The Role of District Energy In Future Energy Systems

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ABSTRACT

This article provides an overview of district energy systems (DES) technologies including cogeneration, CHP, Combined Heat and Power, distribution systems and thermal energy storage. The role of DES as a catalyst for cogeneration and renewable energy, and as a way to reduce air pollution, greenhouse gases and ozone-depleting chemicals, is described.

The benefits of DES relative to economic growth, energy security and power grid reliability are explained.

A quantitative analysis is presented which compares DES integrated with CHP to conventional technologies for heating, cooling and power generation. The article draws substantially from a report prepared by the author for the U.S. Environmental Protection Agency.[1]

INTRODUCTION

What are District Energy Systems? District Energy Systems (DES) distribute steam, hot water and/or chilled water from a central plant to individual buildings through a network of pipes. DES provide space heating, air conditioning, domestic hot water and/or industrial process energy.

DES can use a diversity of energy resources, ranging from fossil fuels to renewable energy to waste heat. They are sometimes called "**community energy systems**" because, by linking a community's energy users together, DES provide opportunities to connect sources of waste energy (e.g., electric power plants or industrial facilities) or renewable resources with consumers who can use that energy. Heat recovered through Combined Heat and Power (CHP) or other sources can be used for heating or can be converted to cooling using absorption chillers or steam turbine drive chillers.

District Energy in the United States

DES in the United States primarily serve commercial and institutional buildings, although some multi-unit residential and industrial buildings are also served. Over 10 percent of commercial building space is served by district heating and over 4 percent is served by district cooling.[2] There are an estimated 5,800 DES in the US, providing over I quadrillion Btu (quads) of energy annually.[3]

Utility DES, which sell heating and/or cooling services to a number of independent building owners, represent only 2 percent of the total number of U.S. systems, but are estimated to represent about 16 percent of all district energy production. All remaining facilities are institutional systems, composed of a central plant and distribution network to serve buildings owned or managed by a single organization.[4]

Most DES in the US are steam systems, and many of these systems were developed decades ago. Decline of some of these systems in years past has led some to perceive district heating as an outdated approach. This perception persists despite the revitalization and significant growth that has occurred within the DES industry.

Since the late 1970's, numerous electric-utility-owned district steam systems have been purchased by companies whose sole business is DES. These specialists have invested heavily in upgrading existing systems to improve their reliability, efficiency, and cost-effectiveness.

The industry's recent growth has not been limited to the revitalization of existing systems. New systems have been constructed by DES utility companies, including for-profit and non-profit corporations, publicly owned municipal utilities and investor-owned electric and gas utilities. Many major utility companies have entered the district energy business during the 1990s, generally with unregulated subsidiaries operating district cooling systems using thermal storage.

Cogeneration and District Energy Internationally

Interest in DES and CHP has been stronger in many European countries. For example, in Denmark 55 percent of all building heating is provided from district heating, with 70 percent of district heat generated through CHP.[5] In Finland, district heating accounts for 45 percent of the heating market, with over 70 percent of district heat generated through CHP.[6]

CHP is a key element in the climate change strategies of many of our industrialized trading partners, including the United Kingdom, Denmark, Sweden, the Netherlands, Finland and Germany. In 1997 the European Commission proposed a strategy, in the context of the European Union energy policy, for facilitating the development of CHP and removing barriers to its market penetration.

The plan calls for a doubling of the current 9 percent CHP penetration in the European Union by 2010, providing an estimated reduction in carbon dioxide emissions of 150 million metric tons per year, or approximately 4 percent of the total European Union carbon dioxide emissions reductions in 2010.

Closer to home, Canada has recently moved to facilitate DES in a variety of programs with funding exceeding C$200 million and tax measures to level the playing field for DES.[7]

DISTRICT ENERGY TECHNOLOGIES

This section describes some of the key types of technologies used in DES, and notes recent advances in technology and research directions for the future.

Cogeneration (CHP)

Cogeneration is not one specific technology but a range of technologies that generate thermal and electric or mechanical energy using the same fuel. Steam turbines, gas turbines and reciprocating engine power generation technologies can all be adapted for CHP.

Gas turbine combined cycle plants use the hot gases exiting from the gas turbine to make steam, which drives a separate steam turbine which in turn spins a generator. Combined cycles reach significantly higher power generation efficiencies, and are the technology of choice for new merchant power plants. This technology can also be used for cogeneration.

In a steam cycle (steam turbine plant or the steam turbine in a gas turbine combined cycle plant), the power output drops as the temperature of the recovered thermal energy increases. Decreased output of electricity with higher-temperature thermal recovery is important to the economics of CHP because electricity is generally a more valuable form of energy. The total efficiency (thermal plus electric) in a steam cycle generally also drops with increasing thermal recovery temperature.

What limits the overall efficiency of many cogeneration/CHP systems is the limited availability of steady thermal loads, particularly lower-temperature thermal requirements that can be satisfied with CHP while maximizing power output and ensuring maximum overall energy efficiency.

The optimal use of energy resources occurs with CHP at lower recovery temperatures because this produces the maximum amount of work out of the primary energy consumed. For this reason, hot water rather than steam is generally the preferred distribution medium in new heating systems.

Space heating and water heating are relatively low-temperature energy requirements, whereas industrial process loads can range up to very high temperatures. Figure 1 shows examples of temperature requirements for various industrial end-uses, comparing those with typical space heating and domestic hot water temperatures for buildings.[8]

Most CHP configurations can achieve total efficiencies over 85 percent with a thermal recovery temperature below 250°F. Figure 2 illustrates a representative efficiency of CHP and contrasts this with current average US power plants and various new electric-only power plant technologies.

Energy losses in power generation represent a huge and growing source of carbon and air pollution emissions, during a period in which the US will be seeking to reduce total emissions to below 1990 levels (Figure 3). This adds up to enormous quantities of waste energy, with significant environmental implications.

Distribution Systems

District energy distribution technologies have advanced significantly, and further progress is coming. Modem district energy piping is manufactured in pre-insulated sections that is cheaper to purchase, install and maintain than older piping technologies. Distribution energy losses are minimal—e.g., 5 percent losses annually even in extreme climates.

Figure 1. Temperature requirements for building heating compared to industrial process end-uses.

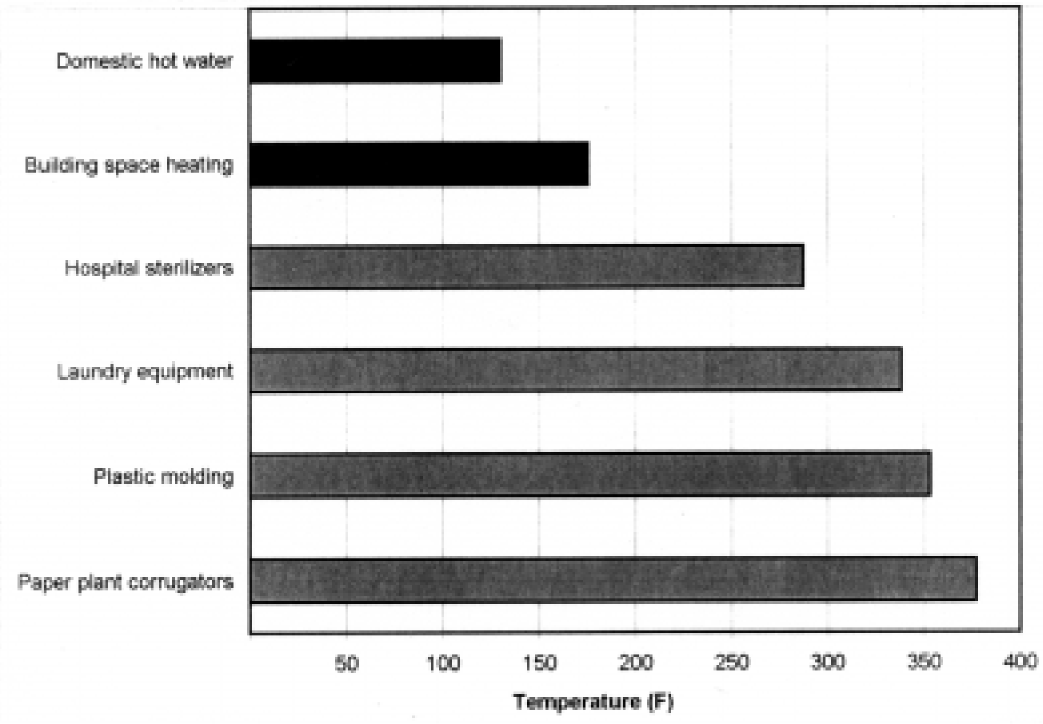


Figure 2 Representative total efficiencies (based on Lower Heating Value of fuel) achievable in non-cogeneration, and cogeneration/CHP plants, of various technologies.

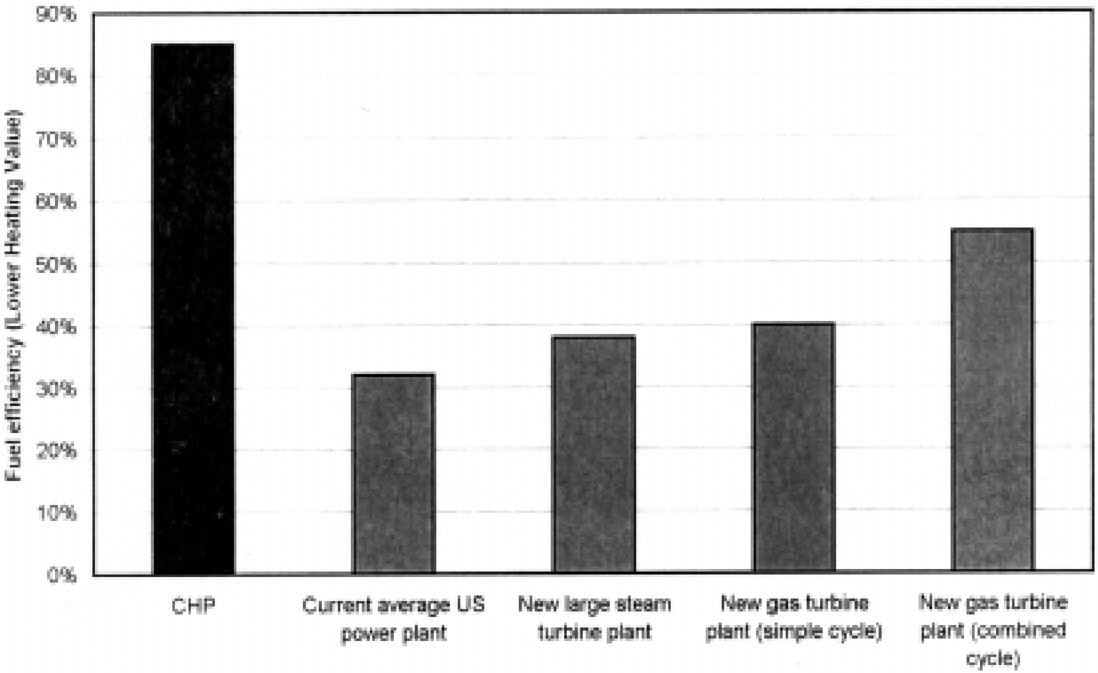
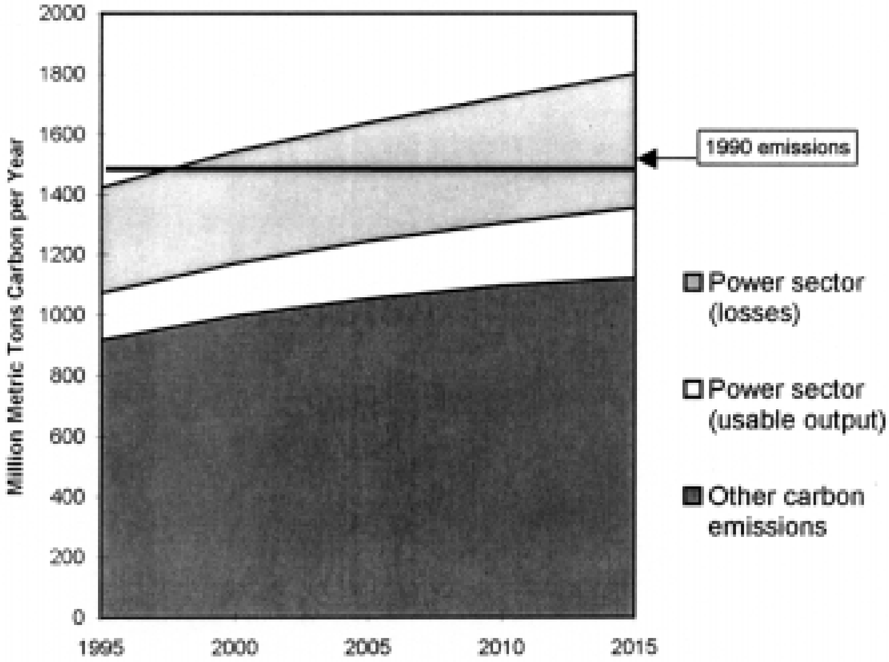


Figure 3. Carbon emission projections (from Annual Energy Outlook 1997, US Energy Information Administration)



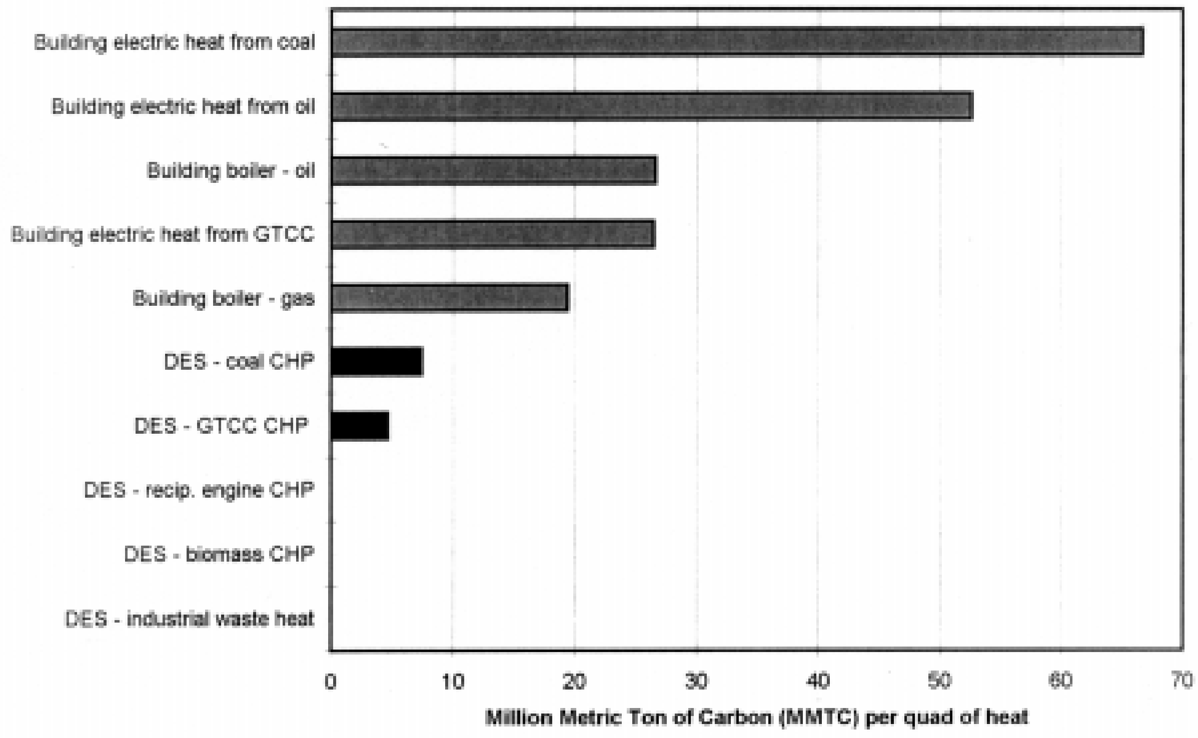
New distribution media and new technologies for pipe manufacture and installation are being developed. Plastic piping is seeing increasing use for both heating and cooling.[9,10] Friction reducing additives hold promise for reducing pipe size and decreasing pumping costs.[11] Ice slurries are being developed as a strategy for energy storage and reduction in pipe size.[12]

Thermal Energy Storage

Storage of chilled water or ice is an integral part of many district cooling systems. Storage allows cooling energy to be generated at night for use during the hottest part of the day, thereby helping manage the demand for electricity and reducing the need to build power plants.

In addition to reducing energy costs, the low temperatures achievable with ice storage, or chemicals which depress the freeze-point of water, help reduce distribution system costs and provide cost-benefits relative to building capital costs.[13,14]

Figure 4. Carbon intensity of building heating options. DES = District Energy System. CHP = Combined Heat and Power. GTCC = Gas Turbine Combined Cycle.



DISTRICT ENERGY ROLE

DES can play a variety of roles in our energy future by integrating multiple energy users and producers so that waste energy and renewable energy can be delivered to users. DES can act as the "community energy broker," delivering waste energy from a variety of power sector, industrial and commercial sources.

DES provides opportunities to strengthen energy infrastructure in a way that increases energy efficiency, reduces air pollution, combats global warming and decreases emissions of ozone-destroying chlorofluorocarbon (CFC) refrigerants. DES in institutional settings, e.g., universities, can be a key tool for minimizing campus energy costs and maintaining reliability as power industry restructuring occurs. (See following article.)

Heat Sink for Cogeneration/CHP

CHP is a key opportunity for productive use of waste energy. DES integrated with CHP (DES-CHP) can play a key role in increasing implementation of CHP. DES-CHP may take a variety of forms. The many existing DES at university campuses, military bases, hospital complexes and downtown areas represent a tremendous opportunity to implement CHP because these "heat sinks" have already been integrated into a sizable load.

In new development, a DES could link buildings in a industrial park or other development, thereby achieving sufficient load to implement technically proven, economical, low-emissions CHP.

DES-CHP is an important complement to the long-range effort to encourage CHP in the buildings sector through small-scale (<1 MW) CHP technologies. In the near term, a push to link buildings together through DES will boost progress toward the CHP goal because this approach enables installation of CUP technologies that are:

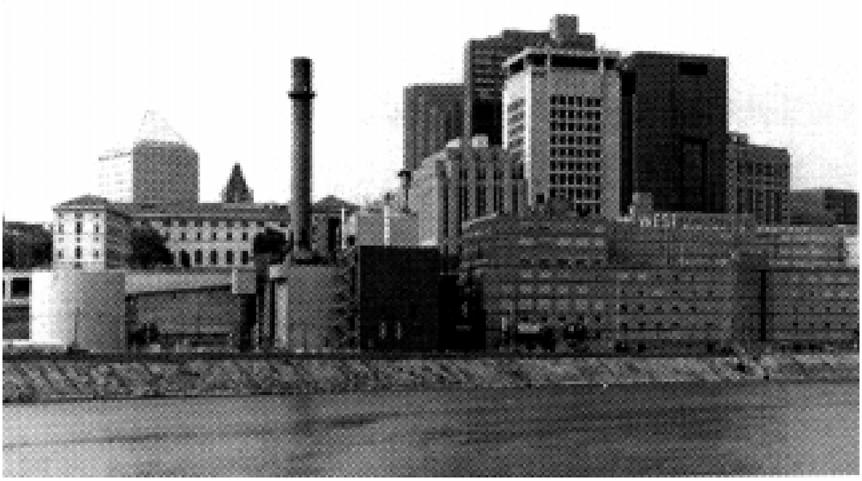
- Proven technically and commercially—"here and now;"
- Economically viable relative to both capital and operating costs;[15] and
- Environmentally attractive.[16]

In the long term, linking multiple CHP systems through DES can provide an economically and environmentally superior approach by optimizing the match between thermal and power loads. DES-CHP takes advantage of the diversity of thermal load patterns among many users.

Renewable Energy

DES can also play an important role in facilitating use of renewable resources, such as geothermal, biomass and natural sources of cooling, by providing the means to connect those resources to energy end-users. Examples include:

- Geothermal: "Earth energy" is directly used in many district heating systems in Western cities including Elko, Nevada; San Bernardino, California; Klainath Falls, Oregon; and Boise, Idaho.
- Biomass: District Energy St. Paul, the DES serving downtown St. Paul, Minnesota, is planning a 25 MW_e CHP plant fired with urban waste wood.



Located at the edge of downtown St. Paul, MN, District Energy St. Paul, Inc., provides hot water district heating and district cooling, and cuts peak power demand with a chilled water storage system. This community energy system is now developing a 25 MW cogeneration plant fired with urban waste wood.

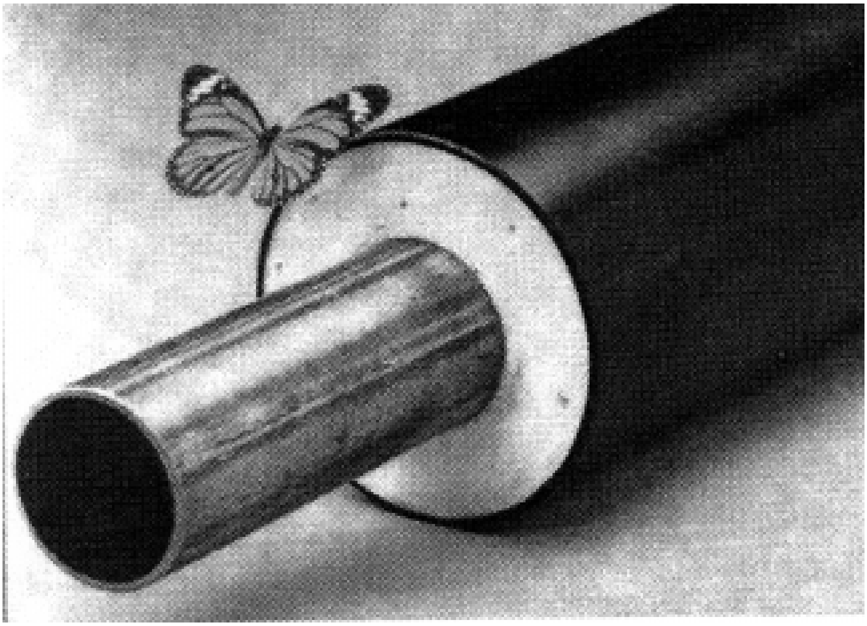
- Natural cooling sources: Cornell University is now starting up a district cooling system serving 10 million square feet using cold water from the depths of nearby Cayuga Lake.

Greenhouse Gases and Air Pollution

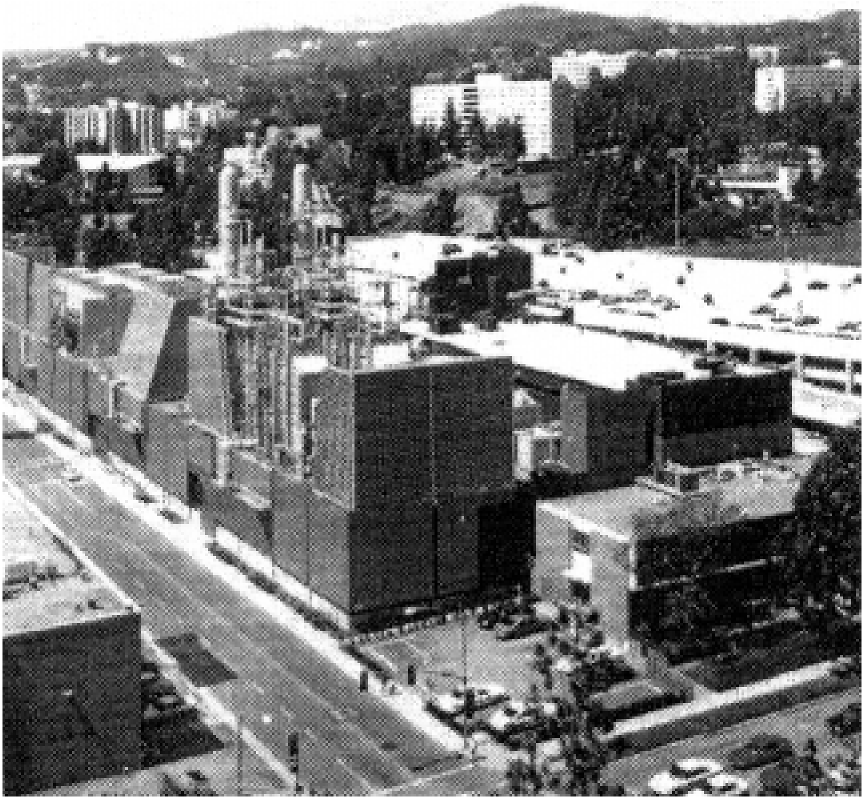
By increasing energy efficiency and effectively managing emission control systems, DES reduce emissions of greenhouse gases (GHG) and regulated air pollutants such as nitrogen oxides (NO_x), sulfur dioxide (SO_x), particulates and other pollutants.

Economies of scale and highly trained staff enable district energy systems to install, maintain and operate systems for superior control of air emissions from a variety of fuels, including coal. With CHP, DES can bring even more dramatic reductions in emissions compared to conventional technologies.

CHP and DES are economically productive approaches to reducing



Many new district energy systems use pre-insulated welded steel pipe, incorporating polyurethane insulation and a polyethylene jacket. These piping systems provide both high efficiency and high reliability.



The district energy system serving the University of California at Los Angeles, uses landfill gas in a combustion-turbine cogeneration plant to provide power, heating and cooling.

emissions because it is accomplished through pollution prevention, whereas traditional pollution control achieved solely through flue gas treatment provides no profitable output and actually reduces efficiency and output.

In addition, since CHP displaces older generating equipment with newer, cleaner and more efficient equipment, air pollution and GHG emissions are further reduced.

By increasing the productivity of our use of fuels, capital and human resources, DES-CHP can boost US competitiveness. Recovery and productive use of power generation waste heat is a critical first step in a productivity-oriented environmental strategy.

The advantage of district energy relative to reducing carbon dioxide emissions is illustrated in Figure 4, which shows carbon emissions in million metric tons of carbon (MMTC) per quadrillion Btu of thermal energy supplied for heating buildings from a variety of sources.

Ozone Depletion

Chlorofluorocarbons (CFCs) used as refrigerants in chillers destroy the stratospheric ozone layer. District cooling can be a key strategy for accomplishing an economical and environmentally wise phase-out of harmful refrigerants.

Through better staffing and operational practices for monitoring and control, district systems are better able to control emissions of whatever refrigerant is used. District cooling systems also provide excellent opportunities to use cooling technologies with zero impact on the ozone layer, such as ammonia or absorption chiller systems.

Economic Growth and Urban Revitalization

Many of our urban centers continue to decline, with businesses and jobs departing to the suburbs. Compared to suburbs, the urban core is usually at a competitive disadvantage relative to development costs, infrastructure and air quality.

District energy helps the urban core compete, during both system development and ongoing operations. DES help reduce capital costs for new or renovated buildings and help attract and retain businesses by providing heating and cooling which is economical and stable in price.

DES increase energy security and cost stability because they increase flexibility to use a variety of energy sources, including local energy resources. By using local human and energy resources, DES provide added growth as these expenditures multiply through the local, regional and national economies.

District cooling, particularly systems using ice storage, can significantly reduce the capital costs of new buildings by delivering low-temperature water. This reduces the size of the required building because space for air ducts is reduced. This is an added stimulant for new development.

Energy Security

The U.S. is still highly dependent on foreign energy sources, resulting in continued vulnerability to supply disruptions, price volatility and threats to our national security. DES offer significantly greater energy source flexibility compared to individual building energy systems, facilitating the substitution of domestic fuels and/or renewable energy sources for imported fuels.

Power Grid Reliability

DES can play a key role in furthering DOE goals relative to increasing power grid reliability, an issue of increasing visibility.[17] DES boosts grid reliability by: shifting demand to off-peak hours using thermal storage; delivering cooling end-use through district cooling systems rather than the power grid; and (with DES-CHP) generating power close to load centers.

QUANTITATIVE ANALYSIS

Approach to the Analysis

A quantitative analysis was prepared for the U.S. Environmental Protection Agency to address the energy efficiency, emissions and economics of DES with cogeneration and compares those characteristics to conventional separate generation of power, heating and cooling.[17] Two major categories of DES opportunities are quantified:

- new cogen/DES including plant and distribution systems; and

- retrofit of existing DES to incorporate cogeneration as a major source of energy.

The conventional scenarios are modeled to generate the same outputs as the DES:

- electric power to the grid;
- heating delivered to building space;
- and cooling delivered to building space.

For the conventional generation of power, two alternatives are modeled:

- new power plant capacity using the same technology and fuel as the CHP system (gas turbine combined cycle) but assuming a larger plant (260 MW) which has a lower cost per MW; and

- the mix of fossil fuel power generation projected by the US Energy Information Administration for the years 2000, 2005, 2010, 2015 and 2020.

Model DES

The efficiency, emissions and economics of DES will vary depending on a number of variables, including: system size; cogen technology; density of building space served; climate; and other plant and distribution technologies. The analysis is based on a model system that is relatively small (10 million square feet of building space), of medium density, in a northern climate and using a 28 MW gas turbine combined cycle cogen plant.

To provide a sense of perspective, in Table 1 the peak heating load of the model system is compared to peak loads for existing district heating systems.

The district heating system is assumed to distribute hot water at a temperature which varies from 250°F at peak heating conditions to about 190°F during the summer. With supplementary boilers available to boost the send-out temperature during colder conditions, the cogen plant was designed to provide hot water at 212°F.

In the model system, cogen provides 35 percent of the peak heating capacity and 76 percent of the annual heating energy. The balance of heating requirements is provided by gas-fired boilers. District cooling is provided with a combination of absorption chillers (driven with cogen heat), electric centrifugal chillers (driven with cogen power) and chilled water storage. Absorption provides 22 percent of capacity and 72 percent of energy. All DES electricity requirements are met with cogeneration, with most of the power exported.

Conventional Approach

Heating was assumed to be provided with a mix of new and older gas and oil-fired boilers. Cooling was assumed to be provided with a mix of new and retrofit electric centrifugal chillers. Power was assumed

Table 1. Comparison of peak heating loads for model systems with peak loads in selected existing systems.

	Peak heating send-out (million Btu/hour)
New York	13,548
Philadelphia	2,160
Detroit	1,800
Indianapolis	1,721
Milwaukee	1,200
U. of Minnesota	924
Baltimore	780
Minneapolis	744
Lansing	656
St. Louis	612
U. of Michigan	587
Seattle	540
Denver	498
Cornell U.	480
Pennsylvania State U.	444
National Institute of Health	402
U. of North Carolina	384
St. Paul	375
Hartford	372
Pittsburgh	366
Ohio State U.	365
San Francisco	338
Iowa State U. Ames	300
Birmingham	276
Lansing	270
Omaha	260
MODEL SYSTEM	**245**
Harrisburg	240
Tulsa	234
U. of Colorado Boulder	210
U. of Oklahoma	173
Oregon State U.	156
Nashville	144
U. of Alaska Fairbanks	112
Utah State U.	83
Fairmont	50
Willmar	29

to be provided under two alternative scenarios as noted above.

The new state-of-the-art gas turbine combined cycle plant is considerably bigger than the DES CHP plant (259 MW compared to 28 MW), so it has economies of scale which reduce the capital cost. In addition, this larger plant operates at 3 pressure levels, so its power generation efficiency is significantly higher than the power generation efficiency of the smaller plant operated in condensing mode.

The second calculation assumed the projected mix of fossil fuel-fired power plants for the years 2000, 2005, 2010, 2015 and 2020, based on US Energy Information Administration projections.

New DES reduces carbon emissions 58 percent compared to the projected year 2000 mix of fossil fuel power plants and 22 percent compared to new combined cycle plants.

Retrofit of Existing DES with Cogeneration

Existing DES represent a significant opportunity for implementation of CHP because these systems provide "thermal sinks" in which substantial capital investment has already been made for the infrastructure to distribute thermal energy to users. Fuel use and emissions reductions were based on the following fuel mix for existing DES: **60 percent natural gas, 28 percent coal and 12 percent fuel oil**.

Retrofit of DES with cogeneration reduces carbon emissions 61 percent compared to the projected year 2000 mix of fossil fuel power plants and 26 percent compared to new combined cycle plants. The payback for the cogeneration plant investment was highly sensitive to the price assumed for power exported for sale.

Integrated Analysis of Potential

The technical potential for DES development and achievable potential by the years 2005, 2010, 2015 and 2020 are projected as summarized in Table 2. Two sets of results are shown: the first assumes conventional power is provided with the projected mix of fossil fuel power plants in the years 2000, 2005, 2010, 2015 and 2020; and the second assumes that conventional power generation is provided with new state-of-the-art combined cycle plants.

DES has a technical potential to reduce carbon emissions over 150 million metric tons (MMT) by the year 2020 when compared to the projected 2020 mix of fossil fuel power plants. If DES is compared to the conventional approach assuming that all conventional power is

generated using state-of-the-art gas turbine combined cycle plants, the carbon reduction potential is 40 MMT by 2020.

The achievable results are based on the assumption that effective policies are implemented to address the barriers described above. There is an achievable potential by the year 2020 to implement new DES serving 9 billion square feet of building space by the year 2020 and to retrofit existing DES to provide 25 percent of current DES energy requirements with cogeneration.

Carbon Emissions

DES have achievable carbon reduction potentials for the years 2010 and 2020 of 21 MMT and 51 MMT, respectively, compared to the projected mix of fossil fuel power plants, and 5 MMT and 13 MMT, respectively, compared to new state-of-the-art power plants.

Nitrogen Oxide Emissions

DES would also reduce emissions of nitrogen oxide emissions in the years 2010 and 2020 by 0.34 and 0.81 million tons, respectively, compared to the projected mix of fossil fuel power plants, and 0.07 and 0. 18 million tons, respectively, compared to new state-of-the-art power plants.

Power Plant Capacity

The achievable 2020 DES development would avoid 57.5 GigaWatts of conventional electric generation capacity. This is equal to 14.3 percent of the new generating capacity projected by EIA to be required by the year 2020. In addition to providing peak power capacity for export, DES would also reduce peak power demand through demand shifting and by substituting delivered thermal energy for power otherwise required for cooling.

Energy Consumption

DES would reduce primary energy use in the years 20 10 and 2020 by 0.7 and 1.6 quads, respectively, compared to the projected mix of fossil fuel power plants, and 0.3 and 0.8 quads, respectively, compared to new state-of-the-art power plants.

Economics

To achieve the year 2020 potential, DES cogen will require a net

Table 2. Estimated technical potential and achievable potential for DES development, efficiency, emissions and economics through 2020.

	2005	2010	2015	2020	Technical Potential 2020
Power generation					
MWe generation capacity	6,000	19,000	34,000	50,000	150,000
MWe capacity provided or avoided	6,899	21,846	39,092	57,489	172,466
Displaced generation from electric-only power plants (TWh)	47	148	265	390	1,169
Building space served with new DES					
Additional billion square feet of building space served by DES	1.1	3.4	6.1	9.0	27.0
Annual primary energy savings (quads)					
Compared to conventional power generation using new GTCC plants	0.1	0.3	0.5	0.8	2.3
Compared to projected mix of fossil fuel power plants	0.2	0.7	1.1	1.6	4.9
Carbon emissions reduction (MMTCE/year)					
Compared to conventional power generation using new GTCC plants	1.6	5.0	9.0	13.3	39.9
Compared to projected mix of fossil fuel power plants	7.1	21.3	35.9	51.4	154.3

Nitrogen oxides emissions reduction (thousand tons/year)					
Compared to conventional power generation using new GTCC plants	22	70	125	184	553
Compared to projected mix of fossil fuel power plants	115	342	574	810	2,430
Additional capital investment (billion $)					
Compared to conventional power generation using new GTCC plants	$2.87	$ 9.07	$16.24	$23.88	$ 71.64
Compared to projected mix of fossil fuel power plants	$ 4.63	$13.86	$18.06	$19.54	$58.61
Reduction in electricity costs (billion $)					
Compared to conventional power generation using new GTCC plants	$ 1.49	$ 4.66	$ 8.45	$12.56	$37.69
Compared to projected mix of fossil fuel power plants	$ 1.49	$ 4.66	$ 8.45	$12.56	$37.69
Reduction in total annual costs (billion $)					
Compared to conventional power generation using new GTCC plants	$ 0.38	$ 1.16	$ 2.06	$ 3.10	$9.30
Compared to projected mix of fossil fuel power plants	$ 0.86	$ 2.29	$ 3.85	$ 5.21	$ 15.64

additional capital investment of $20-24 billion compared to conventional separate generation of heating, cooling and electricity, but will reduce annual costs by $35 billion.

CONCLUSION

District energy systems can make important contributions to achieving key goals for future energy systems, including reducing emissions of air pollution and greenhouse gases, enhancing power grid reliability, increasing energy security, and boosting local economies by using community energy resources to meet community energy needs. A variety of technologies and energy sources can be used in district energy systems. The most important near-term role for district energy is in facilitating expanded use of cogeneration.

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volving fund, supports project implementation. Loans from the fund will be repaid and then recycled to support new projects. Both programs will be administered by the Federation of Canadian Municipalities.

The new budget also continues CA$210 million (US$147 million) in support for the Climate Change Action Fund over the next three years. This money funds the implementation of technologies, including district energy, which reduce carbon dioxide (CO_2) emissions.

In February 2000, the Canadian government also announced two tax law changes expected to increase investment in district energy systems. The first change reduces the corporate tax rate for district energy systems from 28 percent to 21 percent. Although the budget proposal specifically addresses district steam systems, it is anticipated that this change will also apply to hot water and chilled-water systems when detailed provisions are written. The second tax law change raises depreciation for district heating investments from 4 percent to 8 percent per year.

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ABOUT THE AUTHOR

Mark Spurr is vice president of Kattner/FVB District Energy Inc., a district energy consulting firm with offices in Minneapolis, USA; Edmonton and Toronto, Canada; Stockholm and Vasteras, Sweden; Wroclaw, Poland; and Dubai, United Arab Emirates. Since 1990 Mr. Spurr has also served as Legislative Director of the International District Energy Association. In this role he is responsible for developing and advocating energy and environmental policies and programs to encourage the development and expansion of district energy systems.

For Kattner/FVB, Mark directs district energy consulting services for utility companies, municipalities, universities and other operators of central systems. His responsibilities include: district energy business development; feasibility and financial analysis; contract and rate structure development; marketing and sales assistance; strategic planning for energy utilities; environmental impact analysis; government affairs and regulatory issues. Current projects include development and advocacy of carbon dioxide emission trading mechanisms for promoting district energy and cogeneration as a climate change strategy for the International Energy Agency.

Mr. Spurr has over 20 years of experience in the energy industry, including 15 years of consulting experience in the district energy industry. Between 1985 and 1998 he owned and operated Resource Efficiency, Inc., a consulting firm specializing in district energy systems and CHP. His consulting work included:

- Feasibility analysis of district heating and district cooling systems, including load assessment, technology options and economic feasibility;
- Analysis of CHP technology options and economics.
- Analysis of utility service costs and rates;
- Marketing of energy services, including analysis of district energy services compared to alternatives for heating and cooling buildings;
- Strategic planning and management consulting for energy utilities;
- Analysis of the environmental impacts of energy systems.

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