A Study of the Feasibility of Utilizing Waste Heat from Central Electric Power Generating Stations and Potential Applications

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A Report By

The Connecticut Academy of Science and Engineering

For

The Connecticut Energy Advisory Board

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This study was initiated at the request of the Connecticut Energy Advisory Board on September 5, 2008. The project was conducted by an Academy Study Committee with the support of David Pines, PhD, Project Study Manager and Tom Filburn, PhD, Study Consultant. The content of this report lies within the province of the Academy's Energy Production, Use and Conservation Technical Board. The report has been reviewed by Academy Members Sten A. Caspersson and Robert J. Hermann, PhD. Martha Sherman, the Academy's Managing Editor, edited the report. The report is hereby released with the approval of the Academy Council.

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EXECUTIVE SUMMARY

THE PURPOSE OF THIS STUDY

A significant by-product of power generation plants is rejected (or "waste") heat. Rejected heat resulting from inefficiencies of the power generating process is then rejected into the atmosphere or into bodies of water—Connecticut rivers and Long Island Sound. Large quantities of heat are rejected in Connecticut—enough energy to heat every building in the state.

The Connecticut Energy Advisory Board (CEAB) requested that the Connecticut Academy of Science and Engineering (CASE) investigate the feasibility of using the rejected heat rather than wasting it.

BRIEF STATEMENT OF PRIMARY CONCLUSION

Connecticut's power plants transform energy stored in nuclear and chemical fuels, with roughly one-third being converted into useful energy and two-thirds being rejected as heat. The total heat currently being wasted from Connecticut's power plants is an untapped resource that is roughly equal in value to all of the fossil fuels used for the state's residential, commercial, and industrial sectors for process and space heating.

Proven combined heat and power technologies can be utilized to capture rejected heat for useful purposes and will pave the path towards energy independence and security by reducing dependence on fossil fuels, while creating jobs and providing economic benefits, as well as improving the environment and energy efficiency. The challenge is to develop the policies and infrastructure necessary to utilize this valuable resource that is currently wasted.

The Study Committee concluded that there are several beneficial uses for the heat that is rejected into the environment by power plants in Connecticut. It is recommended that

- Rejected heat should be used to develop district energy (heating and cooling) systems in high population/employment areas;
- Waste heat enterprise zones should be created to encourage economic development; and
- To complement this effort, Connecticut should also explore the potential of growing algae for generating biofuel from fossil fuel stack gases, or cooling water reject heat.

Upside:

In general, the potential for using rejected heat from electrical generating facilities is significant. For example, the residential, commercial, and industrial sectors in Connecticut burned approximately $3.8 billion worth of fossil fuels for process and space heating in 2006 (Department of Energy (DOE) Energy Information Agency (EIA)). It is important to consider

that every BTU of fossil fuel burned in Connecticut involves dollars leaving Connecticut. Almost every BTU of rejected heat discharged into the environment is a resource that is entirely wasted. It is also important to consider that rejected heat discharged into the environment can have negative environmental impacts.

Downside:

Although the rejected heat is plentiful and readily available, it is not at conditions suitable for distribution and high value end use nor is it always conveniently located for use. These conditions are a result of striving for maximum electrical efficiency, a goal arising from current practices and regulations that is based on limited thinking of energy as disparate forms (electricity, natural gas and heating oil) rather than considering all forms of energy as an integrated whole. The realization of maximum economic and social benefits resulting from using the rejected heat will require current laws, practices and regulations to be modified to consider the larger energy perspective by desegregating the treatment of energy and by including land use planning and associated economic development.

Benefits:

- Reducing state's "exporting" of financial resources to purchase fossil fuels
- Creating in-state jobs to build the infrastructure needed to transport the waste heat
- Providing environmental benefits
- Creating incentives for durable manufacturing jobs in Connecticut
- Lowering energy cost to support economic development
- Increasing national security

STUDY DESCRIPTION

This report includes the following elements:

1. Operational and rejected heat characteristics of base load power plants of 65MW or larger.
2. Types and quantities of rejected heat available.
3. Domestic and foreign examples of productive and politically expedient uses for reject heat.
4. Investigation of successful industrial, institutional and municipal examples of combined heat and power (CHP—a power plant that produces two products, electric power and heat), also commonly referred to as cogeneration.
5. Investigation of successful industrial, institutional and municipal examples of district heating.
6. Review of potential uses for Connecticut's reject heat.

STUDY COMMITTEE CONSIDERATIONS

In general, electric power generated in central station power plants has been optimized for maximum electrical efficiency with the technology available at the time of construction, rather than optimized for maximum energy utilization. Rejected heat from these plants is usually available at relatively low temperatures (about 100°F).

The Study Committee considered technical viability, energy efficiency, economics, national security, environmental impact, and regulatory impact when examining potential uses for reject heat. For many of these applications, the heat may not be needed 24/7, 365 days a year. The seasonal needs of some applications were also considered.

Past Policies and Where We Are Now

- Deregulation has encouraged companies involved with electricity, natural gas or fuel oil supply for buildings to focus on their core commodity and sometimes on a specific aspect of the supply—for example, electric generation or energy transmission and distribution. They do not provide integrated energy generation and distribution services. For example, Dominion Resources, Inc (Dominion) and NRG are in the electricity generating business; Connecticut Light and Power and United Illuminating are in the electrical transmission and distribution business; and Connecticut Natural Gas, Southern Connecticut Gas and Yankee Gas are in the natural gas distribution business. This structure is not conducive to energy districts where the challenge is to realize the advantages that result from increasing the integration of thermal and electricity generation, transmission, and distribution.
- Environmental policy needs to be coordinated with energy policy. They can and do have shared interests. For example, the renewal of Millstone's National Pollution Discharge Elimination Systems (NPDES) permit may require the installation of cooling towers to minimize adverse environmental impacts from Millstone's cooling water intake structures. Dominion may be required to build cooling towers that could cost more than $1 billion to mitigate an environmental impact to the Niantic Bay and Long Island Sound. The cost would be passed on to the rate payers. In effect, this would move the reject heat from Long Island Sound to the atmosphere. Either way, it would be entirely wasted. Alternate use of the heat on a grand scale would solve the environmental impact and provide an energy resource to the area. The money for the cooling towers could be better used and the rejected heat can be viewed as an asset.

SUMMARY OF FINDINGS AND RECOMMENDATIONS

Findings

A significant amount of energy is being wasted as rejected heat in the generation of electricity and it is possible to recover much of it to increase overall energy utilization.

USES FOR REJECTED HEAT

There are different categories of waste heat uses based primarily on the changes to power plants that are required to achieve them. They are

1. Applications which don't require any modification to the basic power plant and in which the equipment using the heat can be located at the power plant site;
2. Applications which require modifications to the power plant and which could be located at the power plant or remotely; and
3. New distributed generation power plants located near or co-located at sites using the heat.

I. Rejected Heat Applications That Do Not Require Significant Retrofit of Existing Power Plants

For existing power plants, the study first considered uses for rejected heat that did not require significant retrofit to existing facilities and minimal infrastructure to transport the heat to locations relatively near the plants. These include

- Algae Farms: Algae farms are a promising technology for utilizing waste gases and heat from stack gas for producing biofuel. Fuel production per acre is much higher than that for other biofuel sources and does not require use of land suited for agriculture. Currently, there are no existing commercial algae farms, but pilot testing of closed-system photobioreactors that utilize the carbon dioxide, nitrogen oxides, and waste heat from fossil fuel power plant stack gases have produced encouraging results. In the colder Connecticut environment, it may also be possible to use some of the heat currently rejected to cooling water. Because the biofuels would be produced using carbon dioxide from fossil plant stack gas, overall production of greenhouse gas would be reduced and Connecticut would have an indigenous supply of transportation fuels, improving energy security, increasing jobs and keeping some of its energy expenditures within the state. Estimated production of biofuel from the 850 MWs of base load fossil fuel generation plants in Connecticut is 30 million gallons per year, which is 15% of Connecticut's transportation fuel requirements. Use of power plant exhaust gases to produce this quantity of algae would reduce carbon dioxide emissions by 1.8 million tons per year for these same plants. Current estimates of total land required to achieve these results is 7,000 acres among the several base load plants, and technology to reduce this land requirement should be pursued.
- Industrial Ecology Parks: Industrial zones near power generating facilities could provide incentives to locate businesses and industries in Connecticut, creating durable jobs and strengthening tax bases. The waste heat is essentially free and available to stabilize heating and cooling costs as well as to provide readily available process water. Although the heat is at low temperature, there are some industrial processes which could use this heat.
- Greenhouses: Radiant floor heating for greenhouses could be designed to utilize 100°F water. Greenhouses may also be able to benefit from carbon dioxide in the exhaust of fossil fuel power plants. Connecticut currently has 300 commercial greenhouses, which primarily grow flowers, with total land area of less than 200 acres. Absorbing a significant portion of the heat produced by a plant such as Millstone would require 5,000 to 10,000 acres. Therefore, there is not sufficient greenhouse demand in Connecticut to alleviate environmental effects of once-

through cooling of this or other plants in Connecticut. However, should use of power plant heat and other factors make greenhouse food production attractive, this application may make a significant contribution to reducing the environmental effects of power plant cooling.

II. Rejected Heat Applications That Require Retrofit of Existing Power Plants

When rejected heat is available at higher temperatures, there are more potential uses for it. With modifications or retrofits to existing electricity generating facilities, the potential exists for CHP: two or more useful sources of power or energy. This is not a difficult technical challenge, but does increase the capital cost to utilize the reject heat.

Each of the following applications reduces power plant electrical efficiency by lowering the MW rating due to the diversion of steam that otherwise would have been used to generate electricity. The benefit of this modification, however, is higher overall thermal efficiency (i.e., more of base fuel's energy is utilized). These applications include

- Industrial Ecology Parks: Co-located industrial facilities could be used to absorb the heat. Several Connecticut generating facilities have available land adjacent to or near the existing plants. A search for industrial customers for "over the fence" heat could be conducted to determine whether the capital expense, heat cost and land availability are consistent with sale to industrial customers. The benefit of this approach is that a significant amount of thermal energy can be utilized with minimal amount of infrastructure cost needed for piping since the application will be near the source. This type of CHP has not been widely adopted in Connecticut, but successful examples of using a small portion of heat include AES Thames (Montville) and Algonquin Power (Windsor Locks). These facilities provide steam to one dedicated customer in addition to generating electricity.

- District Heating and Cooling: District heating and cooling systems are not a new technology. In most northern European countries and Scandinavia, there is a high penetration of district heating and cooling. Furthermore, in the European Union, nearly every country also takes advantage of local biomass in the form of municipal waste, and these waste-to-energy power plants are incorporated into district heating and cooling systems. District heating requires comprehensive planning to ensure the proper density, distribution corridors and coordinated government action. Another viable example of an existing large-scale (although under-utilized) district heating and cooling system is Hartford Steam and the Hartford steam loop. The system serves the capital area, downtown, and south end (Hartford Hospital).

  Typically, hot water can be piped about 12 miles from the centralized generating facility. Chilled water loops also have advantages: they significantly reduce the summer peak electricity demand caused by electrical air conditioning. This would reduce the need for peaking electric generating units that only operate a few hours each year. Because of the lower temperature difference between the desired indoor air temperature and the chilled water, the typical distance that chilled water can be piped is about 4 miles.

  A dramatically successful example of distributed cogeneration as part of a countrywide energy strategy has been demonstrated in Denmark. Foreign oil dependence nearly devastated the Danish economy during the oil embargo of 1973.

The government moved quickly and decisively, as a matter of national security, to develop a strategy to change from foreign oil dependence to energy independence. By 2006, the Danish economy was no longer dependent on foreign oil and even exported some forms of energy. The transition increased national security, and created durable jobs and economic growth. Denmark's land area and population density is similar to Connecticut. The strategies, policies and technology used in Denmark can also work in Connecticut.

II. Distributed CHP

In Connecticut, CHP systems providing space heat and cooling to a district loop are widely used on university and institutional campuses (e.g., University of Connecticut (UConn), Yale, etc.) where there is common ownership of land, power plant and buildings and where the university owns the electric distribution system (therefore no conflict exists with public utility law). Applications involving power plants located at, and supplying heat and power to, an individual building are another CHP approach in use in Connecticut and worldwide. Any and all new generation facilities planned for Connecticut should be considered as part of a statewide (and possibly region-wide) energy strategy.

Heat Utilization Implications

There are several non-technical implications to the use of heat rejected from power plants. They include capital requirements, current practices and regulations, business models and public education. The alternative—cooling towers—also has utilization implications.

Capital: To provide heat at higher temperatures, power plants would have to be designed appropriately and existing plants would require retrofit, reducing capacity and necessitating construction of new plants. Distribution of heat and cooling in district heating and cooling systems will require significant investment.

Current Practice and Regulation: As noted above, the current energy supply system is designed and operated around separate consideration of electricity, natural gas and fuel oil. For example, power plants are owned by non-utility organizations and regulated and operated with only electric power production being considered. Little or no consideration is given to industrial development or to land use planning which would be required to gain maximum use of heat at minimum distribution costs.

Planning for distribution of all utilities such as electricity, heat, telephone, cable, water and sewers is not integrated, so considerable expense is involved with opening streets multiple times for the individual services.

Electric power plants are operated on the basis of daily auctions. This would be unacceptable when the customer is dependent on heat from the power plant.

Business Models: Under deregulation, electric power plants are project financed and sell to one customer; in Connecticut the customer is the Independent System Operator for New England (ISO New England). Heat is sold to many customers, similar to the situation for electric power distribution utilities or gas utilities. A similar business structure would have to be developed for district heating and cooling systems.

Public Education: Since distribution of heat and cooling in a district heating system is limited to a 4 to 12 mile radius, this means power plants will be quite close to people. In

Europe, where high utilization of energy is an important societal goal, the power plants are accepted by the public.

Cooling Towers

Cooling towers serve to dump heat to the atmosphere. They are expensive to construct and operate, consuming electric power, water and treatment chemicals. These units are physically very large and often cause major public objection in siting. For a large power station, hyperbolic shaped natural draft towers as tall as a 40 to 50 story building emit vapor plumes visible from a radius of several miles.

Recommendations

To meet this challenge, the following first steps are suggested to begin the paradigm shift to integrate the state's electricity and thermal requirements.

1. Require that electricity and thermal generation be integrated into the design and operation of new facilities in request for proposals for new electricity generating capacity.
2. Thoroughly evaluate the connection of the CRRA South Meadows waste-to-energy units to the Hartford heating and cooling loop. This is likely the best opportunity in Connecticut for demonstrating the benefits of combining electricity generation with heating and cooling districts. The economic and societal benefits include increasing energy utilization of the CRRA South Meadows facility from about 25% to over 50%, reducing Connecticut's dependence on fossil fuels, and reducing air pollution, carbon dioxide emissions, and impact on fisheries.
3. Provide that facilities that convert to a CHP mode of operation or new CHP plants and utilities be allowed to pursue long-term purchase contracts for selling electricity to the grid or to each other.
4. Provide Class I or Class II renewable energy credits for use of rejected heat from electricity generating facilities that otherwise would have been disposed of to the atmosphere or a water body. This would incentivize energy districts for urban areas with high population densities by helping to offset the initial costs of retrofitting the electricity generating facility. Also, this would help increase the use of combined heat and power plants for individual buildings where centralized energy districts with district heating and cooling are not feasible.
5. Encourage major urban population areas to develop master utility plans so that utility upgrades (i.e., water, gas, electricity, cable, and phone) can be coordinated along with installation of district heating and/or cooling loops. This will provide a more efficient means for instituting energy districts and provide the data needed to determine the most cost-effective projects.
6. Develop a government or private organization to purchase power plant heat and distribute it to multiple customers as is done in many locations in Canada, Europe and the United States.
7. Develop Waste Heat Enterprise zones around existing and new generation facilities

to promote local development that utilizes the waste heat as part of a smart growth policy. Developers would likely be attracted to locations where only a connection is required to the heating and cooling loop, thereby eliminating the upfront capital costs for mechanical equipment such as boilers and chillers. Furthermore, this would make additional space available for income-generating purposes that otherwise would be occupied by mechanical equipment. US EPA, as required by the 2007 US Energy Independence and Security Act (EISA), is in the process of developing a survey of waste heat energy sources in order to create a registry that would provide companies with access to information for industrial and business development purposes, as well as serving as the basis for potential waste heat energy recovery projects to qualify for financial and regulatory incentives.

8. Initiate an algae farm demonstration project at the UConn CHP power plant. The study should evaluate the cost and yield of growing algae using the stack gases from a natural gas combined cycle power plant in comparison to an algae farm using nuclear power plant condenser reject heat with (1) carbon dioxide concentrated from the atmosphere via an air extraction process; and (2) from another non-fossil fuel CO_2 source such as waste water treatment plants. The results could then be used for determining the viability of using this type of process at a nuclear power plant, such as Millstone.

Benefits

The benefits to integrating electricity generation and thermal needs are

- Reduced energy consumption, since waste heat from all electricity generating facilities is about equivalent to the fossil fuels utilized by Connecticut's industrial, commercial, and residential sectors.
- Utilizing the waste heat will reduce the approximately $3.8 billion that is spent each year in Connecticut by the residential, commercial, and industrial sectors on fossil fuels imported from out of state and from outside the country.
- Current uses of fossil fuel in buildings in Connecticut generate amounts of carbon dioxide similar to that generated by electric power generation in Connecticut. Use of power plant waste heat to meet needs currently satisfied by separate burning of fossil fuel will reduce carbon dioxide and other emissions accordingly.
- Use of fossil fuel power plant exhaust to grow algae could generate biofuel which could supplant up to 15% of the transportation fuel used in Connecticut with attendant reductions in carbon dioxide emissions.
- Utility corridors that bundle all services in a common right of way could provide sound infrastructure that will serve Connecticut for many years, providing an incentive for in-state business development, job creation, and promotion of smart growth strategies.
- Reduced air emissions including carbon dioxide and nitrogen oxides by burning less fossil fuels.
- Increased national security by reducing dependence on imported fossil fuels.
- Reduced peak electricity demand resulting from the use of chilled water loops, thus

reducing the need to make investments in peaking units that run less than 50 hours a year.

CONCLUDING REMARKS

The challenges for implementing the committee's recommendations are not technical, but will require a paradigm shift in Connecticut's energy policy and planning—to consider all energy forms/sectors along with their impacts on the environment and economic development holistically. The potential for beneficial use of power plant rejected heat is significant. The benefits have been amply demonstrated in several metropolitan areas in the United States and Northern Europe, particularly Scandinavia, and can also be achieved in Connecticut. However, policy changes are needed to integrate electricity and thermal requirements, and more detailed analysis is suggested to determine the portion of rejected heat that can be practically utilized from Connecticut's power generation plants. The question can no longer be how do we best dispose of the waste heat, but how the facilities can be best designed (new or retrofitted) to beneficially use the rejected heat.