Clean Energy Services Without Pain: District Energy Systems

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The techno-economic performance of district energy systems is evaluated for two specific Canadian locations. The comprehensive life cycle cost analyses based on detailed engineering cost data suggest that district energy systems are economically feasible today. In addition to economic attractiveness, district energy involves a number of urgent environment-related issues.

La performance techno-économique des systèmes d'énergie de district est évaluée pour ce qui concerne deux locations spécifiques au Canada. Les analyses exhaustives des coûts du cycle de vie en se fondant sur les données détaillées des coûts d'ingénierie suggère que les systèmes d'énergie de district sont économiquement faisables aujourd'hui. En plus de son attrait économique, l'énergie de district soulève un certain nombre de problèmes urgents qui sont liés à l'environnement.

This paper summarizes the results of a detailed study on the economics of district energy supply systems (Rogner, 1993) based on centralized combined heat and power generation (CHP or cogeneration). The competitiveness of district energy is assessed for two distinctly different sites, which may be viewed as bookends to the spectrum of conceivable district energy applications. The first site is a new suburban residential development project where the investment decisions are least affected by sunk cost considerations. Sunk costs, however, are a prime concern of the second site — the downtown core of Toronto. In both cases, district energy systems provide the full spectrum of residential and commercial energy services including space heating, domestic hot water, space cooling, industrial process energy and, of course, electricity for thermal and non-thermal uses. In an ideal configuration, all these services are distributed to the consumers via underground transmission and distribution systems.

The objective of this analysis is to develop a better understanding in a Canadian context of the benefits of district energy systems experienced elsewhere. Typically, Canadian energy

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prices have been significantly lower than in those European countries where CHP- based district heat systems have been successfully implemented. Also, energy policy at all levels of jurisdiction has incorporated a longer term view than is practised in Canada. The latter has given reason to believe that district energy systems must necessarily be subsidized by public funds. This report views district energy systems through the lens of full life cycle cost performance. The collateral environmental and other benefits associated with district energy systems definitely enhance the prospects for district energy. But first of all, district energy must outperform present heating and cooling service supply systems entirely on economic grounds.

District energy is a flexible and adaptive concept. There is no universally correct solution. Because the economics are essentially a function of the heat and cold distribution distances, district energy is a community-oriented concept. The geographical, climatic and infrastructure conditions vary greatly across Canada. Consequently, district energy must be evaluated on a location specific basis.

Why District Energy?

Low temperature heat accounts for some 35% of current Canadian final energy use. Not only residential and commercial space heating but also many industrial processes require heat at moderately low temperatures of less than 200°C. At present, most of this heat is supplied by fossil fuel combustion or electricity. The combustion of coal, oil or natural gas, however, involves temperatures far in excess of those needed for home heating or many process steam applications.

From the perspective of thermodynamics, the temperature difference between the products of combustion and the heat demand could be used to produce work, e.g., shaft power or electricity. Given current low temperature supply practice, this opportunity is forfeited. Likewise, the use of electricity for low temperature heat supply represents a mismatch between a high quality energy supply and a low quality form of energy demand.

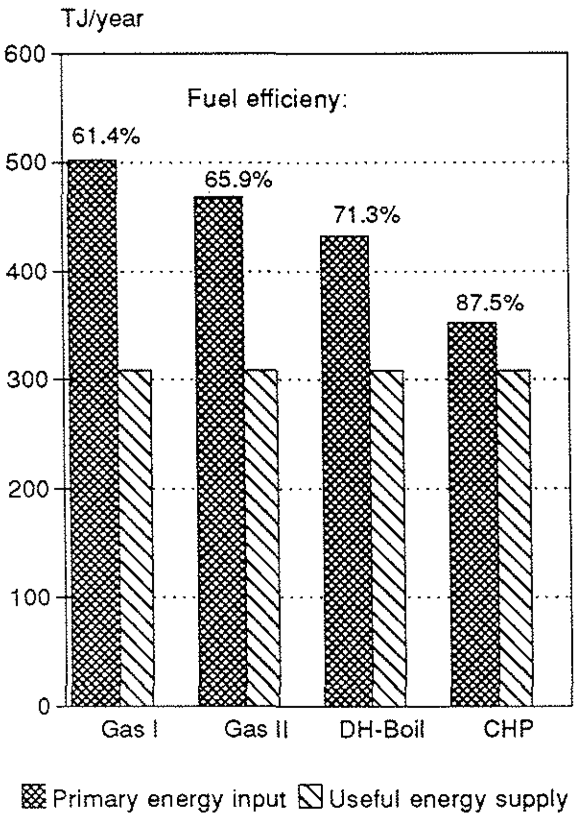
It is thermodynamically preferable to utilize the temperature difference between the combustion products and the low temperature heat demand to produce electricity, and to obtain the desired low temperature heat from the heat rejected in a steam condenser or by utilizing the combustion gases after the expansion in a gas turbine. The net thermodynamic effect is drastically improved fuel utilization.

With regard to the economics of district energy systems, the bonus of improved fuel utilization and thus lower fuel and operating costs occurs at the expense of high initial capital costs for the heat and cold distribution infrastructure. The economic feasibility of district energy, therefore, is often a trade-off issue between high up-front capital requirements but low fuel and operating costs versus low capital and higher fuel costs of conventional energy service supply systems.

The essence of any CHP district energy system is the use of the low temperature heat demand of densely populated areas as the sink for the rejected heat from standard power cycles.

Conventional electricity production based on vapor or gas cycles rejects up to 70% of the fuel energy input as waste heat to the environment. Although thermodynamics suggest that the heat rejected has little potential to produce additional work, the temperature of that heat may well match the requirements associated with space heating and low temperature process heat. Figuratively speaking, the space heating of buildings replaces the condenser of vapor power plants.

For some years the concept of fossil-fired combined heat and power generation has raised considerable interest among regional and urban planners. The basic attraction of a CHP plant is its overall high thermal efficiency (see Figure 1). Modern gas-fired combined-cycle plants achieve efficiencies in excess of 85%, i.e., an efficiency greater than the combined efficiency of a separately operating heating plant and electricity generating station. Higher efficiency means using less energy, reducing or avoiding some of the



Gas I	=	Average new gas-fueled individual building furnace technology
Gas II	=	Best available gas-fueled individual building furnace technology
DH-Boil	=	District heating based on centralized boilers
CHP	=	CHP using natural gas turbines with heat recovery for district heat

Figure 1: Fuel Efficiency of District Energy Systems

environmental externalities resulting from present space heating and cooling practices. The different energy service supply options and their associated fuel demand shown in Figure 1 are typical for a development area comprising some 3200 new homes. CHP curbs overall fuel use between 25 to 30% when compared to the individual building heating systems Gas II and Gas I. In absolute terms, the CHP option reduces natural gas use by some 115 and 148 million standard cubic feet (scft) every year, respectively.

The environment benefits directly from the reduced fossil fuel use. In addition, the single stack of a CHP plant is easier to equip with emission control devices than hundreds of dispersed residential furnaces and boilers.

While not necessarily utilizing rejected heat, district cooling can also be attractive. Centralized cooling and storage of chilled water curb the summer peak electricity loads by up to 50%. If absorption cooling is deployed for the cold production, heat diverted from the power cycle analogous to district heat provides the energy input to thee cooling process. Capital costs and the coefficient of performance of absorption chillers, however, leave much to desire. Alternatively, high performing electrically operated screw chillers may be used for centralized cold production. Irrespective of the central cooling technology deployed, the main economic benefit of district cooling is a drastic reduction in peak electricity load. To a large extent, this reduction is a result of cold storage.

A fully integrated district energy system provides heating, cooling and electricity services to its commercial, industrial and residential customers.

Barriers to District Energy

Although the much higher overall thermal efficiency and collateral environmental benefits of CHP energy systems are beyond debate, the economics of such systems depend greatly on the heat and cooling loads, the costs of delivering the energy services to consumers and the prices of competing technologies and associated fuels.

The diversity of factors determining the economics is further augmented by the fact that the distribution infrastructure of district energy systems is inherently capital intensive with payback periods resembling those in the utility sector. Consequently, utilities are best suited to own and operate district energy systems. Regulatory constraints, however, often confine utilities to generate and sell electricity. In addition, regulators are often concerned because there is no mechanism in place that would allocate costs to the different products of a CHP system in a truly equitable manner. These issues, and a general lack of knowledge about the benefits, have been effective barriers to the introduction of district energy in North America (MacRae, 1992).

Because the economics are very dependent on local circumstances, district energy systems have to be evaluated on a case by case basis. In this study two potential district heat applications are analyzed. The first application — a new residential development — is conventionally thought to be least accommodating for district energy. Although not hampered by existing infrastructures and sunk cost considerations, the urban sprawl type of housing development often results in too low energy load densities to justify the capital intensive heat and cooling distribution infrastructure.

The second application involves the core of downtown Toronto where heating and cooling load densities are most attractive for district energy. On the downside, existing non-amortized individual building plant and equipment tend to spread subscription rates over lengthy periods thus delaying the project's economic break-even point. The up-front capital costs for the construction of the thermal energy distribution system are particularly high in central metropolitan areas. In addition, the construction of the distribution system may cause temporary disruption to the daily routine of the downtown business life. Although not really a serious barrier, inconvenience may adversely influence the public perception of district energy.

District Energy Systems for a New Residential Development Area

The analysis of the new residential development case — labeled Greenfield scenarios for short — centers around the use of natural gas. Natural gas-fired CHP-based district heat and electricity supply compete against individual natural gas-based residential furnaces and electricity purchased from the public grid. Since this new development area adopts insulation standards which meet or exceed those postulated by the current Ontario Building Code, thermal energy off-take densities are modest, i.e., 2.8 W/m^2, which is well below the established minimum rule-of-thumb value of 10 W/m^2. Recent advances in heat distribution technology, however, have effectively lowered this minimum density requirement.

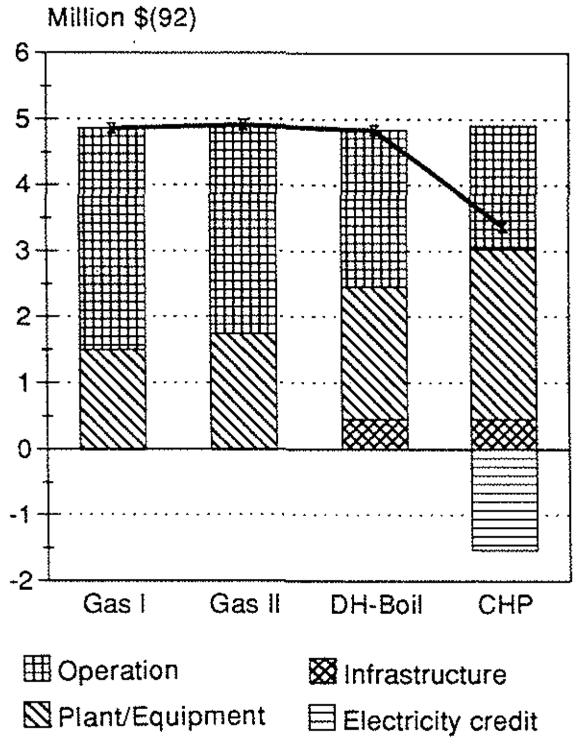
The Greenfield analysis does not include district cooling. The cooling load associated with a new residential development is too low and renders central cooling submarginal.

This study uses a life cycle cost approach which includes the capital, operating and maintenance costs and fuel costs of all technologies and infrastructures involved in the supply of the required energy services. The economic performance calculations are based on a real discount rate of 5.3%.

Figure 2 depicts the annual levelized costs of different energy service supply options. The bars above the zero line in Figure 2 contain the actual cost breakdown into capital costs for plant and equipment (home furnace or CHP), operating and fuel costs for thermal (heating an hot water) and electricity services, and infrastructure costs (district heat distribution grid, substations, etc.).

On an absolute annual cost basis all four options are almost identical. The CHP option, however, generates electricity in excess of the Greenfield requirements. Assuming an electricity credit of 2.0¢/kWh for electricity supplied to the public grid fetches some $1.5 million per year in revenues (bar below the zero line). The actual annual levelized costs for each option in Figure 2 is depicted by the solid line. CHP then becomes the least-cost heat and electricity supply option.

The analysis shows that CHP district heat is economically feasible despite the low thermal off-take density. The margin over the gas furnace alternative, however, is small and holds only under a utility-type of economic return.



Electricity credit: 2.0 cents/kWh

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Note: Line shows actual net costs, i.e., after deduction of electricity credits.

Figure 2: Levelized Annual Cost Profile —Greenfield Scenarios

District Energy for Downtown Toronto

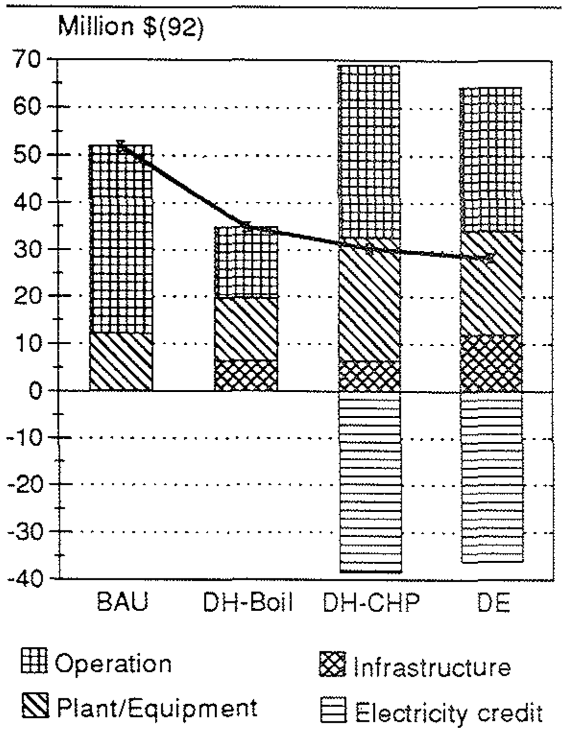
The Toronto case investigates the economic and environmental benefits of a fully integrated district energy system supplying all energy services to the downtown core of Toronto. The Toronto district energy scenarios developed in this study are based on the following premises:

1. Development of the Rail Lands for commercial and residential use. The Rail Lands are zoned for district energy.
2. Over a period of 10 years some 50% of the downtown buildings en-route of the district energy transmission lines will connect. En-route means a 400 m wide corridor over a distance of 3.5 km.
3. Reactivation of the Hearn Generating Station.
4. The Hearn station cogenerates electric, heating and cooling energy.

The district energy scenarios are evaluated against individual building gas furnace heating and electric air conditioning equipment.

The Toronto scenarios confirm the economic feasibility of district energy for a metropolitan area with high heating and cooling loads. This is particularly the case when a CHP generating site is nearby the energy intensive downtown core. As regards the annual levelized system costs for supplying all commercial and residential energy services, the findings of this study indicate that there is competition between different CHP district energy system configurations rather than between district energy and conventional energy service supplies. On average, district energy systems outperform the conventional alternative by 40%.

In this study, the development of the Rail Lands serves as a crystallizing event for the introduction of district energy to Toronto. The economic and environmental viability of district energy for the downtown core, however, does not hinge upon the development of the Rail Lands. The analysis accounted for the age structure of the existing downtown heating and cooling equipment. Sunk cost considerations tend to delay subscriptions to district energy systems and adversely affect its economic feasibility. Without the Rail Lands development, district energy remains the cost-optimal heating and cooling supply option (based on the 50% subscription assumption above) as long as the existing steam based district heat system is converted to hot water and integrated into the district energy system.



Electricity Credit: 3.34 cents/kWh

BAU	=	Business-as-usual: high efficiency individual natural gas furnaces and electricity-based air conditioning
DH-Boil	=	District heating based on centralized boilers, conventional air conditioning
DH-CHP	=	District heating and electricity based on CHP, conventional air conditioning
DE	=	District energy: electricity, district heating and cooling based on CHP

Note: Line shows actual net costs, i.e., after deduction of electricity credits

Figure 3: Levelized Annual Costs (Maximum CHP Electricity Production, Toronto District Energy scenarios)

Figure 3 depicts the annual levelized costs of different energy service supply options. As in Figure 2, the bars above the zero line contain the actual cost breakdown for the supply of an identical set of energy services. Here, the electricity credit for the CHP and DE options is 3.34¢/kWh which corresponds to the avoided costs of natural gas fired combined cycle generated electricity. The considerably higher credit than the 2.0¢/kWh assumed in the Greenfield scenarios results from the base-load operation of the CHP plants for maximum electricity generation. Here, the electricity generated exceeds the demand of the study area at all times and no electricity exchange is required.

On an absolute annual cost basis, DH-CHP and DE are more costly than the conventional (BAU) and district heat only (DH-Boil) options. This is not surprising, since CHP makes sense only as long as both products are rewarded their marginal costs.

What may be surprising is that district heat outperforms BAU by some 30% or $16 million per year.

Compared to individual, on-site building heating and cooling systems, all district energy alternatives produce significantly lower emissions to provide the same energy services. Reductions in SO_2 and NO_X of 90% can be achieved, while the reduction in the emissions of the major anthropogenic greenhouse gas CO_2 is at least 30%.

From the perspective of demand and supply management, district energy offers an exquisite opportunity for drastic electricity peak load reduction. The reduction potential is particularly large in Toronto where the cooling load is chiefly responsible for extreme summer electricity demand peaks. In fact, summer loads tend to exceed winter electricity peak loads. The key to peak electricity reduction is (1) centralized cold production at the Hearn site based on CHP generated heat and/or electricity; and (2) decentralized cold storage.

Figure 4 shows that some 140 MW of a peak cooling demand of 270 MW (for the downtown area analyzed in this study) is drawn from cold storage. In essence, cold storage reduces peak electricity demand by 140 MW. Moreover, district cooling technology does not depend on the use of chlorofluorocarbons (CFCs) and thus could become a least-cost option to eliminate CFC leakages from individual building chillers. One should also note that some 16% of the total cooling service originates from ambient sources (labeled

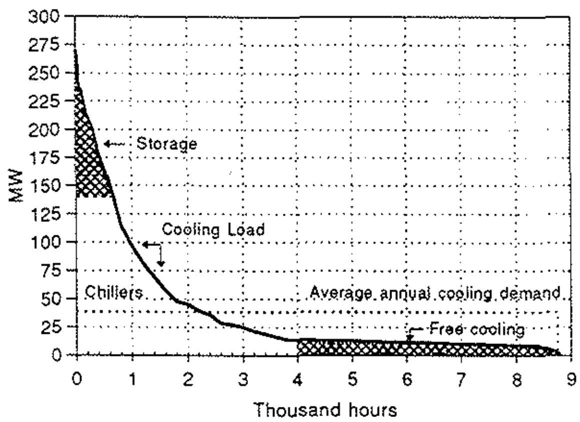


Figure 4: Annual Cooling Duration Curve for Toronto

"Free cooling" in Figure 4) such as air or lake water.

Conclusion

District energy systems present a rare opportunity to reduce costs and emissions simultaneously without any adverse effects on the quantities and qualities of the energy services provided. The analyses suggest that investment in district energy system should commence immediately. The economic benefits materialize without subsidies and do not depend on environmental regulation or policy. But they do depend on two essential deviations from current business practice: (1) the adoption of life cycle economics and (2) downstream integration to sell energy services rather than kWhs or BTUs.

Environment policy involving regulation or monetary incentives such as green taxes only better the prospect for CHP and district energy. To that extent, district heat and district energy represent least-regret cost energy supply options. The investment in these systems is well protected no matter how the future unfolds.

The ultimate beneficiaries of district energy are human health and the environment. In the short run, local air quality improves drastically. In the longer run, the reductions in greenhouse gas emissions help safeguard against climatic surprise.

References

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