Copenhagen's District Heating System – Recovered Waste Heat Cuts Carbon Emissions and Delivers Energy Security

By Robert P. Thornton

When the world's energy and environmental policy leaders converge on Copenhagen for the UN Climate Change Conference, they will be meeting, eating, sleeping and blogging in buildings served by clean energy from one of the world's best kept secrets—district heating. Copenhagen boasts one of the greenest and most innovative district heating systems in the world. Over 97% of the city's 35,000 buildings have no boilers and smokestacks, receiving all their space heating and hot water needs from an underground piping network. Yet when compared to spinning offshore wind turbines or gleaming blue solar panels, district energy is the Rodney Dangerfield of energy solutions. This highly efficient and reliable thermal energy infrastructure "gets no respect at all" and is virtually overlooked in climate and energy policy discussions.

The Copenhagen district heating system captures and uses surplus heat from electricity generating stations and waste incineration plants - heat that is normally wasted and simply released to oceans. An 800 mile network of underground pipes supplies over 165 million square feet of customer space with all their space heating and domestic hot water (Figure 1 – Copenhagen District Heating.). Recycling waste heat on this scale allows the 1.2 million citizens of Copenhagen to cut greenhouse gas emissions by 655,000 tons of CO_2 and displace 203,000 tons of oil consumption annually. The district heating network is the essential foundation for Copenhagen's transformation to one of the most energy-efficient cities in the world and should be the envy of any big-city mayor seeking city-wide sustainable solutions. Yet, most energy policy discussions focus on electricity and seemingly ignore that approximately forty percent of energy consumed is for heating and cooling buildings and industrial process heat.

Oil Embargo Economics as Catalyst for Policy Change

It wasn't always clean and green in Copenhagen. 36 years ago, at the time of the first oil embargo of 1973, Denmark relied on almost 80% imported oil. A severe price shock and supply curtailment nearly froze the Danish economy as the oil embargo triggered emergency nationwide measures to conserve oil, including a moratorium against driving on Sunday. Determined to reduce their economic exposure to foreign supply volatility, the Danish federal government, in conjunction with municipal governments, began a shift to indigenous energy supplies and away from fossil fuels.

By 1976, Denmark passed the Electricity Supply Plan to establish a national policy that electricity generating stations would be required to recover and reuse waste heat, rather than simply exhausting useful thermal energy to the oceans and atmosphere, thus establishing combined heat and power (CHP) as the standard for electricity generation. CHP systems can reach 90 percent energy efficiency, compared to less than 40 percent for electricity-only production, because the "waste" heat is used to heat and cool nearby buildings.

Denmark then passed the first Heat Supply Law in 1979, which contained regulations for heat planning in Denmark, launching a new public planning approach for municipalities to optimize investments in energy infrastructure. While the Heat Plan effectively diminished customer choice by mandating heating supply options, similar to zoning in the US where municipal sewer and water districts assess betterment fees to contiguous properties regardless of whether they hook up or not, the Heat Plan also served to reduce development risk and resulted in uptake rates of nearly 100% and even lower costs for customers. Consequentially, planners were able to optimize around environmentally desirable heat sources, such as co-generation of heat and electricity to exploit surplus heat from electricity generation. Denmark still relies on coal for 52 percent of its electricity, but the efficiency gained through CHP has allowed the country to reduce its emissions substantially. Nearly 60 percent of Danish electricity is produced in CHP plants, compared to a global national average of only 9 percent.

In 1984, the five Mayors of Copenhagen, Frederiksberg, Gentofte, Gladsaxe and Taarnby decided to scale up and set up a common wholesale district heating network. This heating transmission backbone is analogous to the high tension electricity transmission business, operating out of a modern operations control center in Frederiksberg. The Metropolitan Copenhagen Heating Transmission (CTR) runs the system in partnership with an affiliated company in the west of the city, known as VEKS. The two networks, CTR and VEKS are interconnected so that excess heat and/or reserve capacity in the one area can be utilized by the other and as a result, the district heating system is extremely reliable. The wholesale heat networks collect, dispatch and manage heat supply from four CHP stations, four waste incinerators and more than 50 peak load boiler plants with more than 20 distribution companies in one large pool-operated system, with a total heat production of around 30,000 terajoules. Copenhagen takes 70% of its total heat. The combined capital investment of 3 billion DKK ($ 562 million) for the network was financed through foreign currency loans and tax incentives for the energy companies.

The most efficient CHP plants have an energy efficiency approaching 90% and are dispatched based on competitive pricing. One example are the modern and sleek Avedøre 1 & 2 CHP plants that produce 810 MW of electricity and 900 MW of thermal energy at an average fuel efficiency of over 90%. (Figure 2 – Avedøre CHP. Photo courtesy of Jorgen K H Knudsen.) By simultaneously generating heat and electricity, Avedøre Power Station's Unit 2 utilizes as much as 94 % of the energy in the fuels and has an electrical efficiency of 49%, an achievement that makes the unit one of the most efficient in the world. The share of district heating produced at CHP plants in Denmark has more than doubled, from 39% to 80%, since 1980. Similarly, the share of electricity cogenerated with heat has gone up from just under 18% to over 60% in 2006. (Figure 3 - CHP Share)

Tax Incentives and Consumer Economics

In the mid-1980s, the Federal Government introduced tax incentives on fuel for electricity plants. Electricity generators paid less fuel tax if they used CHP (in some cases this amount equated to less than 50% tax incentive). This enabled the companies to sell heat to consumers at a lower price and discouraged inefficient combustion in individual boiler plants.

The price for district heating is highly competitive to other forms of energy. CTR's heating price, which is a pool system price, is identical for all five municipalities, and has basically been stable over the life of the system. Annual costs per household are half that of oil, for example. About 30% of the annual district heating demand is covered with surplus heat from waste incineration, the next 20% is surplus heat from combined heat and power and the remaining production of district heating is based on biomass and fuels as wood pellets, straw, straw pellets, natural gas, oil and coal. (Figure 4 – Fuel Mix)

Improved Energy Intensity and Balance of Trade

The promotion of cogenerated electricity and heat, one of a long series of measures to improve energy efficiency, has been extremely important for Denmark's environmental footprint and economic prosperity. In 1981, according to the Danish Energy Authority, Denmark's National Energy Account operated at a deficit of nearly 26 billion DKK, which meant nearly $ 5.2 billion out of the country for imported energy. 25 years later in 2006, Denmark had become a net exporter of energy with a trade surplus of over 30 billion DKK ($ 6.1 Billion) in oil, natural gas and a small amount of electricity. (Figure 5 – Denmark Energy Account). Export growth accelerated with discovery of North Sea oil in late 1990's, but when your national energy system is based on using waste heat instead of burning imported fossil fuels, valuable energy resources are preserved for export and a positive trade balance.

The more instructive trend since 1980 is how Denmark's focus on clean energy investment and export has contributed to a GDP increase of 80% while gross energy consumption increased only 5% and CO_2 emissions have declined approximately 18% (Figure 6 – Denmark GDP, CO_2 & Energy). This demonstrates that economic growth does not have to coincide with energy use or environmental depletion.

District energy benefits other cities and campuses around the world.

Copenhagen's successful commitment to clean energy is commendable and instructive, and the ambitious vision for an even more carbon neutral city by 2025 is detailed in the June 2009 Copenhagen Climate Plan. While the municipal mandate approach applied in Copenhagen may not work in all locations, it's clear that mayors and planners around the world are seeking more cost effective and expeditious climate solutions that are quickly scalable. The International Energy Agency CHP Collaborative has identified district energy/CHP as one of the most effective near term investments to improve energy security and cut greenhouse gas emissions on an urban scale.

Seeking to recognize achievements in sustainable district energy infrastructure, the International Energy Agency (IEA) sponsored the District Energy Climate Summit Awards at a November 2009 conference in Copenhagen, jointly sponsored by the Danish Board of District Heat, Danish District Heating Association, Euroheat & Power and the International District Energy Association. A sample of the award winners demonstrates many economic and environmental benefits including job retention, air quality improvement, historical preservation and carbon neutral growth. For example,

- In Dunkirque, France, the district heating system tapped surplus heat from France's largest steel mill to provide lower cost heating services for city residents. This investment improved operating costs for the city's largest employer while displacing expensive fossil fuels and cutting emissions across the community. The city has since added three cogeneration units and a second surplus heat capture unit at the steel plant to increase the share of recovered energy in the network to 90%, significantly lowering overall CO_2 emissions.

- In Jiamusi, China, development of a district heating system has improved local air quality and significantly cut greenhouse gas emissions by shutting down over 60 coal-fired boilers. The plan includes a vision for growth to 2020, when the network will supply 14.5 million m^2 of area, representing 75% of the city's current heating surface. China has been embracing district heating as a key infrastructure investment strategy in reducing greenhouse gas emissions.

- In Krakow, Poland, a UNESCO World Heritage site, availability of district heating service facilitated the architectural renewal of vitally important historic buildings. Krakow's system incorporates a modern, efficient system that is providing energy and economic savings while reducing greenhouse gas emissions through the closure of 392 coal-fired boiler units over the period 1990-2008.

- At the University of Texas Austin, one of the largest universities in the USA with over 70,000 faculty and students, 200 campus buildings are served by a 137 MW cogeneration based district energy system that provides 100% of the power, heating and air conditioning for the campus. Energy efficiency and system upgrades have saved UT Austin over $150 million over the past decade. Compared to 1977, the campus has nearly doubled in size from 9 million to 16 million square feet and annual electricity demand has more than doubled from 183,000 MWh to 372,000 MWh, yet carbon emissions have been reduced to 1977 levels. The highly efficient CHP district energy system has essentially provided carbon neutral growth at the University of Texas Austin.

District Energy in the United States

With approximately 2500 district energy systems in the United States, including most large cities and college campuses, there are a widespread opportunities for integrating new cogeneration into existing district energy systems, to recovering waste heat sources from industry, to connecting local renewable sources like ocean or lake water for district cooling systems. In St. Paul, MN for example, the district energy system underwent extensive renewal and expansion over the past 25 years. In converting the primary fuel from coal to municipal waste wood, it now produces heating, cooling and power for twice the customer square footage at half the fuel volume, and has cut emissions by 250,000 tonnes of CO_2 per year.

District energy systems have been operating in the US for over 100 years and currently serve more than 4.3 billion sq ft of building space, including landmark buildings like the US Capitol and Supreme Court, the Empire State Building, the Mayo Clinic and Harvard Medical School are all served by district energy systems. Since 1990 in North America, industry systems have reported adding 467,686,922 of customer space, averaging about 40 million sq ft of new customer space added per year over the past five years, including 38 new downtown district cooling systems launched.

Policy Opportunities Ahead

When the US Congress finally convenes around a climate bill, it will be critically important that cap and trade regulations do not impair district energy/CHP systems with an imbalance in allowance costs, particularly if electric utilities are granted free allowances. The current House (Waxman-Markey) and Senate (Kerry-Boxer) bills provide limited allowance exemptions to a certain class of CHP systems but fail to fully recognize the potential efficiency gains and carbon reductions possible with expansion of district energy/CHP in cities and campuses nationwide.

If a national objective is to create un-exportable jobs by investing in green infrastructure and improving energy security by cutting reliance on foreign oil, there are hundreds of cities and campuses ready to invest in system renewal and expansion right now. This was borne out by a recent US Department of Energy funding program for district energy/CHP that was oversubscribed by a factor of 25 to 1. The beauty of a district energy system is that in serving 15 or 20 million square feet of building space, efficiency investments in the plant yields benefits to the aggregate of connected users. For example, Princeton University successfully tested bio-fuels in their campus cogeneration plant and with the turn of a single valve, would be able to convert 12 million square feet to renewable fuels.

US energy and climate policies should consider "thermal energy" and not solely focus on electricity if we are to really improve energy intensity and increase efficiency. With all this talk about a smart grid, wouldn't it make sense to actually <u>use</u> two-thirds of the fuel we burn to make electricity instead of simply throwing all that heat away? Fundamentally, achieving 80 or even 90 percent fuel efficiency and cutting greenhouse gas emissions is neither a technology problem nor a capital problem. District energy and CHP utilize "off the shelf" technologies that are proven, reliable and widely available. These systems work day or night, rain or shine, windy or calm. The real uphill climb is a policy gap that fails to value thermal energy, encourages status quo and lacks the vision and common sense embraced 30 years ago in Denmark. Let's hope that US policy makers experience the "best-kept secret" in Copenhagen this December and come home with a new found respect for district heating.

The author is president of the International District Energy Association, a 100 year old US non-profit association based in Westborough, MA at www.districtenergy.org.