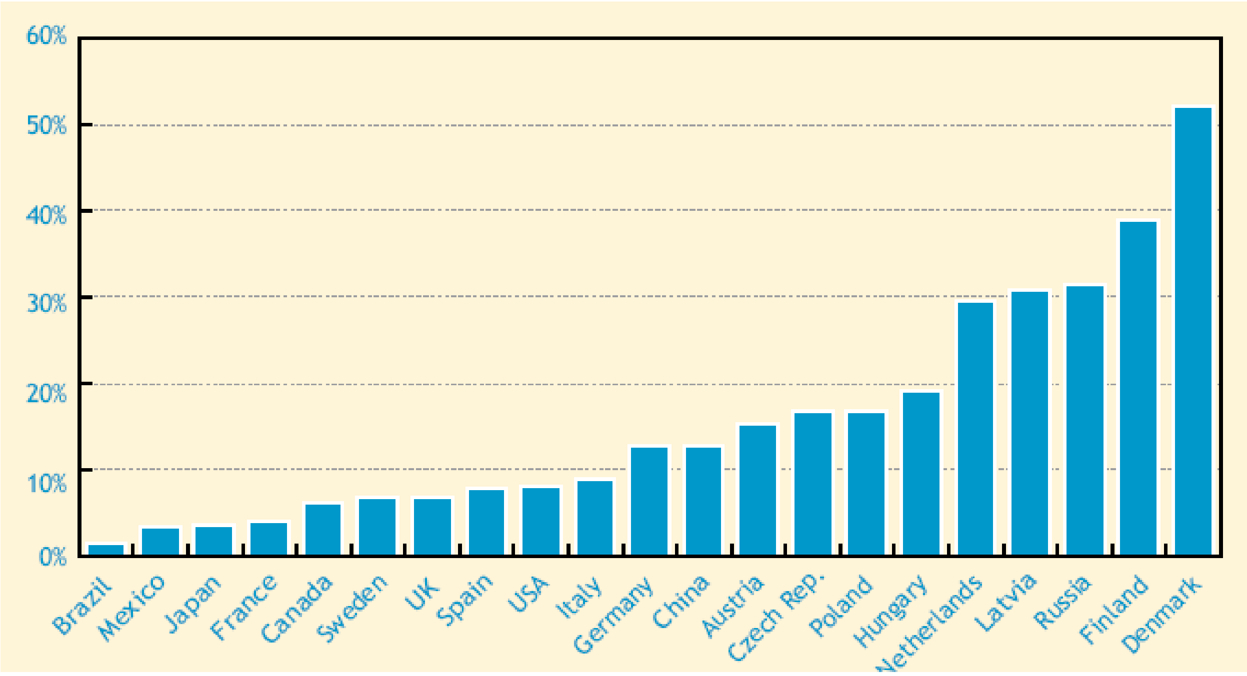

Figure 5: CHP share of national power production for leading countries (IEA, 2009)

CHP used to have a greater percentage of electric generation capacity, particularly during the onset of private electric utilities. CHP capacity fell sharply, however, after electric utilities were regulated. The utilities found themselves in a position that encouraged switching to larger isolated plants that generated electricity more efficiently, but did not supply any thermal energy to customers. Even though this switch lowered the primary fuel efficiency of the plants, it was in the electric utilities' best interests to take advantage of the economies of scale from the new plants.

CHP capacity remained low until the 1970's energy crisis, which spurred a resurgence of CHP in the United States. Enactment of the Public Utility Regulatory Policies Act of 1978 (16 U.S.C. 46 § 2601-2645) was a reaction of the federal government to the crisis. By forcing the regulated utilities to cooperate with "qualified" nonutility power generation companies, high efficiency energy production utilities such as those utilizing CHP and renewables were favored by the law for the first time since the development of the large, monopolized utilities. Specifically, the utilities were required to provide back-up power to these qualified generation plants, as well as buy electricity supplied into the grid from them at a rate equivalent to the avoided cost of the utility from the acceptance of that additional power.

District energy systems benefitted indirectly from the requirements set by PURPA. CHP plants that provided thermal energy to district energy systems had an economic advantage over the regulated utilities since they had a choice to use their generated electricity for on-site consumption or sell it to the grid at a competitive rate. Thermal energy supplied into the district energy systems helped increase profit margins for the plants. This competitive advantage helped quadruple installed CHP capacity from 1980 to 2000 (approx. 12,000 MW to 66,000MW) (The International CHP/DHC Collaborative: USA Scorecard, 2007). Figure 6 shows the growth in CHP capacity from 1970 to 2008.

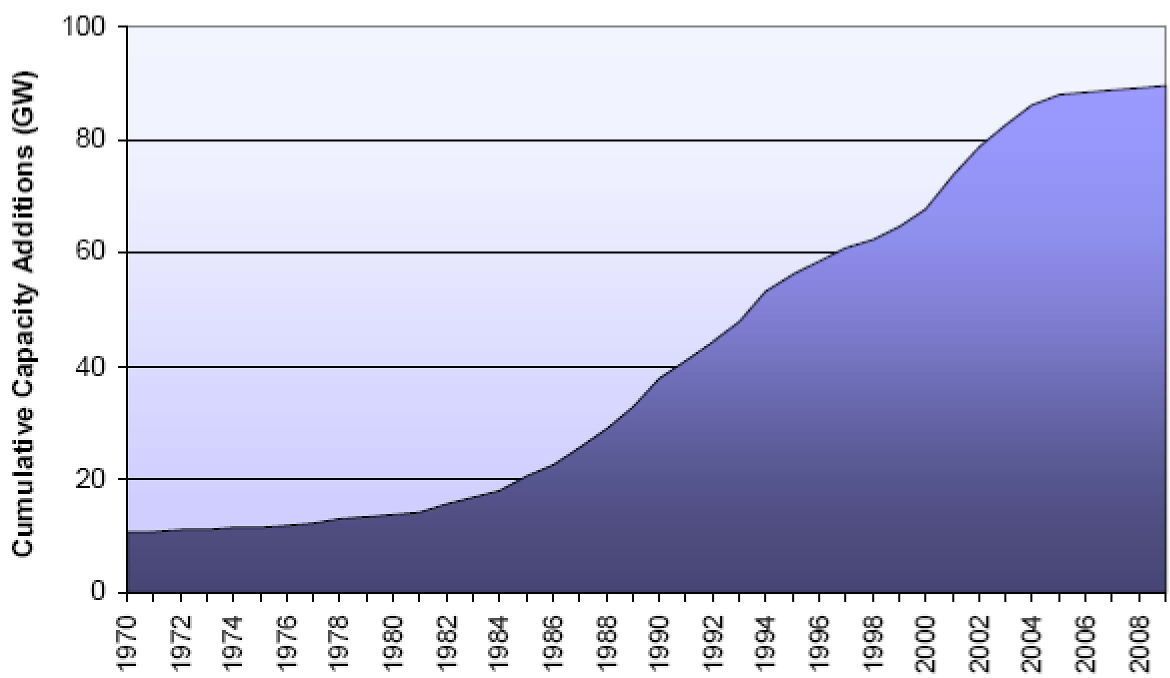

Figure 6: CHP Growth from 1970 to 2008 (Hedman, 2009)

Comparison: Denmark's National CHP/DHC Strategy

While the U.S. made significant improvements in CHP market share in the past few decades, other countries have outgrown the U.S. in their respective CHP and district energy market share in the same time period. Denmark is the prime example. Denmark reorganized its energy infrastructure after the 1970's energy crisis to drastically change the nation's position in the global energy market. At that time, Denmark relied on foreign oil imports for 90% of its energy demand. The nation's response to the crisis was the first Heat Supply Law of 1979, which made heating fuels a public good, even after delivery to the end-user. In effect, the law gave the Danish Energy Agency (DEA) all authority on how any building in Denmark may and may not be heated.

Through the decades following the 1970's energy crisis, the DEA decentralized Denmark's electricity generation, relocating plants to where heating loads existed. At the new locations, CHP plants were designed to supply heating demands with the exhaust energy. At the same time, the DEA developed Denmark's first major district heating networks, forcing buildings to connect to the district energy systems as the systems were expanded. The expansive district heating networks provided a convenient way to utilize the electric generation exhaust heat. Figure 7 shows the nation's electric generation transformation from large remote plants to smaller local CHP plants.

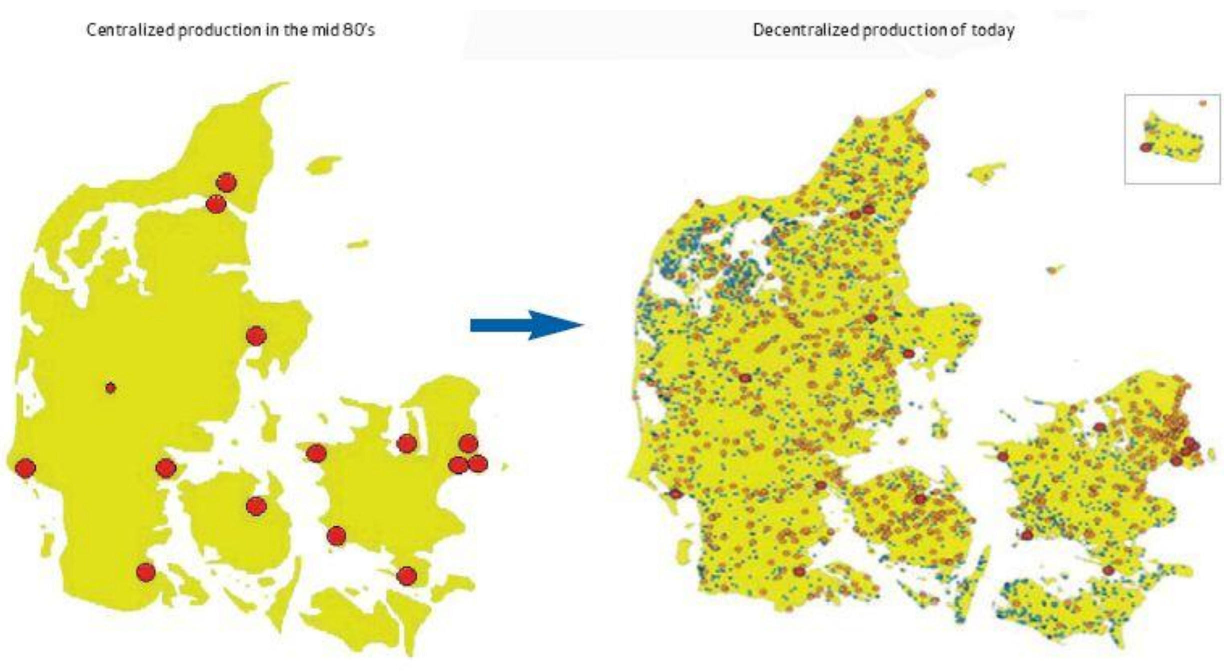

Figure 7: Decentralization of Denmark's electricity generation in the past few decades (The International CHP/DHC Collaborative: Denmark Scorecard, 2007)

The district heating networks in Denmark today are supplied with heat from a combination of CHP and heating-only plants. The district energy systems in Denmark are run almost entirely with hot water. The DEA states they will continue to expand their CHP capacity in the future, and convert more heating load from the heating-only plants to CHP plants. Listed below is the amount of each plant type connected to the Denmark district heating system:

- 285 decentralized CHP plants
- 16 centralized CHP plants
- 130 heating only plants

Comparison: District Heating in Urban Areas of Iceland

Iceland boasts the largest district heating market penetration in the world, where district heating serves over 90% of the country's buildings (all types). The large market penetration is a direct result of the country's efforts (both public and private) to maximize their use of efficient geothermal energy after the 1970's energy crisis. Most of the heating comes from three geothermal CHP plants: Svartsengi, Nesjavellir, and Hellisheidi. Their combination of geothermal, CHP, and district energy has made Iceland a model nation in terms of energy efficiency.

Aside from the direct public and private investor support, many other factors steered Iceland towards developing their geothermal district energy system. The nation's physical isolation from the rest of the world incentivized efficient use of energy. Iceland expects to be energy independent by 2050 by continuing to develop and expand their use of geothermal energy. The nation's heating demand density is also appropriate for district heating. Almost all of the 320,000 Icelandic citizens live in the nation's capital of Reykjavic or in Akureyri. Lastly, the country has a year-round heating demand due to its climate, which keeps the district energy plants' utilization factors high. The average annual high temperature in Reykjavic is 55.9°F.

Distribution Methods

Steam, rather than hot water, is the preferred medium for U.S. district heating networks. 78% of district heating systems today use steam, a lasting result of early district heating systems in the U.S. (Thronton, 2005) The framework for the first downtown district steam systems originated along with the "Edison Electric Utilities", which were being formed around the turn of the 20th century in major cities like Boston, New York, Chicago, Detroit, Philadelphia, and Baltimore. The operators of these new electric utilities realized they could sell the exhaust steam from the steam turbines at minimal additional operating costs so their electricity could be sold at a more competitive rate. This business model simply required an initial capital investment of underground piping networks to all the intended steam customers, many of which were relatively close to the plant.

Many of the piping networks in these early district steam systems laid the roots for the district heating systems of today. The current New York City Con Edison Steam System, for example, is a conglomeration of at least 4 independent predecessor steam distribution networks. The old networks were kept, and even as hot water systems became more popular for their greater distribution radiuses, the steam systems that were already in place were not converted to hot water because of the large cost associated with the conversion.

Comparison of U.S. and Foreign District Heating Transmission

While steam is the preferred medium for district heating systems in the U.S., most foreign district heating systems use hot water. Each choice holds different benefits and limitations, briefly described in Table 2.

Table 2: Steam vs. hot water as heat transfer mediums in district heating systems

Transfer Medium	Steam	Hot Water
Benefits	*High quality of heat* – Able to use district heating for some industrial and other high thermal processes not capable with lower temperature hot water *Phase change heat extraction* – Constant temperature across heat exchange process allows for more efficient and predictable heat transfer *No pumping power required* – Steam travels to consumer through pressure differences	*More efficient transmission* – Hot water travels faster to the consumer than steam and is closer in temperature to the ground in which the pipe is buried, resulting in less transmission losses *Easy expansion* – Booster pump stations can be added to hot water systems, which allows the district energy system to serve a large radius (more customers), as well as less dense areas (such as Residential)
Drawbacks	*Slow transmission* – Compared to hot water, steam travels to customer at a slower pipe velocity (with the exception of high-pressure steam systems, which can travel quite fast, but are also rare) *Pipe quality can be worse* – District steam system will still operate with holes and leaks in piping system (Not good thermodynamics, but it will not prevent operation)	*Pumping required* – Energy required to pump district hot water cannot be neglected in pricing calculations and increase the operating costs of the plant *Requires better pipe quality* – Any holes or leaks in the piping system will greatly reduce the system's performance. Large leaks and holes will render the system unusable.

The benefits and drawbacks of each transfer medium can explain the different growth patterns between U.S. and foreign district heating systems. Successful foreign district heating systems like Denmark, Iceland, and Korea have large penetration across their entire country including residential areas. This penetration is only possible because of the hot water transmission. U.S. steam systems have smaller radiuses, but offer heating services to larger heat consumers like downtown high-rises, industrial process plants, hospitals, and airports.

Government has also affected development of district energy systems worldwide. The national government of Denmark, for example, took a rather forceful approach in developing their district energy system. With the public funding, the government could forgo short-term profitability of the overall infrastructure and focus on long-term and societal benefits, which are paying off now. In the U.S. and other similar style free markets, short-term profitability cannot be ignored as easily. Although district energy offers many long-term and societal benefits (especially when it is combined with waste-heat recovery and CHP), those longer-term benefits are not fully economically incentivized, resulting in slower district energy growth.

Dense Urban Areas

As of 2007, 72 district energy systems were serving downtown city areas, serving a building floor area of close to 2 billion square feet, according to a collaborative report by the EIA and IDEA (IEA/IDEA, 2007). Combined, the dense urban district energy networks have an approximate heating capacity of 50,000 MMBtu/hour and an approximate cooling capacity of 1,000,000 tons.

Many of the most populous cities in the United States have turned to district heating and cooling in their downtown areas. Notably, New York, Philadelphia, Hartford, Washington, DC, and Baltimore all have established district energy systems. There are many cities also, including ones listed above, looking to expand on their district energy market penetration. Publicly driven feasibility studies have been performed in many of these cities and are made available in public archives. Notably, feasibility study results from Portland, OR and Seattle, WA have located multiple regions of their respective cities where district energy investments are promising (Compass Resource Management Ltd., 2009). Extrapolating, district energy has the potential for new market penetration in downtown regions in many of the most populous cities in the United States.

College and University Campuses

District energy is popular in the higher education realm, as it is a convenient solution that eases heating and cooling operation by centralizing the main equipment into one or a few plants. Universities and colleges have many features that favor district energy, including:

- A single owner: All buildings on university campuses are typically owned and maintained by one educational institute, therefore making connection to the district energy networks easier. Also, a full understanding each building use is known before connection to the district energy system.
- Long-term planning: Educational institutes have the privilege of being able to view investments from a long-term perspective. Universities do not move locations and have a steady income. Thus, a longer payback period on investment is acceptable compared to the expected payback of a private investor looking to profit from a district energy system.

As of 2007, there were 330 university and college district energy systems (IEA/IDEA, 2007). The International District Energy Association (IDEA) conducted a census survey of university and college district energy systems in 2002, that collected data on technologies used, capacity of systems, locations, and plans for growth at each respective university (International District Energy Association, 2002). The results showed that many universities have been using district energy for decades; the earliest district energy system reported was built in 1883 at the University of Northern Iowa.

A result of its early adoption, university district heating mirrors the rest of the United States in that 74% of district heating networks on campuses use steam as the heat distribution method. District cooling is not as prevalent as district heating, but the market share is increasing as universities continue to invest in district cooling systems. Only 69% of the IDEA census survey responders had campus district cooling.

Many universities have coupled their district energy networks with innovative heating and cooling strategies. Roughly a third of U.S. universities supply their district energy networks with exhaust heat from electricity generation, realizing a high fuel utilization factor with combined heat and power (Thornton, 2010). Many other examples of innovative heating and cooling strategies exist. Some (including Cornell) are described in more detail in Appendix C.

District energy in the education sector has grown faster than other sectors in the past, and is expected to continue to grow at similar rates in the future. The advantages favoring district energy systems in campus conditions are high, while many established university district energy systems can provide insight into future innovations. From the IDEA campus survey mentioned above, university representatives responded that capital restraints, space restraints, and fuel price uncertainty were the leading concerns and barriers for growth of district energy on each respective campus.

SECTION 2: ECONOMICS OF DISTRICT ENERGY

This section of the report presents two economic models to assess investment conditions and benefits of district energy. Model 1 uses collected construction cost information and utility rates to calculate a 25-year lifecycle cost for investment in a start-up district energy system. Model 2 analyzes the economic effect of recovered thermal energy by editing Model 1 to include a CHP application through absorption refrigeration.

Previous economic examples have already shown that district energy connection can result in a lower 25-year lifecycle cost than installing on-site equipment. Example 1 of ASHRAE HVAC Systems and Equipment 2012 Chapter 12 conducts a lifecycle cost comparison between an owner deciding to connect to a typical chilled water system or install on-site refrigeration equipment. The example results in the district cooling option resulting in a better 25 year net present value with realistic construction and operating costs for each thermal source (ASHRAE, 2012).

Model 1: Lifecycle Cost of District Energy Investment

Model 2 presents a 25-year lifecycle cost for a potential investment in a district cooling system. Table 3 on the next page presents the 25-year lifecycle cost of the system with the stated conditions. The model makes the following assumptions:

Construction costs (ASHRAE, 2012):

- Central plant = $2,500 per ton
- Distribution = $1,000 per foot of piping

General:

- Average plant efficiency = 0.85 kW/ton
- Average load demand factor = 0.8
- Discount rate = 5%
- Electricity escalation values taken from NIST Energy Price Indices and Discount Factors for Life-Cycle Cost Analysis - 2012 (National Institute of Standards and Technology, 2012)

Profits:

- Customer demand charges = $300/ton
- Customer consumption charges = $0.15/ton-hour

Expenses:

- Blended electricity rate = $0.10/kWh
- Operator salaries = $200,000/year
- Insurance, chemical, make-up water, and city sewer rates are assumed from rates found in ASHRAE HVAC Systems and Equipment 2012 (ASHRAE, 2012)

Table 3: 25-year lifecycle cost for a potential investment in a district cooling system – assumptions for the model are listed on the previous page

Cooling Plant Size	10000	tons
Direct-buried Piping	5000	ft
Plant Efficiency	0.85	kw/ton
Average Demand Factor	0.8	
Demand Charge	300	$/ton
Consumption Charge	0.15	$/ton-hour
Discount Rate	0.05	
Blended Electricity Rate	0.1	$/kWh

	Capital		Profits		Expenses						Totals	
Year	Initial Capital	Equipment Overhaul	Demand Charges	Consumption Charges	Electricity	Operator Salaries	Insurance	Chemicals	Make up Water	Sewer Charges	Net Annual Profit	Total Present Value
0	-$30,000,000.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	-$30,000,000.00	-$30,000,000.00
1	$0.00	$0.00	$3,000,000.00	$10,512,000.00	-$5,956,800.00	-$200,000.00	-$960,774.19	-$192,154.84	-$2,882,322.58	-$768,619.35	$2,551,329.03	-$27,570,162.83
2	$0.00	$0.00	$3,000,000.00	$10,512,000.00	-$5,778,096.00	-$200,000.00	-$931,950.97	-$186,390.19	-$2,795,852.90	-$745,560.77	$2,874,149.16	-$24,963,224.81
3	$0.00	$0.00	$3,000,000.00	$10,512,000.00	-$5,658,960.00	-$200,000.00	-$912,735.48	-$182,547.10	-$2,738,206.45	-$730,188.39	$3,089,362.58	-$22,294,517.26
4	$0.00	$0.00	$3,000,000.00	$10,512,000.00	-$5,658,960.00	-$200,000.00	-$912,735.48	-$182,547.10	-$2,738,206.45	-$730,188.39	$3,089,362.58	-$19,752,891.02
5	$0.00	$0.00	$3,000,000.00	$10,512,000.00	-$5,599,392.00	-$200,000.00	-$903,127.74	-$180,625.55	-$2,709,383.23	-$722,502.19	$3,196,969.29	-$17,247,981.93
6	$0.00	$0.00	$3,000,000.00	$10,512,000.00	-$5,539,824.00	-$200,000.00	-$893,520.00	-$178,704.00	-$2,680,560.00	-$714,816.00	$3,304,576.00	-$14,782,056.44
7	$0.00	$0.00	$3,000,000.00	$10,512,000.00	-$5,539,824.00	-$200,000.00	-$893,520.00	-$178,704.00	-$2,680,560.00	-$714,816.00	$3,304,576.00	-$12,433,555.97
8	$0.00	$0.00	$3,000,000.00	$10,512,000.00	-$5,480,256.00	-$200,000.00	-$883,912.26	-$176,782.45	-$2,651,736.77	-$707,129.81	$3,412,182.71	-$10,124,056.40
9	$0.00	$0.00	$3,000,000.00	$10,512,000.00	-$5,539,824.00	-$200,000.00	-$893,520.00	-$178,704.00	-$2,680,560.00	-$714,816.00	$3,304,576.00	-$7,993,897.25
10	$0.00	-$3,000,000.00	$3,000,000.00	$10,512,000.00	-$5,599,392.00	-$200,000.00	-$903,127.74	-$180,625.55	-$2,709,383.23	-$722,502.19	$196,969.29	-$7,872,975.19
11	$0.00	$0.00	$3,000,000.00	$10,512,000.00	-$5,658,960.00	-$200,000.00	-$912,735.48	-$182,547.10	-$2,738,206.45	-$730,188.39	$3,089,362.58	-$6,066,688.87
12	$0.00	$0.00	$3,000,000.00	$10,512,000.00	-$5,658,960.00	-$200,000.00	-$912,735.48	-$182,547.10	-$2,738,206.45	-$730,188.39	$3,089,362.58	-$4,346,416.19
13	$0.00	$0.00	$3,000,000.00	$10,512,000.00	-$5,718,528.00	-$200,000.00	-$922,343.23	-$184,468.65	-$2,767,029.68	-$737,874.58	$2,981,755.87	-$2,765,127.39
14	$0.00	$0.00	$3,000,000.00	$10,512,000.00	-$5,599,392.00	-$200,000.00	-$903,127.74	-$180,625.55	-$2,709,383.23	-$722,502.19	$3,196,969.29	-$1,150,440.65
15	$0.00	$0.00	$3,000,000.00	$10,512,000.00	-$5,658,960.00	-$200,000.00	-$912,735.48	-$182,547.10	-$2,738,206.45	-$730,188.39	$3,089,362.58	$335,595.57
16	$0.00	$0.00	$3,000,000.00	$10,512,000.00	-$5,599,392.00	-$200,000.00	-$903,127.74	-$180,625.55	-$2,709,383.23	-$722,502.19	$3,196,969.29	$1,800,164.04
17	$0.00	$0.00	$3,000,000.00	$10,512,000.00	-$5,480,256.00	-$200,000.00	-$883,912.26	-$176,782.45	-$2,651,736.77	-$707,129.81	$3,412,182.71	$3,288,888.05
18	$0.00	$0.00	$3,000,000.00	$10,512,000.00	-$5,480,256.00	-$200,000.00	-$883,912.26	-$176,782.45	-$2,651,736.77	-$707,129.81	$3,412,182.71	$4,706,720.45
19	$0.00	$0.00	$3,000,000.00	$10,512,000.00	-$5,480,256.00	-$200,000.00	-$883,912.26	-$176,782.45	-$2,651,736.77	-$707,129.81	$3,412,182.71	$6,057,037.01
20	$0.00	-$3,000,000.00	$3,000,000.00	$10,512,000.00	-$5,480,256.00	-$200,000.00	-$883,912.26	-$176,782.45	-$2,651,736.77	-$707,129.81	$412,182.71	$6,212,384.34
21	$0.00	$0.00	$3,000,000.00	$10,512,000.00	-$5,539,824.00	-$200,000.00	-$893,520.00	-$178,704.00	-$2,680,560.00	-$714,816.00	$3,304,576.00	$7,398,536.66
22	$0.00	$0.00	$3,000,000.00	$10,512,000.00	-$5,539,824.00	-$200,000.00	-$893,520.00	-$178,704.00	-$2,680,560.00	-$714,816.00	$3,304,576.00	$8,528,205.54
23	$0.00	$0.00	$3,000,000.00	$10,512,000.00	-$5,599,392.00	-$200,000.00	-$903,127.74	-$180,625.55	-$2,709,383.23	-$722,502.19	$3,196,969.29	$9,569,047.01
24	$0.00	$0.00	$3,000,000.00	$10,512,000.00	-$5,658,960.00	-$200,000.00	-$912,735.48	-$182,547.10	-$2,738,206.45	-$730,188.39	$3,089,362.58	$10,526,959.21
25	$0.00	$0.00	$3,000,000.00	$10,512,000.00	-$5,778,096.00	-$200,000.00	-$931,950.97	-$186,390.19	-$2,795,852.90	-$745,560.77	$2,874,149.16	$11,375,703.42

With the conditions listed, a 14-15 year discounted payback period was found. The accuracy of this payback period length is very volatile, however. Even slight differences in projected conditions could result in a large net present value difference over the course of 25 years. To analyze sensitivity of the model variables, the previous lifecycle model was run for many conditions and plant capacities.

Varying Plant Size

Figure 8 shows the effect of the plant capacity on the system's time period to return a full investment using Model 2.

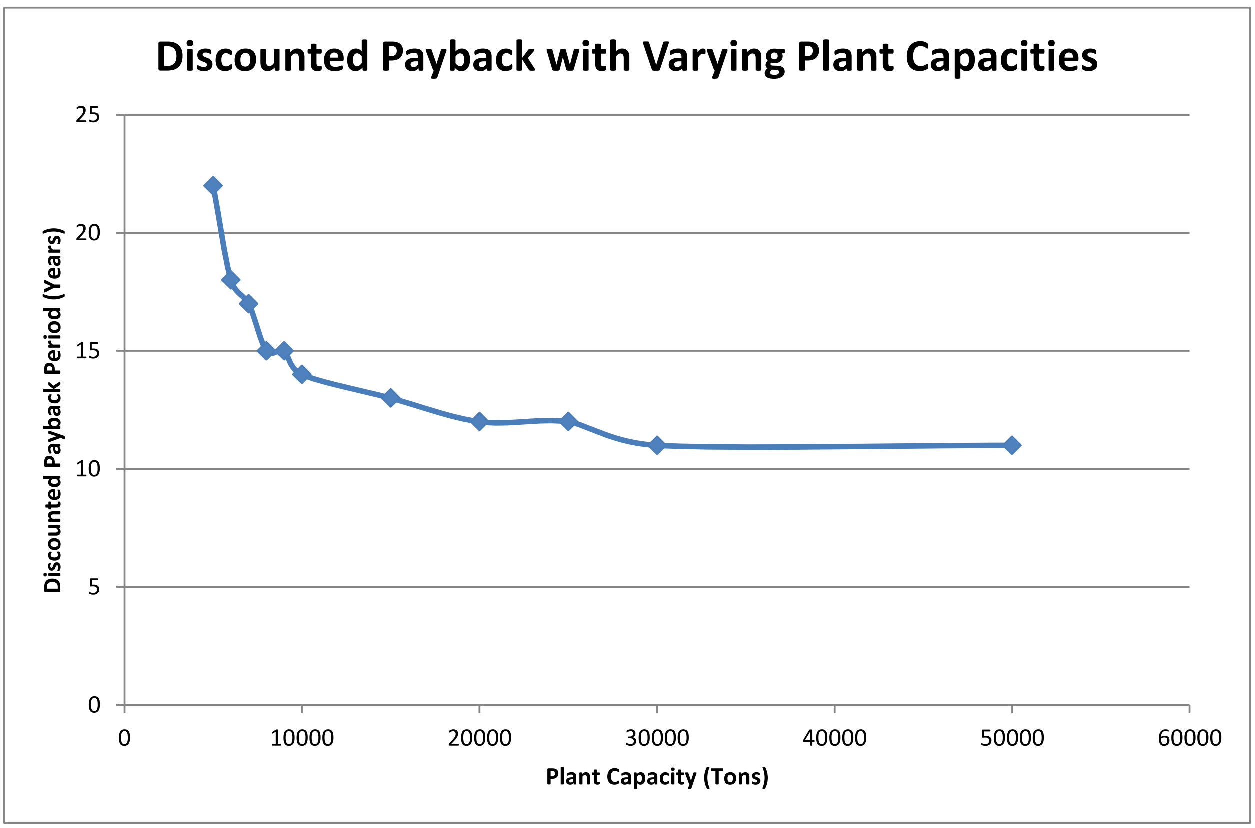

Figure 8: Calculated discounted payback period for varying plant capacities in Model 2 (Piping length remained constant, effectively varying load density)

The amount of pipe length required remained constant throughout each calculation shown in Figure 8, so this graph effectively shows that areas with larger load densities offer more attractive opportunities in district energy investment.

Varying Distribution Lengths

Figure 9 shows the payback period of the system when distribution length is varied.

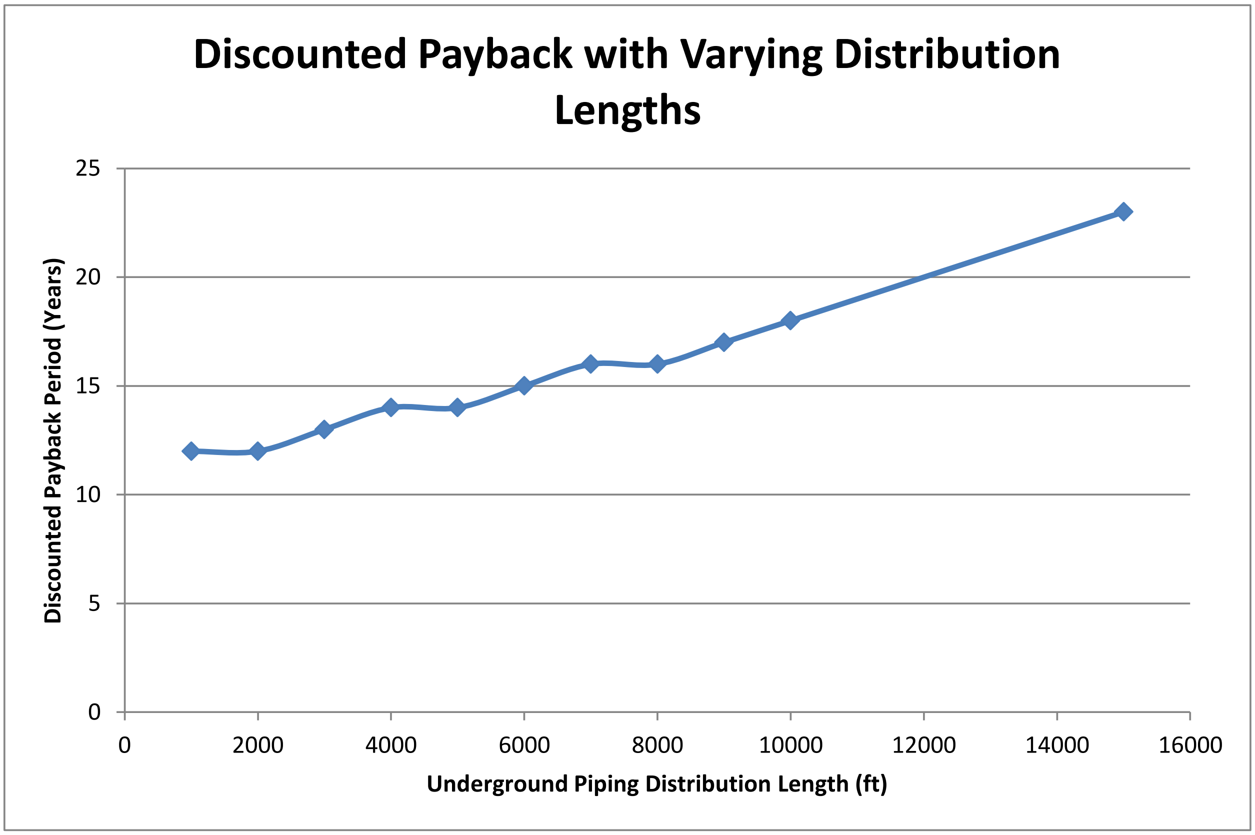

Figure 9: Calculated discounted payback period for varying pipe distribution lengths (Plant capacity remained constant, effectively varying load density)

Figure 8 and Figure 9 show similar results. Essentially, the load density is varied in this model, which shows again that higher load densities are more favorable towards district energy. Not taken into effect in Figure 9 is the additional transmission losses the system will receive due to the additional piping and pumping power required, which is significant. Therefore, the payback periods shown in Figure 5 are optimistic for larger distribution systems.

Varying Average Plant Efficiencies

Figure 10 shows the payback period of the district energy system when the central plant efficiency is varied.

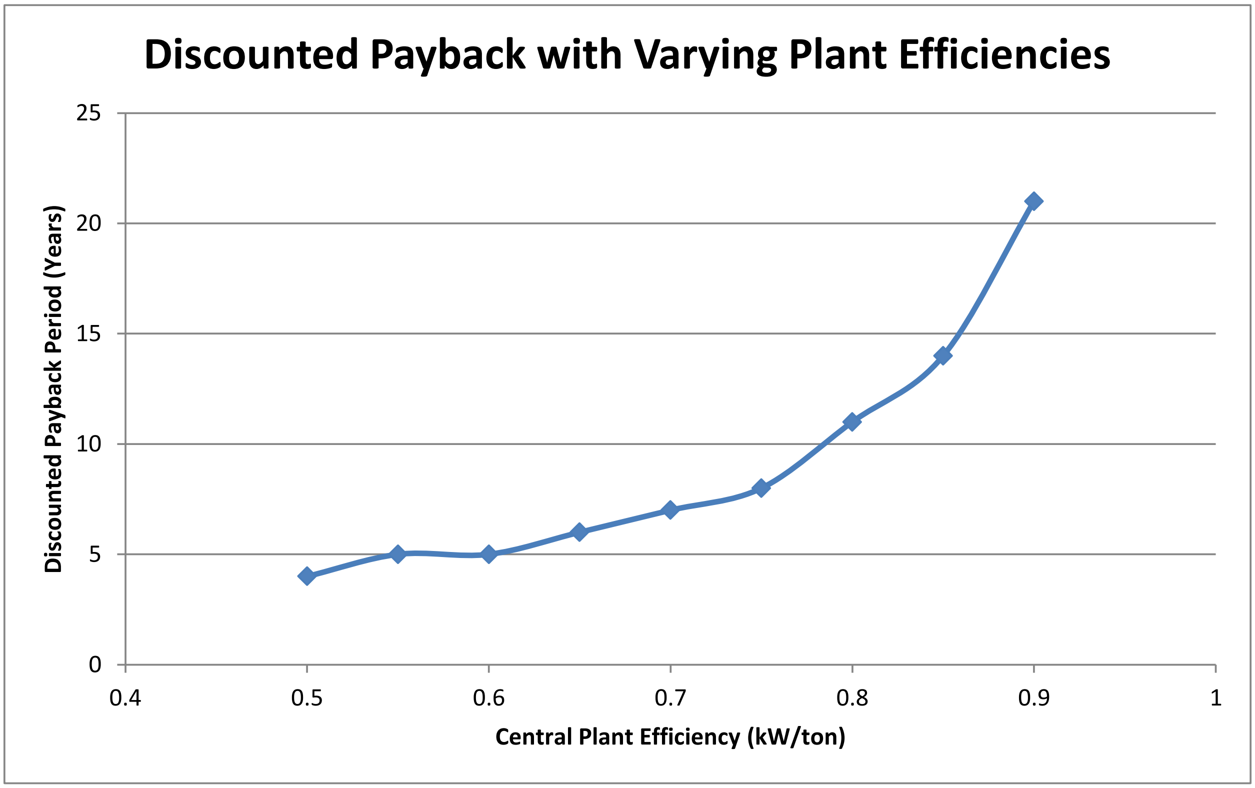

Figure 10: Calculated discounted payback period for varying district energy central plant efficiencies

The results from Figure 10 are obvious: worse plant efficiencies lead to worse return on investment. The rate at which the payback period increases is alarming, though. Even small differences in overall efficiency can make or break a system. It is crucial for district energy providers to utilize all of the opportunities to recover thermal energy from nearby wasteful sources. District cooling providers may be able to use absorption refrigeration to increase efficiency if exhaust steam is available.

Varying Average Load Demand Factor

Figure 11 shows the payback period of the district energy system when the connected load demand factor is varied.

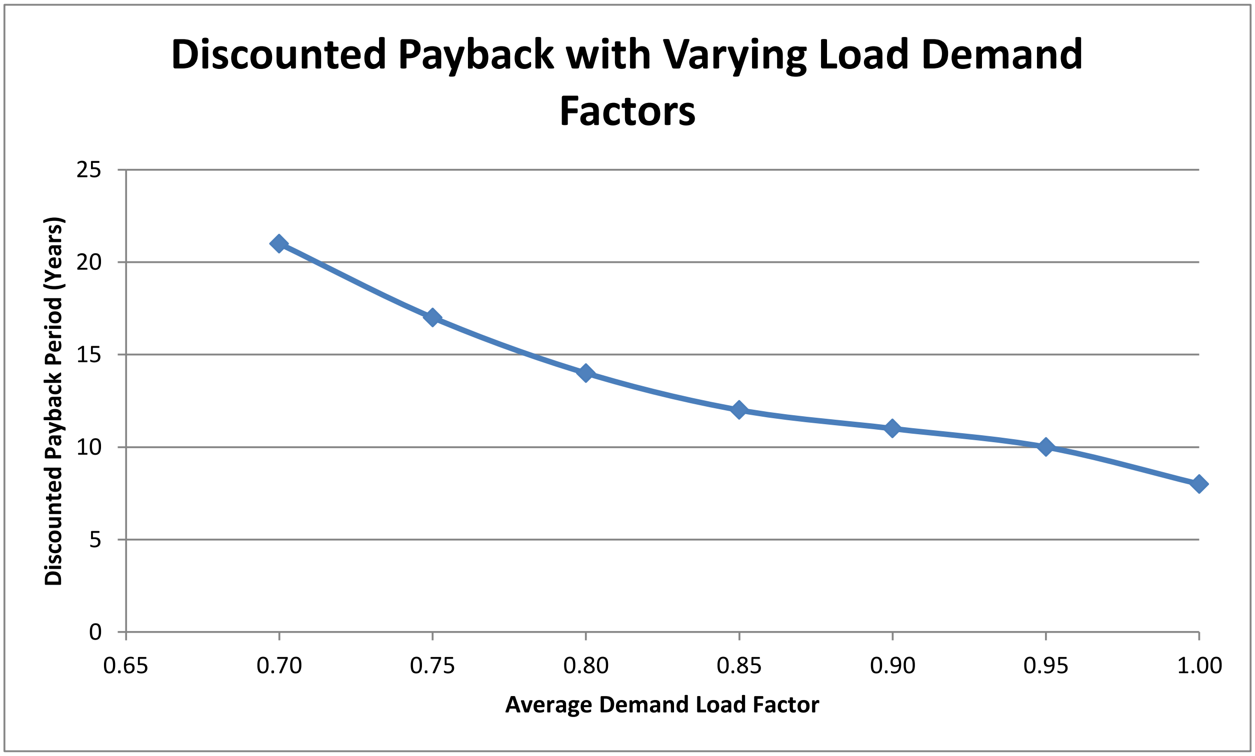

Figure 11: Calculated discounted payback period for varying average demand load factors

Utilization of the district energy is equally as important as the design of the central plant. Plants connected to a high load factor will be more profitable than plants connected to lower demand factored loads. Year-round heating requirements have aided many countries that operate developed district energy systems like Iceland, Finland, and Sweden.

Model 2: 25-Year Lifecycle Cost for a District Energy System with CHP

Model 2 is an edit of Model 1 by switching out 2000 tons of electric-driven cooling with the same capacity of absorption cooling. The heat input required for the newly added absorption chiller is collected from the exhaust of another process and can be considered "free" thermal energy. Electricity consumption in the model is appropriately adjusted.

The construction cost of the central cooling plant is also modified to consider relative costs between electric and absorption chillers. Price estimates from RS Means Mechanical Cost Data 2013 show that construction and installation of absorption chillers are significantly more expensive than electric chillers with similar capacity. A 955 ton indirect-fired absorption chiller is estimated to cost $766,000 (including O&P), while a 950 ton electric chiller is estimated to cost only $488,500 (Reed Construction Data, 2012).

Table 4 on the next page shows the result of the lifecycle cost analysis with the added CHP application. The result is an 11-12 year payback on the system, which is slightly better than the model without the CHP application.

Table 4: 25-year lifecycle cost for a district energy investment with 2000 tons of CHP application cooling through absorption refrigeration

Cooling Plant Size	10000	tons
Direct-buried Piping	5000	ft
Plant Efficiency	0.85	kw/ton
Average Demand Factor	0.8	
Demand Charge	300	$/ton
Consumption Charge	0.15	$/ton-hour
Discount Rate	0.05	
Blended Electricity Rate	0.1	$/kWh

	Capital		Profits		Expenses						Totals	
Year	Initial Capital	Equipment Overhaul	Demand Charges	Consumption Charges	Electricity	Operator Salaries	Insurance	Chemicals	Make up Water	Sewer Charges	Net Annual Profit	Total Present Value
0	-$33,408,400.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	-$33,408,400.00	-$33,408,400.00
1	$0.00	$0.00	$3,000,000.00	$10,512,000.00	-$4,765,440.00	-$200,000.00	-$960,774.19	-$192,154.84	-$2,882,322.58	-$768,619.35	$3,742,689.03	-$29,843,934.25
2	$0.00	$0.00	$3,000,000.00	$10,512,000.00	-$4,622,476.80	-$200,000.00	-$931,950.97	-$186,390.19	-$2,795,852.90	-$745,560.77	$4,029,768.36	-$26,188,815.56
3	$0.00	$0.00	$3,000,000.00	$10,512,000.00	-$4,527,168.00	-$200,000.00	-$912,735.48	-$182,547.10	-$2,738,206.45	-$730,188.39	$4,221,154.58	-$22,542,423.52
4	$0.00	$0.00	$3,000,000.00	$10,512,000.00	-$4,527,168.00	-$200,000.00	-$912,735.48	-$182,547.10	-$2,738,206.45	-$730,188.39	$4,221,154.58	-$19,069,669.20
5	$0.00	$0.00	$3,000,000.00	$10,512,000.00	-$4,479,513.60	-$200,000.00	-$903,127.74	-$180,625.55	-$2,709,383.23	-$722,502.19	$4,316,847.69	-$15,687,306.08
6	$0.00	$0.00	$3,000,000.00	$10,512,000.00	-$4,431,859.20	-$200,000.00	-$893,520.00	-$178,704.00	-$2,680,560.00	-$714,816.00	$4,412,540.80	-$12,394,600.20
7	$0.00	$0.00	$3,000,000.00	$10,512,000.00	-$4,431,859.20	-$200,000.00	-$893,520.00	-$178,704.00	-$2,680,560.00	-$714,816.00	$4,412,540.80	-$9,258,689.83
8	$0.00	$0.00	$3,000,000.00	$10,512,000.00	-$4,384,204.80	-$200,000.00	-$883,912.26	-$176,782.45	-$2,651,736.77	-$707,129.81	$4,508,233.91	-$6,207,339.67
9	$0.00	$0.00	$3,000,000.00	$10,512,000.00	-$4,431,859.20	-$200,000.00	-$893,520.00	-$178,704.00	-$2,680,560.00	-$714,816.00	$4,412,540.80	-$3,362,976.53
10	$0.00	-$3,000,000.00	$3,000,000.00	$10,512,000.00	-$4,479,513.60	-$200,000.00	-$903,127.74	-$180,625.55	-$2,709,383.23	-$722,502.19	$1,316,847.69	-$2,554,546.28
11	$0.00	$0.00	$3,000,000.00	$10,512,000.00	-$4,527,168.00	-$200,000.00	-$912,735.48	-$182,547.10	-$2,738,206.45	-$730,188.39	$4,221,154.58	-$86,524.62
12	$0.00	$0.00	$3,000,000.00	$10,512,000.00	-$4,527,168.00	-$200,000.00	-$912,735.48	-$182,547.10	-$2,738,206.45	-$730,188.39	$4,221,154.58	$2,263,972.20
13	$0.00	$0.00	$3,000,000.00	$10,512,000.00	-$4,574,822.40	-$200,000.00	-$922,343.23	-$184,468.65	-$2,767,029.68	-$737,874.58	$4,125,461.47	$4,451,792.50
14	$0.00	$0.00	$3,000,000.00	$10,512,000.00	-$4,479,513.60	-$200,000.00	-$903,127.74	-$180,625.55	-$2,709,383.23	-$722,502.19	$4,316,847.69	$6,632,093.93
15	$0.00	$0.00	$3,000,000.00	$10,512,000.00	-$4,527,168.00	-$200,000.00	-$912,735.48	-$182,547.10	-$2,738,206.45	-$730,188.39	$4,221,154.58	$8,662,541.45
16	$0.00	$0.00	$3,000,000.00	$10,512,000.00	-$4,479,513.60	-$200,000.00	-$903,127.74	-$180,625.55	-$2,709,383.23	-$722,502.19	$4,316,847.69	$10,640,139.12
17	$0.00	$0.00	$3,000,000.00	$10,512,000.00	-$4,384,204.80	-$200,000.00	-$883,912.26	-$176,782.45	-$2,651,736.77	-$707,129.81	$4,508,233.91	$12,607,066.64
18	$0.00	$0.00	$3,000,000.00	$10,512,000.00	-$4,384,204.80	-$200,000.00	-$883,912.26	-$176,782.45	-$2,651,736.77	-$707,129.81	$4,508,233.91	$14,480,330.95
19	$0.00	$0.00	$3,000,000.00	$10,512,000.00	-$4,384,204.80	-$200,000.00	-$883,912.26	-$176,782.45	-$2,651,736.77	-$707,129.81	$4,508,233.91	$16,264,392.19
20	$0.00	-$3,000,000.00	$3,000,000.00	$10,512,000.00	-$4,384,204.80	-$200,000.00	-$883,912.26	-$176,782.45	-$2,651,736.77	-$707,129.81	$1,508,233.91	$16,832,829.69
21	$0.00	$0.00	$3,000,000.00	$10,512,000.00	-$4,431,859.20	-$200,000.00	-$893,520.00	-$178,704.00	-$2,680,560.00	-$714,816.00	$4,412,540.80	$18,416,677.52
22	$0.00	$0.00	$3,000,000.00	$10,512,000.00	-$4,431,859.20	-$200,000.00	-$893,520.00	-$178,704.00	-$2,680,560.00	-$714,816.00	$4,412,540.80	$19,925,104.02
23	$0.00	$0.00	$3,000,000.00	$10,512,000.00	-$4,479,513.60	-$200,000.00	-$903,127.74	-$180,625.55	-$2,709,383.23	-$722,502.19	$4,316,847.69	$21,330,545.76
24	$0.00	$0.00	$3,000,000.00	$10,512,000.00	-$4,527,168.00	-$200,000.00	-$912,735.48	-$182,547.10	-$2,738,206.45	-$730,188.39	$4,221,154.58	$22,639,390.34
25	$0.00	$0.00	$3,000,000.00	$10,512,000.00	-$4,622,476.80	-$200,000.00	-$931,950.97	-$186,390.19	-$2,795,852.90	-$745,560.77	$4,029,768.36	$23,829,392.11

SECTION 3: FUTURE OF U.S. DISTRICT ENERGY SYSTEMS

This section describes the current barriers that are preventing growth of district energy in the United States. As stated before, district energy technology and design guidelines are well established. However, economic and political conditions are hindering growth of U.S. district energy infrastructure. Until these barriers are addressed appropriately, district energy will only experience modest growth, at best.

Barrier 1: High Initial Capital Required with Slow Return on Investment

Start-up district energy systems are by no means cheap. The systems require high upfront capital for costs including construction costs, feasibility studies, engineering design fees, and local permit fees. The high initial capital required for these projects makes larger systems more attractive investments. Payback periods are reduced for systems that are able to attach more customers to the network. Unfortunately, design and construction logistics are more difficult for these larger systems, as more piping length and interconnections will be needed. District energy systems that are built for dense urban areas can make construction site logistics especially hard to manage.

High initial capital would not be a barrier alone if the investment offered a good return on investment. However, as you can see from Model 1 in Section 2, the payback periods for investment in a district energy system are less than ideal for investors interested in short-term profit. Entities that are willing to sacrifice short-term profit for the long-term benefits that district energy offers (such as universities and hospitals) will continue to invest in district energy. However, in order to encourage a more accelerated growth pattern in U.S. district energy, return on investment needs to improve.

There are several ways in which the U.S. can improve return on investment for district energy. The states and federal government can offer grants and loans for district energy projects and offer short-term incentives for the societal benefits that district energy offers (discussed next). Right now, the U.S.

has some favorable policies that offer investors slightly more attractive return on investments. Particularly, the loan and grant programs for investments in clean and efficient energy projects set up by the Energy Policy Act of 2005 and amended by the Energy Independence and Security Act of 2007 have helped numerous projects realize shorter payback periods. One provision of EPACT 2005 (119 U.S.C. 594 § 1336) stated in section 1336 sets up federal grants for microturbine and fuel cell CHP. Section 373 of the Energy Independence and Security Act of 2007 (121 U.S.C. 1492 § 373) sets incentive programs for groups or states that employ waste heat recovery strategies. Individual states have also developed their own incentive programs for CHP and district energy applications. The loans and grants set up by these acts and by means of individual states may be found at the DSIRE database (US DOE, et al., 2013). Continuation of these types of programs is recommended to encourage growth of district energy.

Barrier 2: Low Fuel Prices

Heating and cooling is a highly competitive market. There exist many options to heat and cool a building, with a diverse fuels portfolio to select from. District energy systems can be fuel-flexible to account for relative price changes, but fuel-flexibility does not matter much in a situation with many cheap fuel options.

Low fuel prices in the U.S. market have hindered growth in district energy systems by making the capital-intensive options like district energy less attractive. Investment in more efficient infrastructure will not occur at a time when energy costs are low. District energy systems will become more attractive alternatives if overall energy prices rise.

Figure 13 shows fuel price index projections for the next 30 years calculated by the National Institute of Standards and Technology. The fuel price indices provide estimates in constant base-date dollars for future-year energy rates when multiplied by current energy rates.

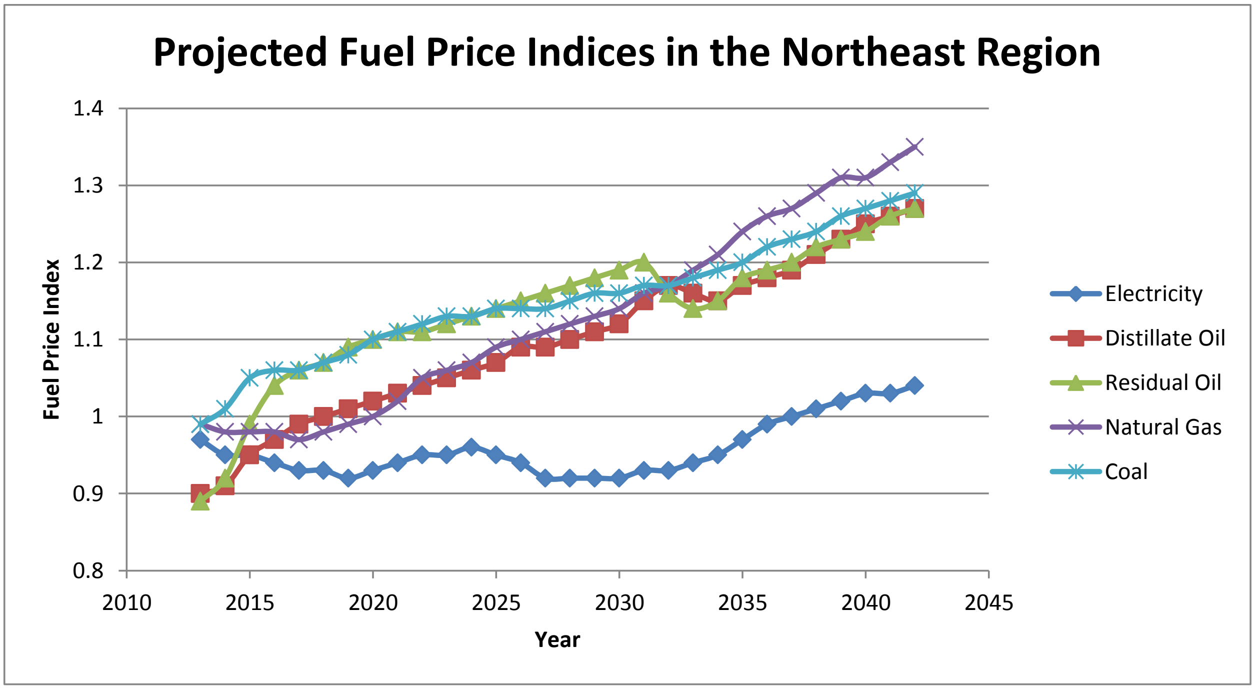

Figure 12: Projected fuel price indices for commercial end-use in the Northeast region (National Institute of Standards and Technology, 2012)

Next, current fuel prices were multiplied by the fuel price indices to view projected fuel prices per unit energy over the same time period. Figure 14 shows these projected fuel prices over time. Current fuel prices were collected from various EIA databases, and are entered into the calculation as follows:

Coal:
Northern Appalachia, 13,000 Btu/lb heating value
$62.10/short ton (US EIA, *Coal and News Markets*, April 1 2013)

Electricity:
Commercial, New England
$0.138/kWh (US EIA, *Electric Power Monthly*, March 2013)

Distillate Oil:
$4.20/gallon (US EIA, *This Week in Petroleum*, April 1 2013)

Residual Oil:
$2.20/gallon (US EIA, *Petroleum & Other Liquids*, February 2011)

Natural Gas:
Commercial Price
$7.81/thousand cubic feet (US EIA, *Natural Gas*, January 2013)

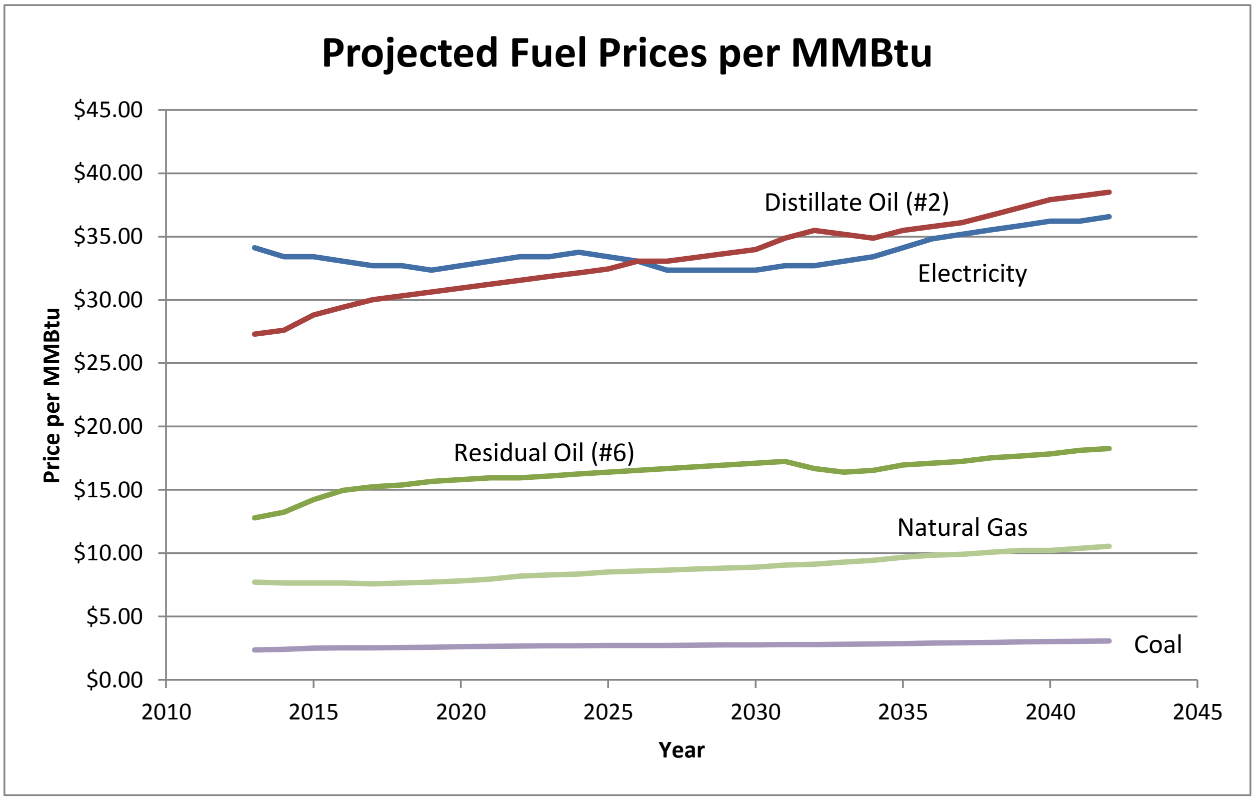

Figure 13: Projected fuel prices over time per MMBtu from NIST price indices and EIA reported current fuel prices

Figure 14 shows that only oil prices are expected to rise drastically. Natural gas and coal, which are two popular heating fuels, are projected to remain steady. The benefit of fuel-flexibility is rendered negligible if these fuel projections are found to be accurate over time since fuel prices are projected to be consistent. Likewise, electricity prices are not expected to increase drastically. An increase in electric rates could offer district cooling an advantage for district cooling systems that are able to use thermal recovery with absorption cooling.

Barrier 3: Lack of Short-term Incentives for Societal Benefits

Current market conditions do not offer incentives for many of the societal benefits that district energy can offer. District energy can reduce primary energy use (leading to reduced emissions, etc…), and can also increase property value inside the district energy radius. Those areas of downtown can be more attractive to potential building investors due to avoided capital and maintenance from heating and/or cooling equipment. District energy investors do not directly realize these societal benefits, and are thus left out of consideration when planning investments.

One possible solution is to publicly fund district energy systems, since the societal benefits are high. This approach has been done in U.S. cities before, notably District Energy St. Paul, which is a publicly funded non-profit district energy company. The city has been able to utilize some innovative energy solutions since the conception of that system. Some foreign countries have also viewed the societal benefits of district energy large enough to publicly fund the infrastructure, particularly the Scandinavian countries.

The federal government has indirectly favored district energy in the past by restricting practices harmful to society. Evidence shows that district energy grows when beneficial practices to society have been incentivized or enforced. A prime example is the effect of the Clean Air Act refrigerant phase-out on district cooling. Title VI of the Clean Air Act carries out the scheduled phase-out of ozone-depleting CFC's (chlorofluorocarbons) and HCFC's (hydrochlorofluorocarbons) as agreed upon in the international Montreal Protocol. Many of the to-be phased-out refrigerants were popular in building cooling systems at the time of enactment. Thus, in the mid-1990's when the phase-outs began, building owners switched to district cooling options rather than performing in-house cooling system overhauls. The option allowed the district cooling company to worry about the volatile refrigerant market, while locking in long-term cooling contracts that stabilized the building owner's cooling costs. The refrigerant market has since stabilized, with the long-term phase-outs already established through 2030.

Future advances in energy codes can support district energy growth for the same reason as the refrigerant phase-out. If existing buildings were to be strictly forced to use heating and cooling equipment with a minimum rated efficiency, district energy options can look very attractive. The building can connect to the system already meeting the efficiency minimums without a large equipment overhaul. EPACT 1992 (106 U.S.C. 2866) required states to create energy codes for commercial buildings, which led to the significant modification of standards such as ASHRAE Standard 90.1.

Barrier 4: Utility Regulation Policy

The current shift towards deregulation of the electric and natural gas markets could result in a rise of CHP and district energy. As these markets continue to be deregulated, new competition entering the market could drive more competitive pricing of both natural gas and electricity. New generation utility companies no longer have to sell electricity to the monopolized utility, but can rather sell electricity directly to the consumers. This set-up finally gives a fair chance to previously hindered companies like CHP plants that are able to sell a combination of thermal and electric energy at lower rates due to its primary fuel efficiency.

Growth in district energy will mirror growth in combined heat and power. It is not a coincidence that areas and sectors with a large market share of CHP also exhibit a large market share of district energy (Examples include university campuses, Scandinavian countries). District energy systems offer a convenient infrastructure to utilize exhaust heat from the prime mover of the CHP plant. Currently, electric utilities view CHP plants as an inconvenience as the utility must buy generation capacity to supply back-up power to the CHP plant. The utility will only agree to supply this back-up capacity for an increased rate, and often will give a counteroffer utility rate in order to deter the CHP investment by making it less attractive.

The U.S. government has used a forceful method in the past to require cooperation of the electric utilities with CHP and more efficient power plants through enactment of PURPA in 1978. The effects of PURPA are slowly wearing off as the contracts made between the electric utilities and non-utilities have been slowly expiring.

Deregulation has been the next approach used by the federal government to encourage more efficient energy generation. A competitive energy market will benefit generation companies that are able to realize better primary fuel efficiency. While utility deregulation is underway, there are still states that have yet to restructure their utility monopolies. Figures 15 and 16 show electric and natural gas restructure statuses by state, respectively.

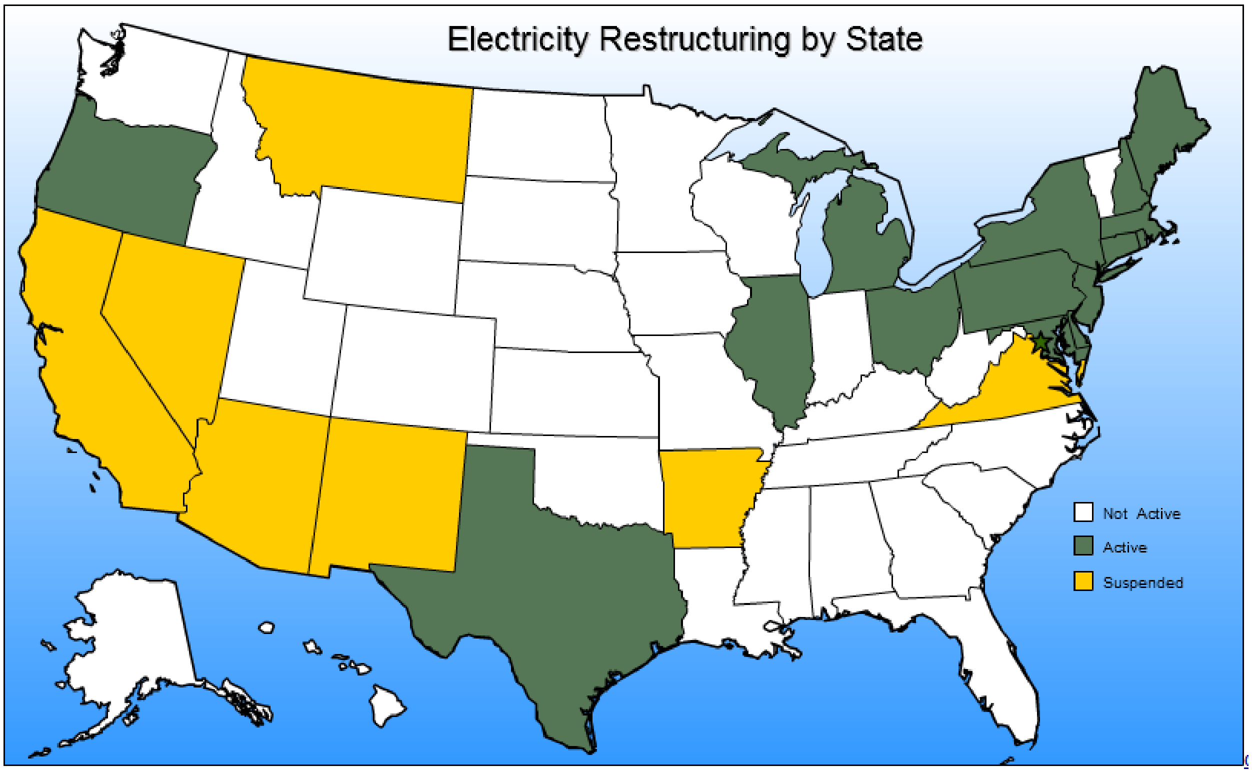

Figure 14: Electricity Restructuring by State in 2010 (US EIA. *Electricity.* 2010)

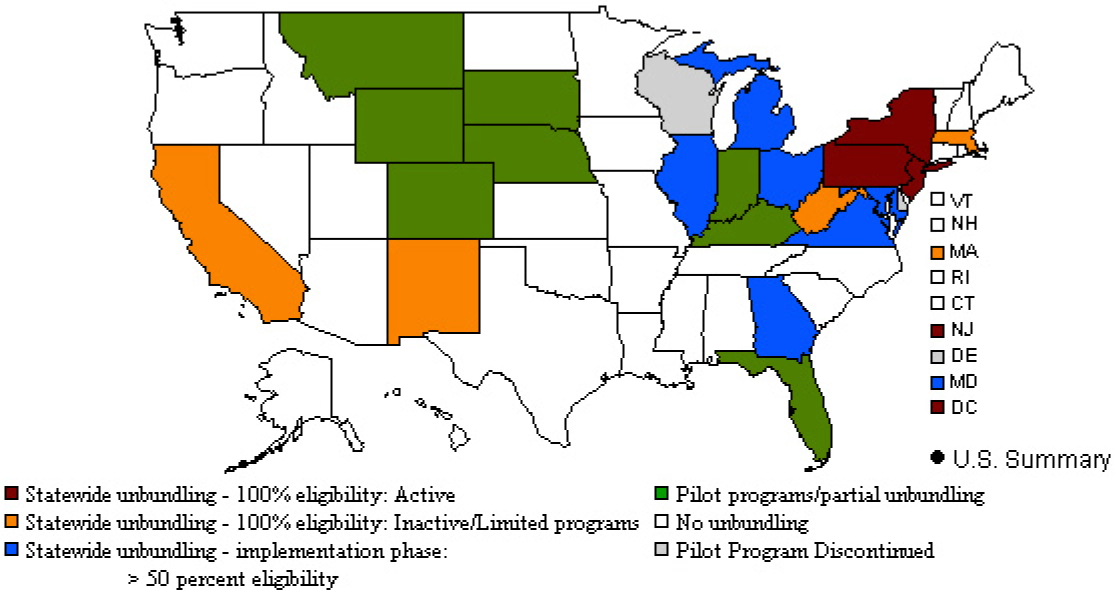

Figure 15: Natural Gas Restructuring by State, 2009 (US EIA. *Natural Gas.* 2010)

While it is different for each state, district energy systems in states that have not restructured their utility scheme are often being double-taxed as the district energy system is considered a utility because of their use of natural gas. This is an unfair and discriminatory policy towards district energy because competition in the heating and cooling markets is high. The higher taxing structure imposed on district energy systems has and still is hindering growth of future market penetration, even in areas where district energy will be beneficial to the city.

Barrier 5: Lack of Data Collection

District energy systems require information regarding thermal end-use of the buildings in the proposed area. Thus, feasibility studies are necessary prior to any sort of design conceptions. The "smart-grid" is an ideal solution, but is a far-off technology. The smart-grid is not required to create long-term energy plans, however. Information collected from utility bills can be useful in determining thermal load densities. Sub-metering in a sample selection of buildings in the given area can determine relative percentages of end-use consumption. Finally, meeting with utility and industry located in the area will offer perspectives on where thermal energy recovery can occur. Collection of all this information takes time, and if you are paying a consultant to do it, significant fees as well.

Cities and states can greatly support district energy solutions by spearheading the collection and reporting of thermal data regarding load density and wasted heat sources. The success of the CHP/district heating network in Denmark can be attributed to the public feasibility studies mandated by the First Heat Supply Law in 1979. Under the law, all cities were required to collect the above-mentioned data, and prepare reports that analyze where energy conservation strategies should be prioritized. The U.S. infrastructure could benefit from a similar national feasibility study.

Regardless, the public sector, whether it is the city, county, state, or country, still needs to be active in any district energy project. The local authorities in particular can offer the most helpful guidance to district energy investors by providing data relating to building heating and cooling loads, streamlining permits and construction fees, and sharing master plan information for analysis of future city growth. Cities can also assist in district energy investment by including it as a possible solution to their long-term energy goals. Portland, Oregon for example includes district energy systems as a key component to their long-term energy goals stated in their Climate Action Plan 2009.

CONCLUSIONS

District energy can be found in much of the United States. Current systems serve over 67,000 buildings which are mostly located in dense urban areas or on campus grounds like universities, hospitals, airports, and military bases. District energy offers many benefits to its users including ease of operations, fuel flexibility, and reduced energy use if the central plant is high efficiency or makes use of innovative heating/cooling strategies.

Rapid growth of district energy is apparent in campus environments like universities and hospitals. Long-term goals of these types of institutions match the long-term benefits of district energy systems. Also, a single campus owner reduces the complexity of district energy design. Growth in the campus sector will occur naturally – no additional help or incentives are required to encourage future growth of district energy in these types of systems.

The urban sector offers many possibilities for new district energy markets. However, multiple barriers were found that are preventing the growth of district energy systems in dense urban areas. The high initial capital required coupled with a long payback period is not enticing to potential investors in both the private and public realms. Current low fuel prices are driving the slow return on investment, as future revenue from the system is heavily based on primary fuel prices. Also, utility regulation is hindering system return on investment through double taxation of district energy systems owned by natural gas companies.

In short, this report suggests the following for policymakers, city planning boards, and professional societies related to district energy:

- Continue to collect census data on current district energy systems. Knowledge of previous successes and limitations will help potential future investors.

- Improve metering and sub-metering strategies for both thermal and electrical loads, particularly in dense urban areas. Accurate energy consumption information will ease district energy design. Also, gain an understanding where thermal energy may be recovered from wasteful sources in each respective city.
- Deregulate both electric and natural gas utilities across all states. Deregulation will force competing utilities to use primary energy in more efficient manners as energy costs rise, encouraging CHP and district energy. Increased competition could also result in more favorable rates to non-utility CHP plants.
- Incentivize the societal benefits from district energy systems to private investors. The incentives can be customized to match the long-term planning of each respective city, district, or state. Incentives should be designed to benefit systems that increase primary fuel efficiency.

APPENDIX A: AVAILABLE RESOURCES FOR DISTRICT ENERGY SYSTEMS

The following appendix is an annotated list of available resources that promote or offer policy and/or design help for district energy systems.

International District Energy Association (IDEA)

IDEA is a non-profit organization that serves to facilitate information exchange regarding district energy. The association is the premier source of information regarding district energy census data, and also hosts many articles and design guidelines surrounding district energy. IDEA is a highly recommended professional organization for any investors and designers that wish to view district energy options.

International Energy Agency CHP/DHC Collaborative

This collaborative was created to create a global CHP/district energy database for capacity, model political approaches towards CHP/district energy, and benefits clean energy infrastructure. The collaborative is a recommended source for policy makers looking to favor CHP and district energy in their respective region.

American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE)

Technology and engineering design guidelines involving district energy systems are well-established. ASHRAE in particular offers exceptional technical information in their published handbooks and journals. Chapter 12 of HVAC Systems and Equipment 2012 (ASHRAE, 2012) offers the following help for district energy systems:

- Applicability

- Economic Considerations
- Central Plant Design
- Thermal Distribution Design
- Connections to the System
- Metering
- Operation and Maintenance

ASHRAE also offers design guidelines for many topics indirectly related to district energy. In particular, Chapter 7 of HVAC Systems and Equipment 2012 discusses combined heat and power (CHP) and Chapters 11 and 13 of HVAC Systems and Equipment 2012 discuss thermal distribution mediums.

USGBC LEED Guides

The United States Green Building Council recognizes that connection to district energy systems can result in overall energy savings when compared to a baseline building with traditional heating and cooling equipment. Therefore, LEED credits can be fulfilled by connection to district energy systems by following the supplied district energy guides (U.S. Green Building Council, 2010).

U.S. Department of Energy Clean Energy Application Centers

These regional application centers promote the growth of CHP, waste heat recovery, and district energy across the United States. The application centers provide services including market assessments, education and outreach, and technical assistance for any potential investors and designers considering CHP and district energy technologies.

Database of State Incentives for Renewables & Efficiency (DSIRE)

This database can help any potential investors and designers view current incentives for clean and efficient energy investments. The incentives can be sorted by state or region, and show multiple types of incentives including grants, loans, and tax breaks.

APPENDIX B: CASE STUDIES

The following appendix is a small selection of unique district energy case studies not fully discussed in the report. The case studies are accompanied with lessons that can be learned from each district energy system.

Cornell Lake Source Cooling

In July, 2000, Cornell University finished a $58.5 million project that replaced all chillers in their main district cooling plant with heat exchangers that reject heat from the district cooling network to cool, deep lake water pumped to the plant from nearby Cayuga Lake. The conversion resulted in a significant 80% decrease in annual campus energy use for cooling, saving an annual 25 million kW of energy per year. The expected lifespan on the system is 75 to 100 years, much longer than typical heating and cooling equipment, and will thus result in decreased system overhaul costs (Cornell, 2005).

The lake source cooling project at Cornell proved that feasibility studies can be very expensive and time consuming. The project was proposed by the university in 1994, and required four years of environmental studies to prove that the additional heat rejected to the lake did not negatively affect the ecosystem of the lake. The project was finally approved by the New York State Department of Environmental Conservation in 1998.

University of Missouri

University of Missouri has had a long tradition of CHP and district energy systems, dating back to its first central power plant and district heating system in 1892. Today, the campus's energy infrastructure includes a CHP steam plant that generates 66 MW of electric power, and a district cooling plant with a capacity of over 24,000 tons. Close to half of the cooling capacity is achieved through steam absorption cooling (Coffin, 2009).

The district energy system at University of Missouri is renowned for its fuel flexibility. In particular, the university has had recent success with using various biomass fuels found locally in the state including shredded truck tires, corn cobs, and switch grass. Co-firing of these different biomasses with coal has led to reduced GHG and carbon emissions, while still maintaining stable combustion and high heat output. The lesson to take away is that the district energy network allowed the university to change fuel types in a cost-effective way, which will help the university comply with future climate and emission regulations.

District Energy St. Paul

District Energy St. Paul supplies district heating and cooling to the St. Paul and Minneapolis region. The hot-water district heating system heats approximately 200 buildings and 300 single family homes. The district cooling system has a capacity of 29,000 tons, which serves more than 60% of the downtown St. Paul area (District Energy St. Paul, 2013).

The system is served through various sources. A wood-fired CHP plant constructed in 2003 provides 25 MW of electricity to the grid, and supplies 65 MW of thermal energy to the district energy system, which is used for a combination of heating and cooling through absorption refrigeration. Various other heating-only plants complement the CHP plant. The wood-waste and other alternative fuels have proven to keep energy costs from the district energy system relatively stable, despite recent volatility of fossil fuels. Figure 17 compares the price of district energy from District Energy St. Paul with the price of natural gas that could be used for on-site heating equipment.

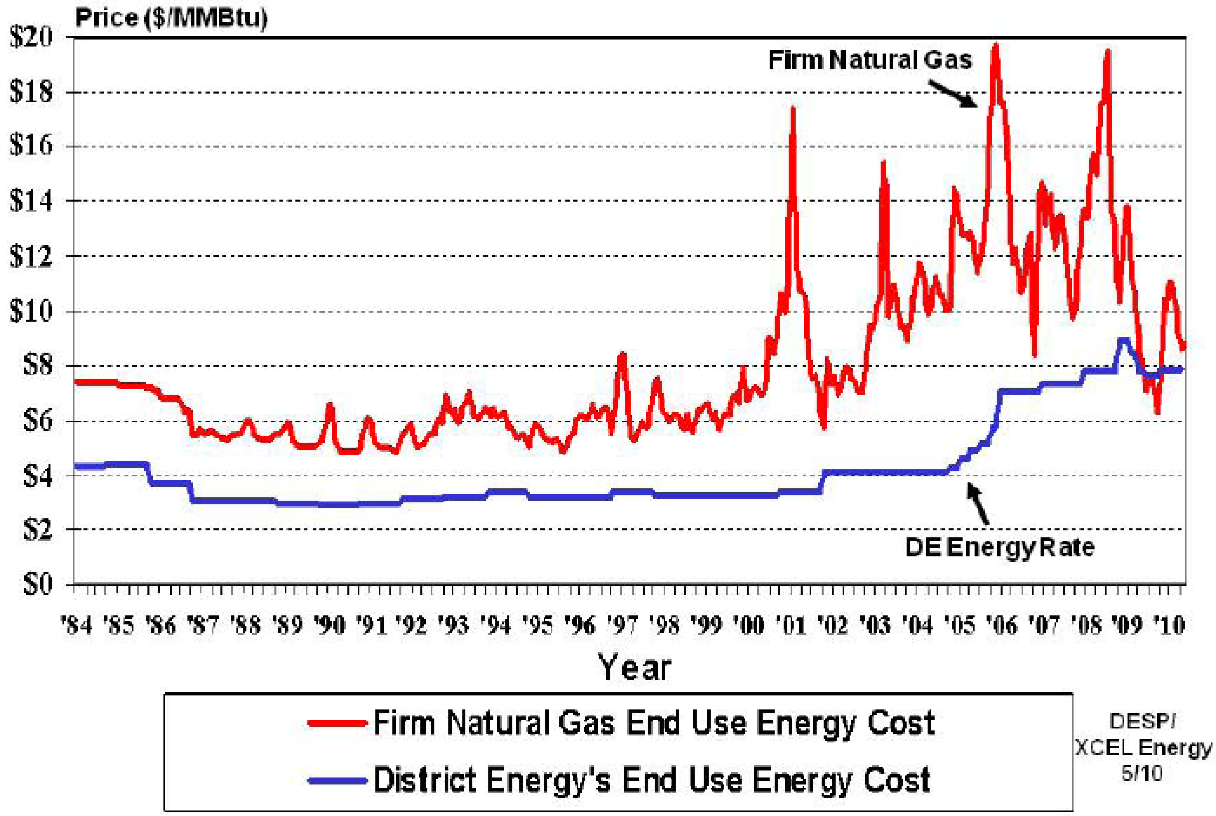

Figure 16: Energy Changes - District Energy St. Paul vs. On-Site (Burns, 2010)

REFERENCES

106 U.S.C. 2866

119 U.S.C. 594 § 1336. “Energy Policy Act of 2005”.

121 U.S.C. 1492 § 373. “Energy Independence and Security Act of 2007”.

16 U.S.C. 46 § 2601-2645. “Public Utility Regulatory Policies”.

American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE). *HVAC Systems and Equipment*. Atlanta, GA: 2012.

Burns, Michael. *District Energy St. Paul*. http://www.epa.gov/chp/documents/wbnr052010_burns.pdf. 2010.

Coffin, Gregg. *Growing Green Energy at Mizzou: University tests, incorporates biofuels.* IDEA District Energy Journal, Third Quarter, 2009.

Compass Resource Management Ltd., *Business Analysis for a Neighborhood Energy Utility in the North Pearl District*. Report prepared for the City of Portland. Vancouver, BC, 2009.

Cornell University. *Lake Source Cooling.* http://energyandsustainability.fs.cornell.edu/util/cooling/production/lsc/default.cfm. 2005.

Danish Energy Authority. *Heat Supply in Denmark: Who, What, Where, and Why.* Copenhagen, Denmark. 2005.

Database of State Incentives for Renewables & Efficiency. *Federal Incentives/Policies.* http://www.dsireusa.org/incentives/incentive.cfm?Incentive_Code=US02R 2012.

District Energy St. Paul. *District Energy St. Paul Brochure*. St. Paul, MN, 2012.

District Energy St. Paul. *History.* http://www.districtenergy.com/inside-district-energy/history/. 2013

EIA/IDEA. District Energy Services Commercial Data Analysis for EIA’s National Energy Modeling System. August 2007.

European Commission. Energy 2020: A strategy for competitive, sustainable and secure energy. Brussels, 2010.

European Commission. Energy Roadmap 2050. Brussels, 2011.

Hedman, Bruce. *CHP: The State of the Market*. U.S. EPA Combined Heat and Power Partnership 2009 Partners Meeting & NYSERDA CHP Roundtable. 2009.

HVAC Systems and Equipment. Atlanta, GA: American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), 2012.

International District Energy Association. *District Energy and Combined Heat & Power: Local Solution, Global Benefits.* Presentation for the US EPA CHP Partnership. http://www.epa.gov/chp/documents/wbnr052010_thornton.pdf. 2010.

International District Energy Association. *District Energy Space '10*. http://www.districtenergy.org/district-energy-space/. 2011.

International District Energy Association. Oak Ridge National Laboratory and the United States Department of Energy Census of Central Plant District Energy and CHP Systems at Colleges, Universities, Hospitals, Healthcenters, and Airports. 2002.

International District Energy Association. *U.S. District Energy Systems Map by State.* http://www.districtenergy.org/u-s-district-energy-systems-map/. 2009.

International Energy Agency. *Cogeneration and District Energy*. Paris, France. 2009.

National Institute of Standards and Technology. Energy Price Indices and Discount Factors for Life-Cycle Cost Analysis – 2012.

National Institute of Standards and Technology. Energy Price Indices and Discount Factors for Life-Cycle Cost Analysis – 2012.

Reed Construction Data. *RS Means Mechanical Cost Data 2013.* October, 2012.

Sherwood, Trudy. *District Energy St. Paul: CHP District Energy Fueled by Biomass.* The Minnesota Project, Minnesota, MN, 2003.

Spurr, Mark. *Thermal Renewable Energy and Efficiency Act of 2010.* IDEA District Energy Journal, Third Quarter, 2010

The International CHP/DHC Collaborative. CHP/DHC Country Scorecard: USA. Rep. Paris, France: International Energy Agency, 2007

The International CHP/DHC Collaborative. *CHP/DHC Country Scorecard: Denmark*. Rep. Paris, France: International Energy Agency, 2007

Thornton, Robert P. *IDEA Report: The District Energy Industry*. Rep. Westborough, MA: International District Energy Association, 2005.

U.S. Department of Energy, Interstate Renewable Energy Council, & North Carolina Solar Center. Database of State Incentives for Renewables & Efficiency. http://www.dsireusa.org/. 2013.

U.S. Energy Information Administration, *Commercial Buildings Energy Consumptions Survey*, 2003.

U.S. Energy Information Administration, *Natural Gas*. http://www.eia.gov/dnav/ng/ng_pri_sum_dcu_nus_m.htm. January, 2013.

U.S. Energy Information Administration. *Coal News and Markets.* http://www.eia.gov/coal/news_markets/. Release date April 1, 2013.

U.S. Energy Information Administration. *Commercial Buildings Energy Consumptions Survey*. Washington, DC, 1999.

U.S. Energy Information Administration. *Electric Power Monthly.* http://www.eia.gov/electricity/monthly/pdf/epm.pdf. March, 2013.

U.S. Energy Information Administration. *Petroleum & Other Liquids.* http://www.eia.gov/dnav/pet/hist/LeafHandler.ashx?n=PET&s=EMA_EPPR_PTA_NUS_DPG&f=M. February 2011.

U.S. Energy Information Administration. *This Week in Petroleum.* http://www.eia.gov/oog/info/twip/twip_distillate.html. April 1, 2013.

U.S. Energy Information Association. *Electricity.* http://www.eia.gov/cneaf/electricity/page/restructuring/restructure_elect.html. 2010.

U.S. Energy Information Association. *Natural Gas.* http://www.eia.gov/oil_gas/natural_gas/restructure/restructure.html. 2010.

U.S. Green Building Council. *Treatment of District or Campus Thermal Energy in LEED V2 and LEED 2009 – Design & Construction*. Washington, DC, 2010.

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