COVER STORY

# 21 years on, Cornell's lake source cooling project has more than proven its worth

## Substantial long-term cost savings and carbon-emission reductions

***By Deirdre Lord, Robert R. Bland, and Angela Zeng***

Jason Koski/Cornell University

Cornell University, with its student population of about 25,000, is on the south end of Cayuga Lake in New York.

In the mid-1990s, Cornell University faced a significant capital investment decision about how to meet growing campus cooling needs. The global Montreal Protocol agreement was forcing the phaseout of ozone-depleting refrigerants, and increased cooling demand and load growth were requiring major changes to its campus chilled-water system. The university identified two potential paths to providing the 25,000 tons of chilled water the campus would need in 2024:

1. replace the three existing chiller plants with ones that used ozone-friendly refrigerants (termed the "base case") or
2. use the cold, deep waters of nearby Cayuga Lake in a heat exchange facility to supply lake source cooling (LSC), along with three ozone-friendly chillers to help meet peak load requirements.

Cornell, which is in Ithaca, N.Y., studied both options through a collaboration among faculty, facility staff and consultants. This included assessment by the faculty Technical Review Committee, formed by the university to guide the environmental studies related to LSC (which it does to this day). An environmental impact statement found that drawing cold lake water through a heat exchanger was feasible and environmentally sound, and it would reduce energy use below the base case by 85%. So, after the project received Board of Trustees approval and obtained the necessary permits, the $58.5 million system was built and began serving the campus in 2000.

Since then, Cornell's lake source cooling system – the first and largest in the U.S. – has earned the university recognition for its leadership in sustainable energy solutions. Among numerous honors received, the campus chilled-water

Jon Reis

The lake source cooling system's heat exchange facility is a linchpin of the $58.5 million project.

and steam/combined heat and power systems were collectively named IDEA's System of the Year in 2001.

The presence of the system offers opportunities for teaching and research related to the technology – creating an on-campus "living laboratory." In the spring of 2021, students in an undergraduate capstone course in the university's environment and sustainability major reviewed the 21-year performance history of the LSC system. Analysis covered actual environmental impacts on Cayuga Lake and greenhouse gas reductions (see sidebar), as well as community perception of the project. The evaluation also studied cumulative financial impacts and compared operating experience to the base case projections.

This study of project economics may provide insights that other district energy managers can apply in their own capital investment decisions. How did Cornell assess the cost-benefit of replacing aging chillers versus investing in LSC? Once the university decided to pursue LSC, how did the next 21 years of operating performance compare to the 1996 projections? Finally, what conclusions can district energy operators draw from these analyses?

## System snapshot: Cornell University

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|---|---|
| **Campus chilled-water system** | |
| Total cooling capacity: | 26,000 tons |
| From lake source cooling: | Approximately 18,000 tons (at 39 F lake temp) |
| From Chilled Water Plant 3: | 7,500 tons (3 chillers) |
| From thermal energy storage: | 32,000 ton-hrs |
| Space served: | 11 million sq ft in 140 buildings |
| Temperatures: | 44 F supply/55 F return |
| Design pressure: | 420 psig |
| Distribution piping: | 50,000 trench ft (9.5 miles) |
| **Lake source cooling system** | |
| Efficiency: | 0.03 kW/ton (lake pumps only), 0.15 kW/ton (with distribution pumps) |
| Intake depth: | Approximately 250 ft, screened |
| Intake piping: | More than 10,000 ft from lake to heat exchange facility wet well, 63-inch high-density polyethylene |
| Lake water pumps: | 3 @ 350 HP, each 13,000 gpm, 80-ft head |
| Heat exchangers: | 7 plate-and-frame, each 3,000-ton at 4,600 gpm, 16 F delta T |
| Chilled-water pumps: | 5 @ 600 HP, each 6,600 gpm, 280-ft head |
| Outflow piping: | 750 ft of 48-inch HDPE, 6-inch nozzles during the last 100 ft to promote mixing, maximum discharge rate approximately 31,500 gpm |
| Piping to loop: | 12,000 ft from heat exchange facility to campus |

Source: Cornell University

## EVALUATING AND PRESENTING CAMPUS COOLING OPTIONS

Cornell estimated that lake source cooling would require a capital investment of $55 million, nearly twice the $30 million cost of the base case chiller option. However, efficiency benefits from the simple plate-and-frame heat exchangers and pump design used in LSC energy were expected to reduce maintenance and operating expenses and lower electricity consumption and peak demand enough to justify the expense. Lake source cooling uses only 0.15 kW/ton, including the requisite distribution pump energy – about six times less than new conventional chillers. The project evaluators' presentation to the Cornell board would need to clearly describe the very different financial profiles of these alternative approaches to campus cooling.

Cornell analyzed the present value of future costs of each option assuming a nominal discount rate of 8%, which was the approximate cost of its long-term borrowing at the time and was also roughly equal to the estimated long-term return on the university's endowment. The present value of both options took 30 years of future costs into account, including operating expenses, electricity and maintenance costs, capital spending and, in the case of LSC, the residual value of the project.

### Cost calculations

In 1996, project evaluators calculated the present value of the costs of LSC and subtracted the present value of the costs of a new central chiller system. The resulting net present value of LSC project costs was $17 million – meaning that the total LSC project lifecycle cost was expected to be $17 million less than the chiller option.

To determine the likely return on the LSC investment, analysts looked at the internal rate of return of the increased capital costs of LSC over chillers (treated like an outflow) versus the future benefits of lower ongoing costs of LSC versus chillers (treated as an inflow). The 1996 calculation resulted in a 17% internal rate of return on the LSC project investment, which was well over the university's hurdle rate and indicated a simple payback of six years.

These results suggested that lower operating costs would more than compensate for the higher initial capital costs of lake source cooling, justifying the greater initial investment. However, any assessment of 30 years of future costs would not be complete without a thorough analysis of potential future conditions and risks. The most salient economic variables for evaluating the LSC investment included energy prices, demand for chilled water, borrowing costs and maintenance costs. Early modeling of these variables demonstrated that cost projections for both cases were most dependent on future energy costs.

### Probabilistic analysis

Cornell ran a probabilistic analysis to evaluate a wide range of future energy costs in order to calculate the expected cost of the LSC and chiller options. First, a Monte Carlo simulation was used to project likely future electricity prices, giving decision makers the ability to understand and visualize the uncertainty around future economic and operating conditions affeting lake source cooling.

In addition, analysts presented the likely cost outcomes for both options using a probability distribution function. This statistical tool describes possible values and likelihoods that a random variable can take within a given range. In this case, the variable was the total cost of each option. Analysts modeled the variability of each separate cost component and summed these costs to produce a total distribution for each project alternative. The greater the spread, or dispersion around the expected outcomes in this probability distribution, the greater the risk.

This probabilistic approach to cost projections allowed the university to evaluate both the expected costs of the two alternative projects as well as the risk of higher-than-expected costs. Both models as well as underlying campus demand assumptions provided important data for university decision makers.

## ACTUAL COSTS AND PERFORMANCE VERSUS FORECAST

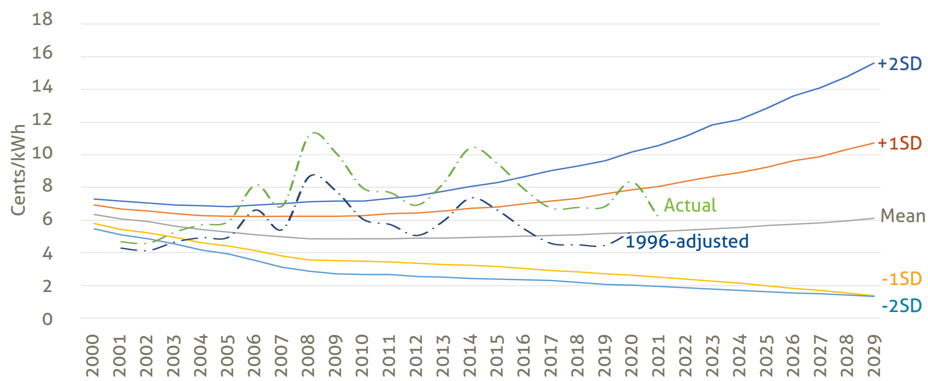
In the spring of 2021, Cornell students – along with campus energy staff and outside advisors – looked at the variables that had affected the actual costs of the lake source cooling system. Their analysis compared 1996 forecasts versus actual performance, including chilled-water demand, electricity unit rates and project costs.

Demand for chilled water was just one of the uncertainties surrounding the economic analysis, planning and construction of the lake source cooling facility. Planners projected that chilled-water peak demand would grow from 14,000 tons in 1996 to 25,000 tons in 2024. The demand did, in fact, increase to 21,000 tons by 2021 and is on track to reach 25,000 tons by 2024. The increase reflects the addition of 20% more gross square footage of campus building space over 21 years, driven by the construction of new research and teaching facilities.

### Electricity unit rate

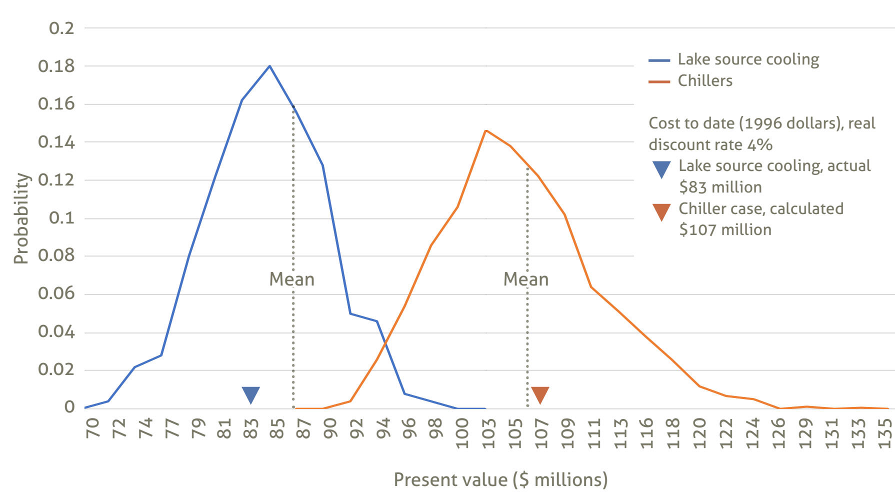
The 1996 Monte Carlo simulation forecast expected electricity unit rates (in real terms without general inflation). The 2021 analysis reproduced the results of this simulation, as illustrated in Figure 1. The original projection had Cornell's electricity rates falling from 6 cents/kWh to roughly 5 cents/kWh by 2008, and then increasing to 6 cents/kWh by 2029. The unit rate was expected to fall in real terms because of the impact of New York state's

**FIGURE 1.** Comparison of forecast electricity unit rates (mean and standard deviations in 1996 constant dollars) with actual realized and inflation-adjusted 1996 rates, 2000-2029, Cornell University.




Source: Cornell University

**FIGURE 2.** Probability distributions for the present value of lake source cooling versus conventional chillers and realized costs to date (1996 dollars), Cornell University.




Source: Cornell University

utility deregulation, which began in 2000. In 2021, Cornell students superimposed the nominal, or actual, then-year realized rates as well as the inflation-adjusted rates in 1996 dollars over the original forecast.

In Figure 1, the center gray line is the projected mean electricity rate (for electricity supply and delivery summed) for a given year. The orange and yellow lines project electricity prices that are one standard deviation above and below this projected mean (ranging from less than 2 cents to over 10 cents). The two blue solid outside lines are two standard deviations from the mean (ranging from 1.5 cents to almost 16 cents in 2029). The 1996 analysis projected with 95% confidence that actual energy prices would fall within one standard deviation of the mean.

Students reviewed 21 years of cost data to determine the actual realized rates in cents per kilowatt-hour (green dotted line) and then converted the nominal units into 1996 dollars (blue dotted line).

Apart from the first few years, actual electricity rates increased to over 10 cents when gas prices were high through 2007-2008, declined sharply with the advent of fracking and demonstrated periodic volatility due to black swan weather events like the 2014 polar vortex.

For most years, the original forecast consistently and significantly underestimated future electricity prices. The assumption at the time of the original analysis was that the base case chillers would use six times the electricity of lake source cooling.

Thus, underestimating future electricity prices had the effect of underestimating the cost savings from LSC's significantly lower energy consumption, peak demand and capacity cost relative to conventional chillers.

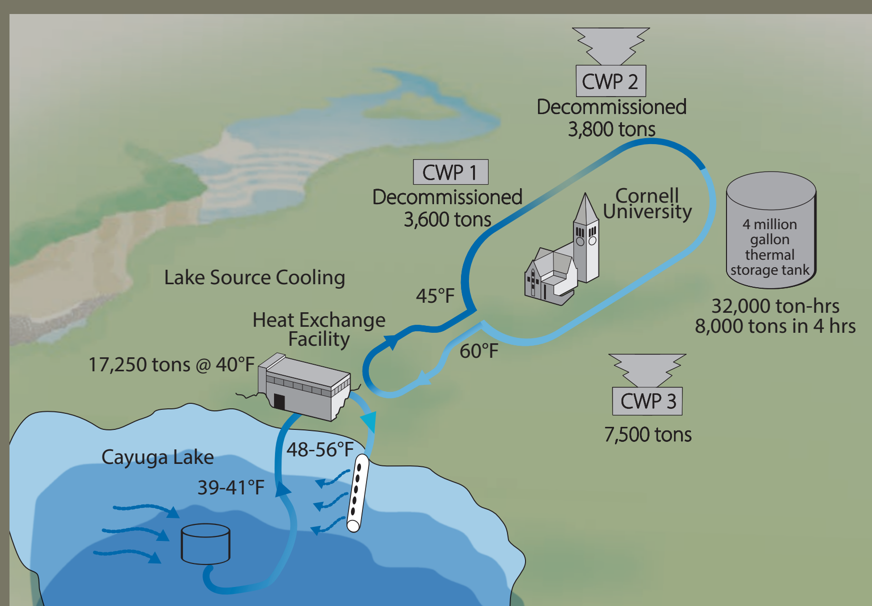
## Overview: Lake source cooling at Cornell

The introduction of lake source cooling in 2000 ushered in a new era of sustainability for Cornell's chilled-water system (Figure 3). The project involved decommissioning two of three campus cooling plants, including all five system chillers using ozone-depleting chlorofluorocarbon refrigerants. One plant remains in operation equipped with three ozone-friendly hydrochlorofluorocarbon chillers that, together with a 4.4 million-gal thermal energy storage tank, can be tapped to meet peak loads or as backup to LSC.

The system draws water from Cayuga Lake through a screened intake about 10 feet above the lake bottom at a water depth of 250 feet. At 39 to 41 degrees F year-round, the water is piped to the onshore heat exchange facility where its coldness is transferred to the campus chilled-water loop. This water is then returned to the lake at 50 to 55 degrees F through a diffuser 500 feet offshore at a water depth of 10 feet. No chemicals are added to the recirculated lake water.

The environmental impact of LSC on Cayuga Lake is continually assessed and monitored, including by Cornell's faculty Technical Review Committee. The New York Department of Environmental Conservation has also continued over 20-plus years to determine that the system is not a significant contributor to water quality impairment, leaving Cornell's LSC permit in effect.

**FIGURE 3.** Cornell University's lake source cooling system.




**Source: Cornell University**

### Probability distribution: present values

To appropriately present the uncertainty that surrounded the financial projections, project analysts in 1996 presented the board with two probability distribution functions. These visualizations helped decision makers understand, quantify and characterize the risks of LSC versus the chiller option.

Cornell's Board of Trustees reviewed Figure 2, which shows the probability distributions for the total present value for the chillers (orange) and lake source cooling with residual value (blue). This figure illustrates the variability in possible future outcomes depending on the variability of many inputs, including energy costs. The mean present value of costs for LSC projected over 30 years was $86 million – $20 million less than the mean present value projected for chillers.

For lake source cooling, the maximum present value of costs, based on the worst-case combination of all economic conditions, was calculated at approximately $100 million. This worst-case outcome for LSC was projected to be extremely unlikely, whereas 85% of the projected cost outcomes for the chiller case were above $100 million.

For the chiller option, the distribution of projected costs also had a higher standard deviation ($6.3 million versus $4.7 million for LSC) and was more skewed to the higher end of the distribution than the LSC project. From an investment perspective, the chillers appeared to be not only a higher-cost option but also a riskier project. Given the expected conditions shown in the economic analysis, LSC represented an attractive investment both relative to new chillers and in absolute terms (i.e., projected lower operating costs).

In their 2021 analysis, Cornell students calculated the actual cost to date of lake source cooling and compared those costs to the chiller case. Included in the cost calculation were capital, energy (natural gas, electricity supply and demand), other operating functions such as maintenance, and debt service.

The blue triangle in Figure 2 shows the realized costs to date of LSC in 1996 dollars, at a real discount rate of 4%, while the orange triangle shows the hypothetical cost of operating the chiller plant using the same time frame and discount rate.

Despite the significant underestimation of energy prices in the original analysis, the LSC actual costs to date, in 1996 dollars, are in line with what the 1996 projection showed would be a highly likely outcome. (Note that the original probability distribution function spanned the projected 30 years of LSC operation. The student analysis captured only the first 21 years of operation and compares operating history with 21 years of the chiller case. Over a 30-year time frame, actual costs will not be as in line with the highly likely projections.)

The chiller costs are also closely aligned with the probable costs forecast in 1996. Higher-than-projected energy costs resulted in the higher-than-projected overall costs 21 years after startup. However, thanks to the higher efficiency of Cornell's lake source cooling system – which decreases summer peak demand by 50% – the project has provided solid returns on the initial investment, in addition to helping the university get on the path to lower carbon emissions.

## WHAT CORNELL HAS LEARNED

Cornell's lake source cooling project has proved to be a prescient and sound capital investment. The present value of the savings to the university is $23 million in 1996 dollars. The internal rate of return is 14% (well above the university's hurdle rate and close to the originally expected return of 17%). The simple project payback was just under seven years.

Broadly speaking, district energy managers and financial decision makers face increasingly complex questions

## Accounting for greenhouse gas emissions

Cornell's lake source cooling project has helped set the Ithaca campus on a path to net-zero carbon emissions by 2035. A 2021 student analysis of the impact on campus emissions shows that the LSC system has avoided the creation of approximately 127,500 tons of carbon dioxide since its inception.

### Average emissions

To reach this determination, the analysis used the average $CO_2$ emissions rate for electricity from the upstate New York grid, which supplies the LSC heat exchange facility. Approximately 90% of the upstate electricity is generated by nuclear, hydroelectricity and some renewables. Students calculated the net energy use and corresponding emissions of LSC and compared them to estimates for a business-as-usual scenario of cooling supplied by conventional chillers (Figure 4).

### Marginal emissions

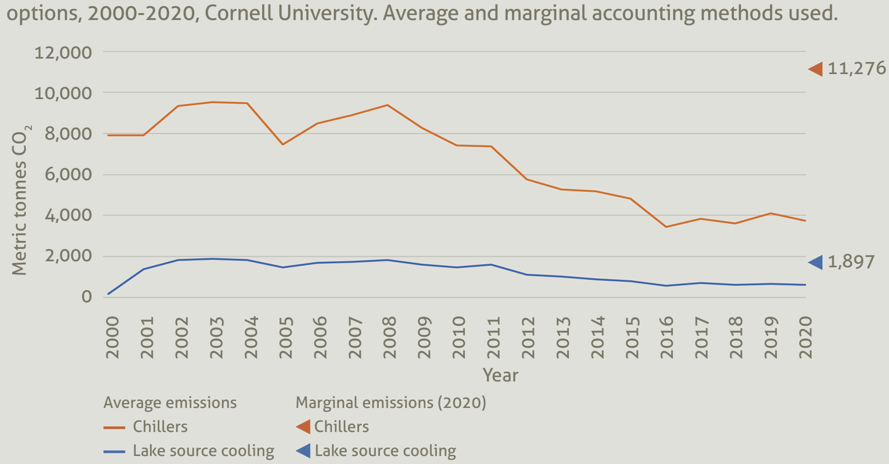
An alternative approach to measuring LSC's impact uses a marginal emissions rate, also indicated in Figure 4. This is the rate at which emissions change due to adjustments in electrical load, like shifting from one cooling technology to another, introducing high-efficiency chillers or installing efficient lighting or windows. In many parts of the U.S., at current levels of grid-tied renewable energy generation, the local marginal unit of power (e.g., the power generation source that would ramp up or down in response to changes in demand) would likely be produced by natural gas peaking plants.

The difference between the average versus marginal emissions rates can be significant, depending on the power-generating resources in a given region. As Figure 4 shows, Cornell is a case in point. While upstate New York is largely considered a low-emissions region – with the predominance of nuclear, hydroelectric and wind energy – the marginal generating unit when adding load in the region is primarily natural gas-fired. Therefore, for Cornell, presenting the impact of LSC using marginal emissions rates showed even larger avoided $CO_2$ emissions than using the average rate.

In evaluating the greenhouse gas impacts of various energy projects, it is important to understand the power generation dynamics of the regional power grid as well as the appropriate accounting method to select when demonstrating project impacts.

For more on marginal versus average emissions rates and the LSC project, visit https://sustainablecampus.cornell.edu/news/mer-vs-aer.

**FIGURE 4.** Comparison of carbon dioxide emissions from lake source cooling and chiller options, 2000-2020, Cornell University. Average and marginal accounting methods used.




**Source: Cornell University**

that require careful, detailed analysis of the costs and benefits of new technologies. This challenge is particularly evident when current known technologies that may combine lower capital costs with higher operating costs are compared with newer, less-proven capital-intensive alternatives. Critical costs are difficult to quantify; benefits are often unclear; and the regulatory environment is in flux. Nevertheless, decision makers must use the best information available to them to forecast costs and benefits of new projects, as Cornell did in 1996.

The university analyzed and presented uncertainty in the evaluation of two strikingly different approaches to supplying campus cooling needs. In 2021, students looked back with the fullness of operating experience, time and realized costs to evaluate how well the 1996 analysis performed in representing risk, cost and benefit.

Both the probability distribution function and the Monte Carlo simulation were effective in evaluating and presenting the most important tradeoffs between the higher capital investment and lower operating expense of lake source cooling.

As Cornell has shown, cost-benefit forecasting is an important component of decision making. While forecasts may turn out to diverge from actual experience, they are nonetheless necessary for framing decisions, highlighting tradeoffs and bringing to light the institutional values that guide major investment decisions.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