

Annex X Final Report

Economic and Design Optimization in Integrating Renewable Energy and Waste Heat with District Energy Systems

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Integrating Renewable Energy & Waste Heat

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Executive Summary

A key argument in favor of district energy from a policy perspective is its ability to facilitate use of renewable thermal energy and waste heat resources (REWH). These low- or no-carbon energy sources include bioenergy, combined heat and power (CHP), industrial waste heat, municipal solid waste combustion, landfill gas, solar thermal, geothermal hot water and deep water cooling. District energy systems can facilitate optimized use of heat pumps to convert extremely low-temperature resources such as groundwater and sewage effluent into useful thermal energy because in a district energy system heat pumps can be integrated with other sources to provide more efficient and reliable thermal service.

Combined heat and power (CHP) is not a resource but rather a range of conversion technologies which convert renewable or non-renewable resources into power and heat. For this reason, and given that the unique issues which arise with integration of CHP have been addressed in other reports, this report addresses CHP only briefly.

This project is intended to guide evaluation of options for integrating renewables and waste heat with existing or potential district energy systems (DES), addressing economic, design and operational issues, including fundamental issues relating to operating temperatures and availability. Case studies were developed to: illustrate a range of examples of integration of REWH in DES; illuminate key design issues associated with such integration; and describe solutions to addressing these issues.

Fundamental Considerations

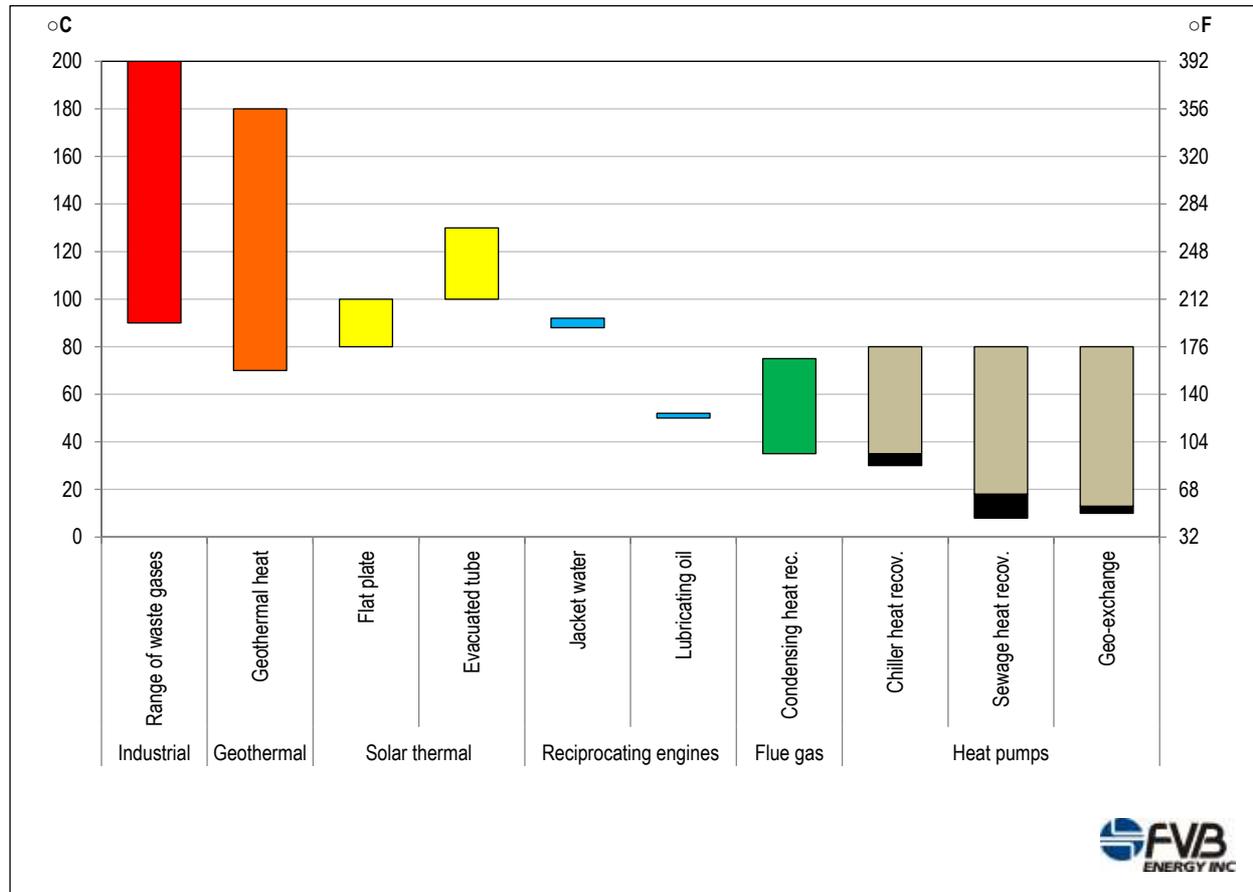
There are two fundamental technical characteristics which must be addressed when evaluating integration of REWH into a DES:

- Temperature – at what temperature is the REWH available, and how does it compare with the supply and return temperatures of the DES?
- Availability – how reliably and when is the REWH available compared with the DES energy requirements on an hourly and seasonal basis?

For any given REWH resource the above design fundamentals have to be evaluated and optimized in the context of economic and environmental trade-offs. In addition, the longevity of the resource must be assessed, both from the standpoint of long-term physical access to the resource (e.g., the continued operations of an industrial plant providing waste heat) as well as economic access (continued economic attractiveness of the price of the resource).

Temperatures

A pervasive issue relative to tapping renewable and waste heat sources is the temperature of the resource compared with the supply and return temperatures of the DES network. Some resources, such as biomass, are fuels that can be used to produce whatever temperature is required. However, with lower district heating (DH) operating temperatures a greater range of REWH sources becomes available. The figure below shows representative temperatures for examples of REWH resources.



This figure is not exact, and certainly exceptions exist, but it gives the reader a quantitative illustration of the characteristics of these resources:

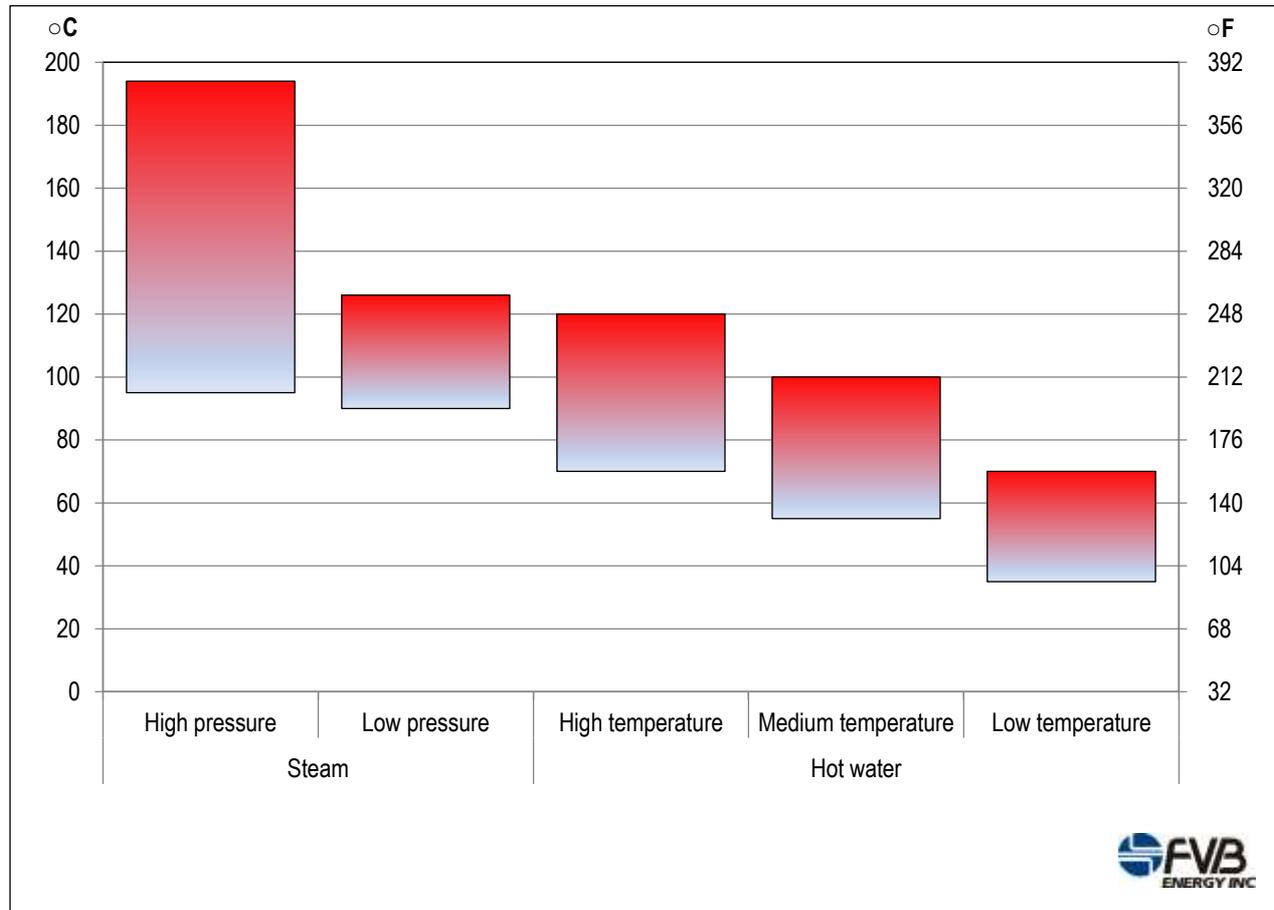
- Given the multiplicity of industrial waste heat sources, only a range is given for simplicity of presentation.
- A broad band of geothermal hot water temperatures is shown because such resources can vary significantly from one site to another.
- The thermal efficiency of engine CHP is increased if the DH temperatures are low enough to recover heat from jacket water and lubricating oil as well as the relatively high-temperature exhaust gas.
- Lower DH temperatures make it possible to produce useful heat with lower-cost flat-plate solar collectors in comparison with higher-cost evacuated tube collectors. (The efficiency of evacuated tube collectors in generating higher temperatures is substantially better than that of flat plate collectors.)
- For thermal sources that require a heat pump, the temperature boost from the heat pump is shown in grey and added to the source itself. The efficiency of these technologies is significantly affected by the required temperature lift, which should always be kept to the minimum required for highest efficiency. While some consider heat pump schemes to represent renewable energy, the reality is that sources such as groundwater or sewage effluent are a means of increasing the efficiency with which electricity is converted to thermal energy. Unless and until electricity grids are decarbonized, such heat pumps systems cannot truly be considered renewable.

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REWH resource temperatures must be compared to the supply and return temperatures of district heating distribution systems. There is a strong trend toward reducing district hot water supply and return temperatures. The evolution of district heating has been characterized in terms of “generations” -- with the first being steam, the second being hot water systems supplying (at peak conditions) >100°C (212°F), the third being hot water systems supplying 80-100°C (176-212°F), and the fourth being systems supplying less than 65-75°C (149-167°F). As district heating temperatures are reduced, the major concern is with the potential for legionella in the DHW, particularly during summer operations.

In this report we will use a somewhat different nomenclature than the categories outlined above regarding the four “generations.” The table below summarizes peak supply temperatures (and steam pressures, as appropriate) for five DH system types. The figure below illustrates a range of these peak supply temperatures as well as typical return temperatures.

		Peak Supply Temperature		Steam Pressure	
		C	F	barg	psig
Steam	High pressure	194	381	13.8	200
	Low pressure	126	259	1.4	20
Hot water	High temperature	120	248		
	Medium temperature	100	212		
	Low temperature	70	158		



One critically important factor when considering the temperature scheme is the understanding of temperature duration and the fact that peak supply temperatures in most systems only have to occur for a few hundred hours per year. Hot water systems are usually designed to reduce temperatures during off-peak times, thereby further facilitating use of REWH.

Resources can be separated into the following groups depending on the specific annual temperatures of the resource:

1. High grade sources have reliably high temperatures that always exceed the DES supply temperature. These sources can be used directly whenever it is available.
2. Low grade sources have lower temperatures that are sometimes or always insufficient relative to the DES supply temperature but always sufficient relative to the DES return temperature. If the temperature of the source falls below the DES supply temperature, the temperature must be polished (increased for heating or decreased for cooling) with other energy sources.
3. Below grade sources always have temperatures lower than the return temperature in the DES. These sources must be upgraded with a heat pump.

As long as the temperature of the REWH is higher than the return temperature in the DES (heating mode, opposite for cooling) the resource can be used directly. When the temperature is lower than the return temperature in the DES (heating mode, opposite for cooling), either the temperature must be upgraded with a heat pump or the existing DES (or the design of a new

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DES) must be modified in order to use the REWH. In considering temperatures it is also important to note that a further temperature differential between the resource and DES temperature generally is required due to the use of heat exchangers.

When the temperature of the REWH is lower than the return temperature in the DES (heating mode, opposite for cooling), an existing DES could adapt in a number of ways, e.g.:

- Make improvements to achieve a lower return temperature (in a heating system) or a higher return temperature (in a cooling system). Typically this could include minimizing bypasses in the system, improving process control and coil performance at customer buildings, or other steps. Such measures have costs, and could be funded either directly by the DES utility (if determined to be cost-effective on a life cycle basis in comparison with other options) or indirectly by encouraging customer investments to improve delta T.
- Curtail the flow or the temperature to achieve low return temperature. This approach requires careful consideration and testing before implementation to ensure continued customer comfort.
- Find other low grade heat sinks to further reduce the DH return temperature, such as use of the return water for preheating, snow melting, etc.

If adaptation is not possible or insufficient, the use of REWH can be enabled by replacing the high temperature DH system (often a steam system) with a lower temperature system.

Availability

Another critical aspect of a REWH is its availability on an hourly or seasonal basis. Some resources, such as solar and wind, are intermittent and therefore are not dispatchable. Further, the seasonal distribution of the resource may be counter to the seasonal distribution of the thermal requirement. The hourly availability of resources such as industrial waste heat is tied to the operating hours of the industrial facility, and may be subject to interruptions.

With a thorough understanding of availability, the capacity of the REWH can be properly sized. Typically, renewable energy sources have lower operating cost but have higher capital costs and lower turndown capability (although some exceptions exist, such as bioliquids).

Sizing a REWH source that is intermittent and/or interruptible requires careful optimization. One option is to undersize the REWH source and continuously polish with a conventional energy source. Integration of the REWH source with thermal energy storage offers greater flexibility. The type of thermal storage depends on the availability pattern of the resources, and may be daily or seasonal storage.

Business Issues

There are three fundamental business drivers for any change to an existing DES:

- Load growth.
- System optimization and cost reduction.
- Reduction in environmental emissions.

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Increased customer load may require additional production capacity, providing an opportunity to integrate REWH. Alternatively, a REWH may offer the potential to reduce life cycle costs compared to current energy sources. Although rarely the key driver, goals for reduction in GHG or other emissions may also affect the decisions on modification of existing systems.

Financing a REWH project is made more challenging because future energy prices are uncertain. This includes the likelihood that waste heat or other resources that are currently free or very low cost may become more expensive. In assessing options it is useful to consider the benefits of a given change relative to the flexibility to respond to new technical opportunities or changing price conditions.

The customer contract is the most important document for communication between the DES system operator and its customers because it can influence the performance of the building system in ways that can help or hinder the total efficiency and cost-effectiveness of the DES. This becomes even more critical with low temperature district heating systems. It is important to incorporate economically transparent price signals in the customer tariffs. Price signals in the contract can influence technical performance, for example by encouraging high delta T and discouraging low delta T, thereby reducing distribution losses and improving energy conversion in the plants.

Optimization Analysis

Based on fundamental design criteria REWH resources can be grouped into the following categories:

		Temperature Characteristic		
		High grade	Low grade	Below grade
Availability Characteristic	Dispatchable	Biomass, Bioliquids, Biogas, Municipal solid waste, Geothermal heating*	Geothermal heating*	Geo-exchange
	Correlated with DES load		Flue gas heat recovery	Chiller heat recovery
	Site-specific annual pattern	Deep water cooling*		Sewage heat recovery
	Intermittent	Wind		
Concentrating solar				
Flat plate solar *				
Industrial waste heat*				

Temperatures

Historically, conventional hydronic building heating systems were designed for supply/return temperatures of 82/71°C (180/160°F). There is a trend toward reduced temperatures for exactly the reasons addressed in this report. On the other hand, a balance must be achieved because designing for higher temperature systems helps improve economics due to the costs of additional heat transfer area in equipment for lower temperature systems.

Technically, it is possible to reduce supply temperatures for building space heating (SH) systems down to near the desired indoor air temperature (20°C or 68°F). There is a trend in Europe toward reducing SH system supply temperatures down to the range of 45-55°C (113-131°F).

The risk related to the Legionella bacteria, amoebae and other microorganism growth in domestic hot water (DHW) systems is the key limitation in reducing district heating temperatures. Beyond the supply temperatures, the return temperatures from building SH and DHW systems are crucial variables.

Whenever there is a temperature limitation of the REWH source, the DES supply temperature duration curve (temperature program) should be given careful consideration. In general, a low DES supply temperature minimizes distribution heat losses, but there may be an economic trade-off because a reduced delta T increases costs for water distribution, and for building systems if building system improvements have to be implemented.

Evaluation and optimization for utilization of a low- or below-grade REWH source should focus both on the DES supply and return temperature vs. the REWH source temperature. By definition, a low-grade REWH source is sometimes or always insufficient relative to the DES supply temperature but always sufficient relative to the DES return temperature. Given the fundamental physics of coils and heat exchangers, and provided there are no bypasses and/or flow control issues, a higher supply temperature should result in a lower return temperature. This means that there may be situations where it could be beneficial to keep a relatively high DES supply temperature throughout the year in order to achieve a lower return and therefore facilitate additional use of the low grade source. This will also reduce costs for flow distribution and building systems but there is an economic trade-off with respect to higher heat losses in the distribution piping system. An alternative strategy is to polish the DES supply temperature only as required for peak loads.

For an existing DES this has to be carefully tested and integrated. In practice, some systems will experience a rise in return temperature in conjunction with the supply temperature due to poor process control and/or bypasses in the system.

A below-grade REWH source always has a temperature lower than the DES return temperature and must utilize heat pumps to further extend the temperature range for heat recovery. In using heat pumps, it is of utmost importance to minimize the temperature lift (difference between the source temperature and the goal temperature) to achieve high efficiency.

Resource Availability

Resources can be grouped in the following categories: dispatchable; correlated with DES load; site-specific annual pattern; and intermittent.

Dispatchable REWH sources typically have no or only minor integration issues when connecting the source with a DES. Examples of dispatchable REWH sources are bio-energy, municipal solid waste, geothermal heating and geo-exchange. The main general technical concern for implementing a dispatchable REWH source is the control integration between the source and other energy sources within the DES.

Examples of REWH sources that correlate with the DES load are flue gas heat recovery and chiller heat recovery. For these sources it is critically important to understand the load pattern when sizing the REWH source. Chiller heat recovery requires a complete understanding of the daily and seasonal load pattern curves for both the DES heating and cooling systems in order to evaluate the overlap of the thermal loads.

Other REWH sources, such as deep water cooling and sewage heat recovery, have a site-specific pattern of availability relative to resource temperature.

Examples of intermittent REWH sources are wind, solar thermal and industrial waste heat recovery. A typical characteristic for these sources is the unreliable nature of the resource supply. As a result, careful consideration must be given to readily available backup from other sources for critical loads/customers.

One thing all sources have in common is the usefulness of integrating them with thermal energy storage. Thermal storage facilitates maximum usage of REWH sources when those sources are available, and allows use of this stored energy when required, thereby maximizing use of sustainable energy sources.

General Recommendations

Confirmation of Goals. Whether the DES system is new or existing, it is appropriate to start any analysis of integration of REWH by confirming the goals to be achieved and the relative emphasis that should be placed on each goal. Goals may include, for example:

- Reduction in emissions of greenhouse gases (GHG) or other environmental impacts.
- Reduction in costs.
- Increased flexibility to respond to future changes in supplies and/or prices of fossil fuels.
- Local economic development.
- Public relations.

DES Loads and Temperatures. It is essential to model the DES loads, ideally on an 8760 hour basis, relative to both energy and temperature. In an existing DES system operating data can inform this analysis. For integrated district heating and cooling systems it is especially critical to understand when heating and cooling loads occur simultaneously or within a 24 hour period.

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To the extent that data allows, it is useful to examine how each of the customers contributes to the delta T performance of the system. If existing buildings are to be served with a low temperature hot water system, it is important to test each building, or a sampling of representative buildings, at low supply temperatures to determine return temperature performance. For a new DES, the choice of DES temperature regime requires a thorough comparative life cycle economic analysis. For new buildings, use of underfloor or in-wall heating systems can help reduce the temperature requirements of the customers.

Resource Assessment. REWH resources must be assessed relative to:

- Quantity of energy potentially available.
- Temperatures.
- Availability and reliability of energy supply, both in the near- and long-term.
- Capital costs.
- Near-term resource price.
- Long-term potential for resource competition that would drive up the price of the resource.
- Other operation and maintenance costs.
- Maturity of the required technologies.

Integrated Assessment. There can be significant benefits in combining multiple REWH sources in a DES to the extent that the temperature and availability patterns of the sources complement each other. On the other hand there is also a risk in combining REWH sources to the extent that one source could displace another if the integration has not been thoughtfully considered.

Monitoring, Control and Dispatch. In any system involving electricity production and/or consumption, and/or systems incorporating multiple thermal sources, a predictive economic dispatch model of the production sources is essential to provide guidance for the plant operators. Dispatch merit order may also take into account environmental attributes. It is important to note that while some plant operations could be automated, the most important decisions should be made by trained, licensed human operators. Instrumentation redundancy and data collection should be planned at the onset of a project. Real time software simulations of the network helps minimize heat losses and pumping energy consumption to ensure the lowest possible environmental impact.

Resource Contracts. For any given REWH project, transparency is a key to ensure win-win solutions for the seller and buyer of thermal energy. Price structures should take into account the temperature of the thermal energy as well as its availability and reliability. For district energy systems procuring thermal energy from multiple outside sources it is important to develop a policy and operational strategy for right of precedence for energy delivery into the district scheme.

Customer Contracts. It is important to ensure an optimized temperature difference between DES supply and return (delta T) in order to maximize efficiency and realize thermal storage design capacity. If new buildings are to be served, it is useful to provide building system design

guidance and review to ensure that the system provides a good delta T. Economically transparent price signals should be incorporated in the customer tariffs.

Life Cycle Economic Analysis. Good decisions about integrating REWH in a DES require a thorough comparative analysis of the capital and operating costs of options relative to: energy resources; distribution systems; building substations; and building heating/cooling systems. The task is made more complex because the analysis should not only address the near term but also future growth and evolution of the system. In this regard it is important at the outset to assess the potential energy resources in the community and how price and technology trends might affect the future viability of that resource for the DES.

Resource-Specific Recommendations

The report provides resource-specific considerations for each REWH and addresses technical and economic parameters, lessons learned and key issues for integration with a DES.

Bioenergy. When planning a biomass project, it is important to focus attention on ensuring a supply of fuel of sufficient quality and quantity. If fuel is to be procured from outside suppliers it should be done under very tight contracts relative to fuel quality, particularly moisture, particle size and non-combustibles. Fuel should be purchased based on the energy contained in the fuel or on a dry basis (price per dry ton of fuel). Additional processing may be required to avoid materials handling problems due to oversize particles. Depending on location, seasonality of supply can be a big issue, so adequate fuel storage is important. Consideration should be given to the long-term potential for price increases due to increased competition for bio-fuels.

Municipal Solid Waste. Generally, the key challenges with integrating municipal solid waste are the distance between the plant and loads, and “Not In My Back Yard (NIMBY)” public opposition. In some countries, such as the UK, municipal waste is commonly incinerated without heat recovery, so the primary challenge relates to the costs of the infrastructure to convey the waste heat to users. In other countries, such as the USA, the NIMBY problem is significant, in which case it is helpful that Waste to Energy systems provide a good complement to recycling programs, and have positive environmental attributes when the avoidance of fossil fuel combustion for thermal and electricity production are counted.

Geothermal Heating. A key economic issue with geothermal energy systems relates to the relatively large initial investment in drilling and the technical risks of not finding enough hot water. It is also critically important to have an adequate understanding of the long-term flow and temperature characteristics of the geothermal resource.

Solar Thermal. Solar thermal availability generally has an inverse relationship to the heating load needs. This is true not only on a daily level but frequently also on a seasonal level. Hence, hot water thermal storage helps maximum utilization. When sizing a solar thermal system for integration with a DES, a low district heating supply temperature is beneficial since collector performance deteriorates with higher temperatures. Thermal energy storage is essential for optimized use of solar heat.

Wind. Wind is relevant to DES primarily in the context of integration of DES with power grids as a power load balancing strategy. Hot water systems can absorb large quantities of electricity

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and convert the energy to storable hot water by using heat pumps and/or immersion heaters. As with solar energy, thermal energy storage is a critical element in a DES wind strategy.

Deep Water Cooling. Prior to design it is important to implement a monitoring program to determine lake or sea water temperatures at various depths at the project site. Deep water cooling is heavily dependent on a stable and predictable range of the maximum depth of the thermocline and a large enough water volume below this depth.

Heat Pump Technologies. When sizing a heat pump system for DES integration, a low temperature difference between the heat source and heat sink is essential since heat pump efficiency deteriorates with a high temperature difference. Commercially available heat pumps have a limited supply temperature, so lower DES temperatures could be a requirement for effective DES integration. Hot water supply temperature plays a major role in heat pump systems since the efficiency decreases with high supply temperature.

When evaluating geo-exchange it is important to carefully consider the following technical and economic parameters:

- Hydrogeological and geochemical description of the site.
- Environmental regulatory acceptance.
- Location and space requirements.

Closed loop systems require multiple boreholes and, if not sized properly, may raise underground temperatures over time, cutting efficiencies in the cooling cycle. Open loop geothermal requires fewer wells but there are more issues with corrosion, particulate filtering and potential groundwater contamination. Additional discussions will also be necessary with the environmental regulatory agencies to gain approvals.

When sizing a chiller heat recovery (HRC) system it is essential to adequately understand the 8760 hour patterns of cooling and heat loads, including their overlap. There must be coincident cooling and heating loads or thermal storage is required.

A key consideration when integrating sewage or sewage treatment effluent is ensuring adequate sewage flows vs. DES heat demand variability. Thermal storage may be a useful optimization technology for optimizing use of these resources. If untreated sewage is used, it is critical to design for easy maintenance to ensure clean heat exchange surfaces.

Industrial Waste Heat Recovery. The key financial risk is related to the capital investment in the piping system to link the industrial source with the DES. In designing the business arrangement between a district energy system and an outside industrial supplier of waste heat, it is essential for the contract to incorporate a transparent and clear picture of economic risks and rewards. Business risk analysis should address short term consequences of sudden shutdown as well as long term costs to finance alternative base load supplies.

Important technical issues to be given careful consideration when evaluating industrial waste heat recovery are:

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- Corrosion and oxidation reactions are accelerated dramatically by temperature increases. Advanced alloys or composite materials must be used at higher temperatures.
- If the source is intermittent, the heat exchanger (HEX) may be exposed to both high and low temperatures and it becomes important to ensure that the HEX material does not fatigue due to thermal cycling.

Flue Gas Heat Recovery (FGHR). When integrating FGHR into a DES it is important to:

- Design the system based on flue gas latent heat content, temperature and dew point versus available DES return temperature, because available waste heat decreases with temperature (especially if flue gas condensation cannot be achieved).
- Size the FGHR based on the operating pattern of the boiler supplying the flue gas.
- Ensure that the boiler is operating as the DES base load to maximize heat recovery.
- Develop a good understanding of physical and chemical impact of gas streams on heat exchangers (heat exchangers designed from inappropriate low-cost materials will quickly fail due to chemical attack).
- Design for adequate emissions control of condensing heat recovery water and air effluent.

Integrating flue gas heat recovery in a CHP system using the DES as the heat sink requires special consideration from an economic perspective. With steam cycle CHP, more electrical power can be generated and higher efficiency attained with a large heat sink and low temperature. However, introducing flue gas heat recovery as a heat source for the DES can reduce the available heat sink and hence the electrical power generation. This may still be a good solution depending on fuel prices compared with the market value of electricity, but nevertheless it is a key issue that must be considered.



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