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SITE-SPECIFIC INVESTIGATIONS OF AQUIFER THERMAL ENERGY STORAGE FOR SPACE AND PROCESS COLLING

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ABSTRACT

The Pacific Northwest Laboratory (PNL) has completed three preliminary site-specific feasibility studies that investigated aquifer thermal energy storage (ATES) for reducing space and process cooling costs. Chilled water stored in an ATES system could be used to meet all or part of the process and/or space cooling loads at the three facilities investigated. Seasonal or diurnal chill ATES systems could be significantly less expensive than a conventional electrically-driven, load-following chiller system at one of the three sites, depending on the cooling water loop return temperature and presumed future electricity escalation rate. For the other two sites investigated, a chill ATES system would be economically competitive with conventional chillers if onsite aquifer characteristics were improved. Well flow rates at one of the sites were adequate, but the expected thermal recovery efficiency was too low. The reverse of this situation was found at the other site, where the thermal recovery efficiency was expected to be adequate, but well flow rates were too low.

INTRODUCTION

Aquifer thermal energy storage is a technology that allows relatively low-grade thermal energy sources to be stored and retrieved for future use on a seasonal or diurnal basis. Water pumped from a set of supply wells is heated or cooled and then injected into a set of storage wells. Later, the storage wells are pumped and the warm or cool water can be used to meet a thermal load. The principal advantages of ATES are the use of existing aquifer formations as both the media and physical containment components of a storage system, the use of water as the heat transfer medium, and the concept's ability to store energy on a seasonal or diurnal basis. The concept is limited, however, to locations where the energy source, energy application, and a suitable aquifer are in close proximity to each other.

The primary objective of this study was to identify prospective sites and determine the technical and economic feasibility of implementing chill ATES technology. A secondary objective was to identify site-specific factors promoting or inhibiting the application of chill ATES technology so that other potentially attractive sites could be more easily identified and evaluated, and R&D initiated to reduce the impact of inhibiting factors.

A previous study [1] developed and screened a list of potential entry market applications for chill ATES. Large industrial structures, in general, and automotive plants, in particular, were identified as attractive opportunities. Cooling systems at Ford Motor Company Plastic Products Division plants in Sandusky, Ohio, (Sandusky plant) and Seline, Michigan (Seline plant), and the General Motors Corporation Delco Products Division plant in Dayton, Ohio, (Dayton plant) were evaluated in this study.

ANALYTICAL APPROACH

The general approach was to calculate and compare the total life-cycle cost of each of the cooling system alternatives. The economic figure-of-merit was the levelized cost of cooling in $/MMBtu. Levelized cost analysis combines initial cost, annually recurring cost, and system performance characteristics with financial parameters to produce a single figure-of-merit (the levelized energy cost or LEC) that is economically correct and can be used to compare the projected energy costs of alternative cooling system concepts. The specific economic methodology employed was that defined in Brown et al. [2]. Some of the key inputs to the LEC analysis conducted for this study are shown in Table 1.

Where available, site-specific design information characterizing the general aquifer conditions, cooling loads, and conventional cooling system was acquired via written and oral communications with site energy managers. PNL specified chill ATES system design, cost, and performance characteristics; any missing data for other systems; and the financial assumptions required to complete the economic analysis. Most of the key modeling assumptions were based on conditions actually known to exist at the three plants. These included local climatic conditions, peak hourly and annual cooling loads, maximum flow rate per well, well cost, well depth, transportation distances, cooling water reject temperature, and electricity cost. Two other key chill ATES variables, aquifer thermal recovery efficiency and well spacing, were set at generically applicable values that would have to be confirmed by further analysis of the site geohydrology.

Initial capital and annually recurring costs for chill ATES systems were estimated by PNL from data produced by the computer model AQUASTOR [3]. Initial capital and annually recurring cost data for non-ATES cooling systems were either set equal to known site-specific conditions or estimated by PNL based on published information sources.

THE SANDUSKY PLANT

The feasibility study investigated storing chilled water in seasonal and diurnal ATES systems for subsequent application to process and/or space cooling loads. Diurnal salt TES and load-following chiller systems were also investigated. Each is described briefly below. Key design and cost attributes at the Sandusky plant are summarized in Table 2.

(a) The Pacific Northwest Laboratory is operated for the U.S. Department of Energy by Battelle Memorial Institute under Contract DE-AC06-76RLO 1830.

TABLE 1. Key Levelized Energy Cost Inputs

Initial Costs		
Site exploration	Heat exchanger	Cooling tower
Piping	Wells	Pumps
Chiller		
Recurring Costs		
Operating and maintenance		Electricity
Operating overheads		
Design and Performance Factors		
Source temperature	Source availability	Peak thermal load
Annual thermal load	Load reject temperature	Well life
Well spacing	Well flow rate	Well depth
Thermal efficiency	Transmission distance	

Financial Assumptions	
Nominal discount rate	9.3%
General inflation rate	3.1%
Capital inflation rate	3.1%
Operation and maintenance inflation rate	3.1%
Electricity inflation rate	3.1 to 9.3%
Investment tax credit	0%
Property and insurance tax rate	2.0%
Combined State and Federal income tax rate	39.1%
System economic life	20 yr
System depreciable life	7 yr
System construction period	1 yr
Price year	1989
First year of system operation	1990

TABLE 2. Sandusky Plant Design Conditions

Design Variables	Value
Source temperature	40 °F
Source availability	90 days
Peak thermal load	
process cooling	17.54 MMBtu/hr
space cooling	47.58 MMBtu/hr
Annual thermal load factor	0.219
Transmission piping length	
Seasonal ATES	6230 ft
Diurnal ATES	660 ft
Electricity cost (effective)	$0.045/kWh
Load reject temperature	59 °F
Thermal efficiency	90%
User heat exchanger	no
Well spacing	5 acres
Well depth	375 ft
Well cost	$27/ft
Well flow rate	200,000 lb/hr
Well life	30 yr

The seasonal ATES system supplies chilled water to meet all of the space and process cooling loads for the months of April through November. No conventional chillers are used in this system. Water withdrawn from supply wells is cooled by surface quarry water during the winter to approximately 42 °F and then injected into storage wells. From April through November, water is withdrawn from the storage wells on demand to meet space and process cooling loads.

The diurnal ATES system serves as a daily chilled water storage "tank". On the peak cooling demand day of the year, conventional chillers operate continuously at their maximum capacity. Water withdrawn from supply wells is cooled by excess chiller capacity during the first part of the day and injected into storage wells. In the afternoon, chilled water withdrawn from the storage wells is used to supplement the chiller capacity to meet the total process and space cooling load. Lesser amounts of water are chilled and stored in the ATES system on non-peak days.

The diurnal eutectic salt TES system provides daily chill storage capacity. On the peak cooling demand day of the year, conventional chillers operate continuously at their maximum capacity. Water cooled by excess chiller capacity during the first part of the day is used to freeze the eutectic salt. In the afternoon, warm water cooled by melting the eutectic salt is used to supplement the chiller capacity to meet the total process and space cooling load. On non-peak days, the eutectic salt TES system is less than fully charged.

As the name implies, the output of load-following chillers varies to meet the total process and space cooling load without any seasonal or diurnal storage augmentation. Load-following chillers were considered to be the reference case.

The levelized energy cost results, presented in Tables 3, 4, and 5, indicate that diurnal ATES would be a strong competitor to load-following chillers at higher cooling water reject temperatures and would have a significant advantage over load-following chillers if electricity costs were to escalate at 2% or more per year in excess of general inflation. The seasonal ATES system is projected to be less attractive than diurnal ATES, but would also have a significant advantage over load-following chillers if higher reject temperatures were allowed and if higher electricity cost escalation rates were expected. On the other hand, if future electricity costs are projected to escalate at the rate of general inflation and the design cooling water reject temperature is fixed at 59 °F, the seasonal ATES system looks unattractive while the two diurnal storage systems show no competitive advantage over load-following chillers. Note that given the level of uncertainty in the analysis, the projected levelized energy costs (in Table 3) for the two diurnal systems and the load-following chiller system should be considered equal.

In the first sensitivity case, the cooling water reject temperature was allowed to increase from the reference condition of 59 °F to 65 °F and 70 °F. The levelized energy cost results shown in Table 4 demonstrate how dramatically chill ATES system costs are reduced if higher cooling water reject temperatures are allowed. The significant savings are attributable to an increase in the energy density per unit of water, which reduces the size and cost of ATES equipment while meeting the same thermal load.

TABLE 3. Reference Cooling System Levelized Energy Costs

System	LEC
Seasonal ATES	$14.10
Diurnal ATES	$ 8.50
Diurnal salt TES	$ 8.40
Load-following chillers	$ 7.70

Notes: Levelized energy costs in 1989 $/MMBtu
Cooling water reject temperature = 59 °F
Electricity cost real escalation rate = 0%/yr

TABLE 4. Alternative ATES System Levelized Energy Costs

Cooling Water Reject Temperature	Seasonal ATES LEC	Diurnal ATES LEC
59°F	$14.10	$8.50
65°F	$10.30	$7.80
70°F	$ 8.30	$7.30

Notes: Levelized energy costs in 1989 $/MMBtu
Electricity cost real escalation rate = 0%/yr

TABLE 5. Alternative Load-Following Chiller Levelized Energy Costs

Electricity Cost Real Escalation Rate	LEC
0%/yr	$ 7.70
2%/yr	$ 8.60
4%/yr	$ 9.70
6%/yr	$11.10

Note: Levelized energy costs in 1989 $/MMBtu

Increasing the cooling water reject temperature would require additional heat transfer area in the space and process cooling heat exchangers, but would also reduce cooling water distribution piping and pumping costs. These cost effects were not included in this evaluation. Increasing the cooling water reject temperature would probably be most effectively implemented for process cooling where the reduction in heat exchanger approach temperature and increased heat transfer area requirements would be relatively minor compared to the space cooling application.

The second sensitivity analysis examined the impact of various electricity cost escalation rates on the levelized energy cost of load-following chillers. For the reference calculations, the cost of electricity was assumed to escalate at the rate of general inflation, i.e., 0%/yr in real terms. The cost of electricity represents more than one-half of the total levelized energy cost for load-following chillers, so increases in the expected future cost of electricity have a dramatic impact on the levelized energy cost of this technology, as shown in Table 5. Higher future electricity costs would not have nearly the impact on the levelized energy cost of a seasonal ATES system, which uses less electricity, but is more capital-intensive.

The levelized energy cost calculations described above were based on an assumed aquifer thermal efficiency of 90%. At this efficiency and a natural aquifer temperature of 55°F, water injected at a temperature of 42°F should be recoverable at 43 to 44°F. A separate evaluation of the geohydrology at the Sandusky plant indicated that a high thermal efficiency is unlikely. Although the well flow rates (400 gpm) are adequate to support a chill ATES system, the limestone formations underground are not conducive to a thermally efficient chill ATES system. Water injected into this type of formation would not usually be retrieved without significant mixing with the natural groundwater, which would degrade the recovery temperature. However, it should be noted that site testing would have to be conducted to confirm or repudiate this expectation and that conditions promoting mixing are less detrimental to diurnal storage than seasonal storage.

THE DAYTON PLANT

The feasibility study investigated storing chilled water in ATES systems for subsequent application to a space cooling load. Each ATES system supplies chilled water to meet all of the space cooling load in the Dayton plant's administration and engineering building. Water withdrawn from supply wells is cooled by passing through an evaporative cooling tower or by heat exchange with onsite lake water. Onsite and nearby offsite aquifers were considered, as were alternative assumptions regarding cooling source temperature, storage injection period, and well flow rates. Thus, 16 different chill ATES systems were evaluated, representing unique combinations of the variables summarized in Table 6. A conventional load-following, electrically-driven chiller system was also evaluated to establish a reference for comparison. Both new construction and continued operation scenarios were evaluated for the chiller system at future real electricity cost escalation rates ranging from 0 to 6%/yr. Key design and cost attributes at the Dayton plant are summarized in Table 7.

The levelized energy cost results, presented in Tables 8 and 9, indicate that a seasonal chill ATES system with wells located in an offsite aquifer could be economically competitive with a conventional chiller system. The levelized energy costs shown for the conventional chiller systems are probably understated because the evaluation of both chill ATES and chiller systems

TABLE 6. ATES System Variables for the Dayton Plant

- Onsite or offsite aquifer
- Cooling tower or natural lake cooling source
- 35°F chilling source for a 70-day storage period
- 40°F chilling source for a 100-day storage period
- 35 or 75 gpm per onsite well
- 100 or 500 gpm per offsite well

TABLE 7. Dayton Plant Design Conditions

Design Variables	Values
Source temperature	35°F or 40°F
Source availability	70 or 100 days
Peak thermal load	11.4 MMBtu/hr
Annual thermal load factor	0.30
Transmission piping length	
onsite aquifer, cooling tower	660 ft
onsite aquifer, lake water	5,580 ft
offsite aquifer, cooling tower	10,830 ft
offsite aquifer, lake water	16,080 ft
Electricity cost (effective)	$0.045/kWh
Load reject temperature	60°F
Thermal efficiency	90%
User heat exchanger	no
Well spacing	5 acres
Well depth	115 ft onsite 35 ft offsite
Well cost	$72/ft onsite $120/ft offsite
Well flow rate	17,500 or 37,500 lb/hr onsite 50,000 or 250,000 lb/hr offsite
Well life	30 yr

TABLE 8. Levelized Energy Cost Results - ATES Systems

Aquifer Location	Cooling Source	Source Temperature	Storage Period, days	Flow Rate per Well, gpm	LEC [(a)]
Onsite	Tower[(b)]	35 °F	70	35	$36
Onsite	Tower	35 °F	70	75	$22
Onsite	Tower	40 °F	100	35	$39
Onsite	Tower	40 °F	100	75	$24
Onsite	Lake	35 °F	70	35	$41
Onsite	Lake	35 °F	70	75	$26
Onsite	Lake	40 °F	100	35	$44
Onsite	Lake	40 °F	100	75	$28
Offsite	Tower	35 °F	70	100	$21
Offsite	Tower	35 °F	70	500	$10
Offsite	Tower	40 °F	100	100	$23
Offsite	Tower	40 °F	100	500	$11
Offsite	Lake	35 °F	70	100	$26
Offsite	Lake	35 °F	70	500	$14
Offsite	Lake	40 °F	100	100	$27
Offsite	Lake	40 °F	100	500	$14

(a) Levelized energy costs in 1989 $/MMBtu.
(b) The levelized energy costs for the cooling tower cases are based on using an existing tower to cool aquifer water in the winter. Purchasing a new tower would add about $1/MMBtu to the levelized energy cost.

TABLE 9. Levelized Energy Cost Results - Chiller Systems[(a,b)]

Electricity Cost Real Escalation Rate	Continued Operation	New Construction
0%/yr	$5.4	$6.2
2%/yr	$6.2	$6.8
4%/yr	$7.2	$7.5
6%/yr	$8.5	$8.5

(a) Levelized energy costs in 1989 $/MMBtu.
(b) Chiller coefficient of performance (COP) assumed to be 3.0 for continued operation and 4.0 for new construction.

was based on an overall average cost of electricity per kWh, rather than explicitly evaluating the demand and energy charge components. Chiller energy consumption is concentrated during the peak demand period of the day and would likely result in a higher average cost of electricity per kWh than the energy demand profile for the chill ATES system. A more detailed examination of electricity consumption and cost, and consideration of diurnal energy storage systems would be warranted, but Delco indicated they did not want to pursue an offsite aquifer location and the onsite aquifer well productivity is too poor for chill ATES to be economically attractive (as shown in Table 8).

The results shown in Table 8 highlight the importance of having productive wells. The levelized energy cost varies by about a factor of four between the best and worst systems with well productivity being the key distinguishing factor. In fact, the offsite systems show significantly better economics because of higher well flow rates despite having much greater transport piping costs.

Operating with a 35 °F chilling source and a 70-day storage period appears to be slightly preferred over having a 40 °F source and 100-day storage period. Two opposing effects are at work here. A cooler storage temperature increases the chilling capacity per unit of water, thus reducing the total amount of water that must be stored and the size and cost of equipment, all else equal. However, the shorter storage period increases the water flow rate and the size and cost of equipment, all else equal. Transportation distances, well flow rates, and well costs, among other factors, affect this tradeoff.

Cooling the aquifer water in an evaporative cooling tower was found to be less expensive than cooling with lake water in a shell-and-tube or plate-and-frame heat exchanger. Using a cooling tower avoids the cost of piping to and from the lake and the cooling tower alone is not expected to cost more than a heat exchanger. However, freezing water could create operational problems for the cooling tower.

The results presented in Table 9 show the impact of various electricity cost escalation rates on the LEC of load-following chillers for continued operation or replacement (new construction) of the current equipment. The cost of electricity represents more than one-half of the total levelized energy cost for load-following chillers, so increases in the expected future cost of electricity have a dramatic impact on the levelized energy cost of this technology. Higher future electricity costs would not have nearly the impact on the levelized energy cost of a seasonal ATES system, which uses less electricity, but is more capital-intensive. The current chillers at the Dayton plant are over 20 years old and were assumed to have a COP of 3.0. Replacement equipment should be able to achieve a COP of about 4.0. Note that a new chiller system could be an attractive option for Delco, especially if electricity costs are expected to escalate in excess of inflation and the actual COP of the current system is less than the assumed value of 3.0.

THE SELINE PLANT

The Seline plant is another Ford facility within their Plastics Division. Ford representatives indicated that the loads at this plant and a nearby plant in Milan were similar to the Sandusky plant and ATES cooling should be considered in Seline and Milan as well. Both plants are located in Southeastern Michigan, about 15 miles apart.

Unfortunately, Ford was unable to provide plant-specific data for the Seline or Milan plants. Aquifer characteristics in Seline and Milan were found to be similar and advantageous for ATES development. Wells drilled in a glacial till aquifer formation to a depth of around 125 ft could generally be expected to produce 1000 to 1400 gpm, according to Larry Wight of Lane Northern Company, a local well drilling contractor. Mr. Wight indicated that a well of this type could be expected to cost about $50,000 to drill and develop.

Well depth, flow rate, and cost characteristics identified above for the Seline area were combined with the other design conditions and system cost estimates for the Sandusky plant (see Table 2) to generate a proxy for the Seline plant. The resulting levelized energy costs for seasonal and diurnal ATES systems are shown in Table 10.

The data presented in Table 10 show that the Seline aquifer conditions result in a 33% reduction in seasonal ATES system costs and a 10% reduction in diurnal ATES system costs

TABLE 10. Seline ATES System Levelized Energy Costs

Cooling Water Reject Temperature	Seasonal ATES LEC	Diurnal ATES LEC
59 °F	$9.40	$7.50
65 °F	$7.10	$7.00
70 °F	$5.80	$6.80

Notes: Levelized energy costs in 1989 $/MMBtu
Electricity cost real escalation rate = 0%/yr

compared to the Sandusky plant (see Table 4). Note that the overall cost reduction for the diurnal ATES system is tempered by the inclusion of non-ATES components in its system. Seasonal or diurnal ATES systems at Seline are projected to be less expensive than load-following chillers, except for the seasonal ATES system at a 59 °F cooling water reject temperature and 0%/yr real electricity price escalation rate. Seasonal or diurnal ATES systems show significant advantage over load-following chillers at higher cooling water reject temperatures and/or higher real escalation rates for electricity.

CONCLUSIONS AND RECOMMENDATIONS

Several conclusions and recommendations were developed as a result of this study. Site-generic discussion is presented first, followed by matters specifically pertaining to the three sites.

Site Generic

Tempering the indoor air within large manufacturing facilities is an attractive application of ATES for space cooling. Tempering is defined here as conditioning indoor air to approximately 50% relative humidity at 80 °F in contrast to the cooler and less humid conditions usually required in commercial buildings. Air conditioning of large manufacturing facilities is currently atypical of U.S. industrial practice, but may become more common in the future because of 1) concerns for worker comfort, 2) the prospect of improved labor productivity, and/or 3) more restrictive operating requirements for computers and other electronic manufacturing equipment.

Space conditioning in a manufacturing environment does not require the strict temperature and humidity control criteria that many commercial cooling applications have. Flexibility in meeting the cooling load removes some of the concern in implementing an innovative cooling technology. Furthermore, the relative large cooling loads associated with such facilities allow reductions in the unit costs of ATES systems via strong economies-of-scale. Finally, tempering conditions substantially improve ATES economics by increasing the amount of cooling that can be accomplished per unit of chilled water supplied to the building cooling water loop.

The importance of the target cooling conditions (temperature and humidity) for chill ATES application cannot be overemphasized when considering the potential feasibility of a chill ATES system. Process cooling conditions in excess of 100 °F are usually more economically served by evaporative cooling towers. Typical office environment cooling conditions (low 70s with low to moderate humidity) require low cooling water loop return temperatures in humid climates that generally make chill ATES less attractive. In between these two endpoints, cooling with ATES systems has its greatest competitive advantage.

The availability of a suitable aquifer is an obvious requirement for any ATES system. The economic feasibility of ATES for cooling requires shallow, low-cost, thermally efficient, productive wells. Future feasibility studies should begin by investigating the geohydrologic characteristics of prospective sites because the lack of suitable aquifers is a constraint inhibiting implementation of the chill ATES concept.

Constructing a winter cooling mechanism (e.g., evaporative cooling tower, air cooler, spray pond, cooling pond) allows greater siting flexibility, but could be more expensive than using natural sources of winter chill (e.g., lakes, ponds, rivers). The cost and performance of these alternative cooling sources should be investigated for alternative design conditions (e.g., source temperature, source availability, transmission distance, peak thermal load).

Both seasonal and diurnal chill ATES systems should be considered at prospective sites. The best chill ATES system will depend on the prevailing electric rate structure and load profile, as well as local aquifer conditions. Seasonal chill ATES systems could displace all or part of a facility's cooling load, while diurnal chill ATES systems could provide the same service as other diurnal chill storage technologies.

The Sandusky Plant

The principal conclusions and recommendations of the preliminary feasibility study of space and process cooling using ATES at the Sandusky plant are summarized below.

1. The geohydrologic characteristics at the Sandusky plant are inadequate for a chill ATES system.

2. Diurnal ATES would be a strong competitor to load-following chillers at cooling water reject temperatures higher than the reference condition (59 °F) and would have a significant advantage over load-following chillers if electricity costs were to escalate at 2% or more per year in excess of general inflation.

3. Seasonal ATES is projected to be less attractive than diurnal ATES, but would also have a significant advantage over load-following chillers if higher cooling water reject temperatures were allowed and if higher electricity cost escalation rates were expected.

4. None of the alternative systems were projected to have an economic advantage over load-following chillers for the reference study conditions.

5. Future electricity cost escalation in excess of general inflation (assumed equal to general inflation for the reference assumption) makes all storage concepts more attractive and would change the technology rankings if future electricity costs escalated rapidly.

6. Increasing the cooling water reject temperature from 59 °F to 65 °F or 70 °F would likely make chill ATES an attractive option, especially for process cooling, if an appropriate aquifer were available.

7. The geohydrology at other facilities with cooling loads similar to the Sandusky plant should be investigated to identify prospective chill ATES applications.

The Dayton Plant

The principal conclusions and recommendations of the preliminary feasibility study of space cooling using ATES at the Dayton plant are summarized below.

1. Onsite well productivity is too poor for chill ATES to be economically attractive.

2. If access to an offsite aquifer approximately 1 mile north of the plant boundary was possible, chill ATES economics would become much more attractive and a more detailed analysis of seasonal and diurnal ATES would be warranted.

3. Chill ATES would be more attractive if applied to a facility with a cooling load and cooling water reject temperature higher than required for the administration and engineering building. For example, chill ATES is probably best suited for tempering the indoor air in large production facilities. With a peak load of only 3.34 MWt, the economies-of-scale available to larger chill ATES systems are not captured in the application evaluated. In addition, the low cooling water reject temperature required for humidity control in an office environment works against chill ATES system economics.

4. Operating with a 35°F chilling source and a 70-day storage period appears to be slightly preferred over having a 40°F source and 100-day storage period.

5. Evaporative cooling towers would be preferred to using onsite lake water and a heat exchanger as the means of chilling the aquifer water, provided potential freezing problems in the cooling towers can be avoided.

6. A new chiller system could be an attractive option for Delco, especially if electricity costs are expected to escalate in excess of inflation and the actual COP of the current system is less than the assumed value of 3.0.

7. The geohydrology at other Delco/General Motors' Corporation facilities with large cooling loads should be investigated to identify prospective chill ATES applications.

The Seline Plant

The principal conclusions and recommendations of the preliminary feasibility study of space and process cooling using ATES at the Seline plant are summarized below.

1. Shallow, productive aquifers in the Seline and Milan, Michigan area significantly enhance the potential attractiveness of an ATES system.

2. Seasonal or diurnal ATES systems at Seline could be significantly less expensive than load-following chillers, depending on the cooling water reject temperature, future electricity escalation rate, and the similarity of the Sandusky and Seline plants.

3. The preliminary results indicate that further investigation of ATES feasibility based on the actual design conditions at Seline is warranted.

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