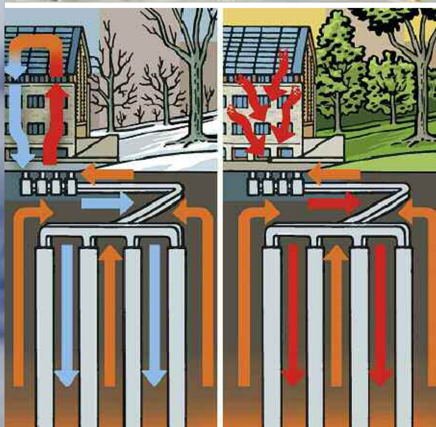

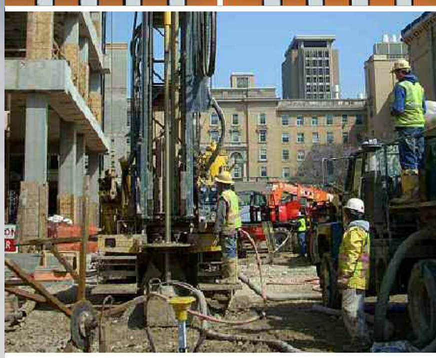

GOING UNDERGROUND ON CAMPUS:

Tapping the Earth for Clean, Efficient Heating and Cooling

A Guide to Geothermal Energy and Underground Buildings on Campus

By Stan Cross, David J. Eagan and Paul Tolmé
with Julian Keniry and John Kelly
Foreword by Robert J. Koester

A comprehensive review of the strategies and steps to implement geothermal heating and cooling on campus, with best practices from U.S. colleges and universities.

National Wildlife Federation® CAMPUS ecology®

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A PUBLICATION IN CAMPUS ECOLOGY'S *CLIMATE AND SUSTAINABILITY SERIES*

GOING UNDERGROUND ON CAMPUS:

Tapping the Earth for Clean, Efficient Heating and Cooling

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A PUBLICATION IN CAMPUS ECOLOGY'S *CLIMATE AND SUSTAINABILITY SERIES*

CONTENTS

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About Campus Ecology

Since its inception in 1989, National Wildlife Federation's (NWF) Campus Ecology program has earned respect as a national leader in the campus sustainability and climate action movement. Originally named Cool-It!, the program has long recognized the opportunities for higher education to lead society to a clean, just and prosperous energy future. Our program's tools, training and expertise serve students, faculty and staff in a wide range of capacities. Its publications, workshops, fellowship program, web-based resources and talented staff have empowered students and inspired environmental stewardship on hundreds of campuses nationwide. Equally important, its personal assistance with energy efficiency and conservation projects has led to significant financial savings. Now, after more than 20 years working to green America's campuses, a wide-scale demand for an educated green workforce has finally emerged. One of the most important roles the Campus Ecology program can play is to help better position colleges and universities (and especially community colleges) to serve this need. In 2009, we shifted our work to include this positive vision of an approaching sustainable, clean energy economy and new, greener careers, while still supporting the critical need to reduce greenhouse gas emissions, protect habitat, and cultivate student leaders in the process. Reducing greenhouse gas emissions goes hand in hand with creating the green jobs needed for a sustainable, clean energy future. NWF's Campus Ecology programs works with many other youth and conservation organizations to extend our reach including the Energy Action Coalition (www.energyactioncoalition.org), Clean Air-Cool Planet (www.cleanair-coolplanet.org), AASHE (Association for the Advancement of Sustainability in Higher Education - www.aashe.org), APPA (Leadership in Educational Facilities - www.appa.org), SCUP (Society for College and University Planning - www.scup.org), and Jobs for the Future (www.jff.org).

If you have questions please call us at (703) 438-6000 or email campus@nwf.org
And be sure to keep up with the latest at www.CampusEcology.org

Overview

"No institutions in modern society are better equipped to catalyze the necessary transition to a sustainable world than colleges and universities. They have access to the leaders of tomorrow and the leaders of today. What they do matters to the wider public."

—David W. Orr, professor and author, Oberlin College, from *The Last Refuge*

David J. Eagan

This geothermal energy guide is for higher education administrators, staff, faculty and students who are exploring the implications of climate change and seeking cost-effective solutions. It presents information about various types of geothermal energy projects, and provides many case studies from 160 campuses in 36 states across the U.S. that are leading the way in the implementation of such projects. Five different geothermal systems are highlighted: ground-source heat pumps, direct geothermal, aquifer and lake-based, geothermal electricity, and earth-sheltered buildings. The goals of this guide are to inform institutions about geothermal energy's potential to heat, cool and power American higher education, to inspire campuses to consider using geothermal technologies to lower long-term energy costs and energy demand, and to reach greenhouse gas emissions reduction targets.

As a founding organization of the climate action movement, NWF's Campus Ecology has helped hundreds of colleges and universities cut greenhouse gas emissions, save millions on energy costs and embed environmental values in campus operations and curriculum. Campus Ecology has worked closely with all types of schools: public and private, large and small, community and technical colleges. As a result, it has a breadth of experience, ideas and resources to offer any college or university. The mission of Campus Ecology is to foster climate leadership on campuses nationwide and to protect wildlife and our children's future against the growing threat of global climate change. This report is a guide for administrators, staff, faculty and students exploring the implications of climate change and seeking cost-effective solutions. It presents a scientific overview of global warming and a review of the business, educational and moral arguments for confronting this problem. Case studies from a diverse group of leading campuses illustrate energy-conserving and emissions-saving projects, effective financing strategies and creative ways to involve the campus community. A section on the planning process and implementation steps is included to help campuses get a jump on cutting costs and reducing their carbon footprint.

NWF's goal for society—and for higher education—is to reduce carbon emissions by 2% per year, leading to an 80% cut by 2050. Achieving 2% or greater reductions each year can start with simple actions like lowering the thermostat or installing occupancy sensors. But this call for action on campus goes beyond asking for small steps. Heeding the world's top scientists who warn that global warming will trigger a potential cascade of negative consequences, Campus Ecology urges bold action and critical leadership today and throughout the next decades, when our actions will determine the fate of the climate for generations to come.

"Students on today's campuses are helping to lead the way now, and will soon be the leaders in business and government who will be called on to address this ongoing worldwide threat."

—Al Gore, former Vice President,
Broadcast of NWF Chill Out: Campus Solutions to Global Warming

The National Wildlife Federation and Global Warming

In 2005, the National Wildlife Federation established global warming as one of three chief concerns for the organization, recognizing that it could not successfully protect wildlife without also working to stabilize the climate. While the impacts of global warming are an overarching threat to wildlife and ecosystems, their reach also will touch every facet of society—human health, agriculture, national security and the economy. Turning the tide on global warming may be the most far-reaching challenge of our time, but it also is an extraordinary opportunity to create more efficient, resilient and sustainable colleges and universities—and to inspire students to make a commitment to climate action in their lives and careers.

Great-horned owls and other native wildlife seek refuge in campus natural areas.

NWF's Campus Ecology program has focused its attention on global warming solutions and is committed to providing resources to assist postsecondary institutions make the transition to a low-carbon, clean energy future. Contrary to conventional opinion, the path to climate sustainability not only is technologically possible but it can save substantial amounts of money. This report offers a roadmap for how colleges and universities can make it happen.

"That's one of the things that's quite powerful about the basics of sustainability – discovering that it's less expensive to operate sustainably."

—Charlie Lord, Director of the Urban Ecology Institute, Boston College

Climate Action Opportunities

for Higher Education

By taking strategic, climate-positive action, campuses can dramatically cut CO_2 emissions by at least 2% per year, 30% by 2020 and 80% by mid-century—the targets advocated by the majority of scientists. By achieving these benchmarks, campuses will also:

- Reduce operating costs and generate favorable returns on clean energy investments.
- Buffer against uncertain future energy supplies, rising costs and mandated emissions limits.
- Identify exciting new research and service-learning opportunities.
- Encourage interdisciplinary collaboration among faculty.
- Prepare students for sustainability and climate leadership in all careers and professions.
- Appeal to current and prospective students, parents and donors.
- Foster a campus-wide ethic of environmental stewardship.

FOREWORD[1]

You are in for a treat. The National Wildlife Federation has compiled in this document a concise, well-organized and very instructive survey of the landscape of opportunities for colleges and universities to employ geothermal technologies and earth-integrated architecture on their respective campuses. The guide will be useful to administrators, faculty, staff and students as they open dialogue, frame questions and conceive strategies regarding the complexities of energy systems intervention—whether for individual buildings or the campus as a whole. This report provides a quick study of the principles of the many geothermal technologies used for energy sourcing (and sinking) as well as climate buffering, and presents case studies of institutions of varying size and location that are engaging the benefits and challenges within this technical arena.

The benefits and challenges are many. From an operations perspective, direct-heat geothermal and ground source heat pump geothermal technologies can be used to offset the carbon dioxide equivalent (CO_2e) greenhouse gas emissions otherwise associated with on-campus fossil fuel combustion. And although the electrical energy needed to power the technology itself can be the product of fossil fuel combustion, the upstream leveraging reduction on CO_2e greenhouse gas emissions remains significant. In fact, because of the high coefficients of performance in the physics of heat pump energy transfer, geothermal heat pumps produce multiple units of heating and cooling thermal energy for every purchased kilowatt-hour (kWh) of electrical power.

These benefits extend further when considering the impact of energy conservation in buildings on campus; for every reduction in energy demand, the upstream impact can be multifold. This is especially true for buildings that are underground or earth-integrated; the relative constant temperature of the ground assures that such buildings see a moderate ambient condition no matter how severe the above-ground, seasonal climate swings might be. This translates to a reduction in demand for upstream energy supply.

For all these reasons it is desirable to use a whole-systems view of performance and to '*bundle*' conservation *with* alternative energy sourcing, when scheming campus system(s) design.

Installing geothermal technologies sets the stage for more strategic climate action planning. Geothermal technologies are scalable; they can yield a measurable cost-benefit for individual buildings or the campus as a whole. And to the extent that a whole campus moves away from (or eliminates completely) on-site fossil fuel combustion, the opportunity to exploit upstream green-power supply becomes ever greater, contributing to the growth of the green-energy, grid-supply market. Geothermal energy distribution networks on campus can be used as well for 'lateral' energy-flow management—whether for the real-time, *synchronous* 'trading' of waste energy from one building to the energy needs of another or for the scheduled *asynchronous* sinking (for future use) of the thermal loads from the sun and occupant activity.

Cost benefit considerations affect decisions. A complication for most colleges and universities is that capital budgeting is funded independently from operational budgeting and evaluating the economics of long-term benefit against the short-term expense is difficult; yet this can be significant, especially when considering the net present valuation of longer-term avoidable costs such as the yet-to-be-realized carbon tax (and/or cap-and-trade carbon market) that is coming!

[1] Ball State University is installing a ground source heat pump district heating and cooling system to service all 45 campus buildings; this foreword is written from the perspective of the importance of a whole-campus perspective. See Ball State story on page 24.

In running such projections, even at modest unit-cost per ton of CO_2e emissions, colleges and universities will face significant long-term annual tax encumbrance for on-site (SCOPE 1) fossil-fuel combustion. Geothermal technology shifts that avoidable cost upstream to the utilities that generate the electrical power. This means that because of the efficiency gains of on-campus geothermal technologies, the utility will pay less in carbon taxes than the campus would have, had it maintained conventional on-site generation. In other words, geothermal is not just about load and cost shifting, it represents true conservation and efficiency and net reduction in greenhouse gas emissions. Moreover, these moves will yield, in today's dollars, a net present value positive cash-flow and annual savings for the avoided on-campus (and upstream) fuel purchase.

Required acreage can be a challenge. To the extent that placement of bore-hole fields for closed-loop heat pump systems can be aggregated in one or two centralized areas of a campus, the challenge is less daunting. But such centralized district-scale system installation offers the longer-term benefits of energy management as noted above. And connecting those supplies to the existing heating, ventilating and air conditioning (HVAC) systems of campus buildings already in place is not as complicated as might be presumed. Since the supply of energy from any centralized campus geothermal system must run through the heating and cooling exchange coils in the air handling systems, as well as the building's hydronic distribution systems, much of the system is not 'new' technology. The main requirement is to balance the face area and flow rates of the main coils or the terminal reheat coils to meet the demands built into the design of the mechanical system already in place.

Another challenge is that of time. On its face, the implication of geothermal technologies might suggest application one building at a time, but such incremental steps only diminish the chance to capture the longer-term gains of campus-scale energy management. The better strategy for implementation over time requires a whole-systems vision and scheduled integration of campus-wide geothermal technologies.

Geothermal technology can be integral to the educational. To the extent that geothermal conversion can be made at the scale of a whole campus, it eases and amplifies the teaching of whole-systems design and the understanding of the campus as a complete operational organism. This can be useful to students of all disciplines. Since much of the mechanical servicing of campuses remains above-the-ceiling, below-the-floor, or in the remotely located boiler rooms and utility closets of campus buildings, the everyday occupants are largely unaware of these technologies. The educational opportunity is to bring into public view the real-time monitoring of performance. This work was pioneered by students who wanted to monitor the performance of the Adam Joseph Lewis Center at Oberlin College and has grown now into a nationwide corporate market for installing turnkey 'dashboard' reporting; nonetheless, some universities such as Arizona State University have continued to rely on graduate students and faculty for that development.

Active learning that can be structured into day-to-day operation of such systems. Buildings by their very existence are thermally loaded by the sun, and affected by wind, temperature and humidity swings—from day to day, season to season. Buildings in and of themselves are users of energy; occupied or not. The occupants, and the associated equipment and lighting add layers of complexity to the climatically-driven heating and cooling loads. The 'dashboard' tools mentioned above are often used as the basis of occupant competitions by which to learn more fully the importance of human behavior in shaping energy demand.

FOREWORD

Campuses are uniquely suited to lead the way in geothermal technology implementation. Colleges and universities have a large number of structures and considerable acreage under single ownership/control. They have in place staff who know, in depth, the performance characteristics (and operational quirks) of those individual buildings and more generally the campus as an integrated whole. Implementing a multi-building, multi-scale geothermal energy intervention is a decision with wide ranging impact. Moreover, the more than 4,000 colleges and universities in the country which have a cumulative economic purchasing power of multi-billions of dollars can bring to life the green energy market, and spur more fully the development and application of innovative uses of the geothermal-based sourcing, sinking and management of energy.

Nonetheless, the jury is still out on several important concerns. One involves the unfortunate continuing use of 'years of payback' as a decision metric. No other purchase or investment that any of us make individually or institutionally is measured by such a criterion. Instead we look to 'returns on investment.' And that really should be the metric used for evaluating any sustainability-related technology. Remarkably with this approach, the otherwise pessimistic impression of a fourteen- or even twenty-year 'payback' is better understood as a 7% or 5% return on investment respectively. An immediate counter argument can be that this is an over-simplified economic analysis because it avoids opportunity costs, financial discount factors, inflation and increased utility expense, etc. But of course, none of those are in the 'years of payback' calculation either. 'Return on investment' really is the best metric for decision making.

Another concern is the confrontational nature of 'reactionary planning' for a new technology. If we continue to frame our concern for greenhouse gas emissions and climate warming from the point of view of problem/solution or right/wrong, we overlook the systems understanding and the profound opportunities embedded in the adoption of a whole-systems view of new technologies.

Thanks to the work of the National Wildlife Federation, however, we now have a guide that offers colleges and universities that opportunity space—a space for aspiration. If we aspire to have colleges and universities serve as exemplars of best practice, and if we aspire to using our economic buying power and scale of influence to affect positive change, and if we aspire to recognize that through our students we are stewards of the future, then we can continue to meet our fundamental mission. Bringing together faculty, students, staff and administrators within this opportunity space of geothermal technology as illustrated with this guide can, and will, be liberating.

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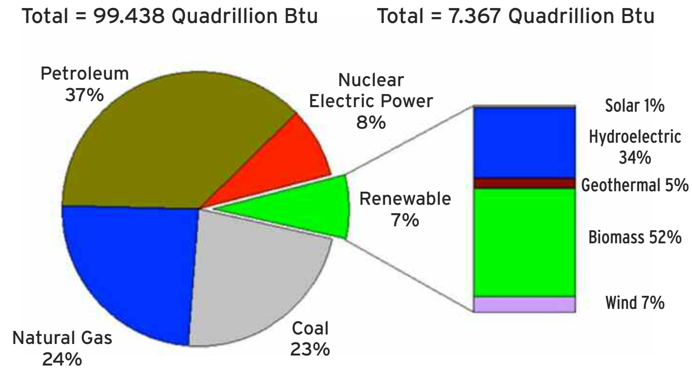
Ball State University
7 January 2011

I. INTRODUCTION

WHAT IS GEOTHERMAL ENERGY?

Renewable energy is steadily gaining ground on higher education campuses, and with good reason. The primary reason may be to reduce greenhouse gas pollution, but many schools are also finding that on-campus renewable energy initiatives create economic advantages, educational opportunities, energy security and even green jobs. Of the sources of largely carbon-neutral renewable energy available to colleges and universities—including solar, wind, biomass, micro-hydro and geothermal—it is geothermal energy that offers the most dependably-constant and low-impact supply.



The Growing Role of Renewable Energy Consumption in the Nation's Energy Supply, 2008
Energy Information Administration, Office of Coal, Nuclear, Electric and Alternate Fuels

http://www.eia.doe.gov/cneaf/solar.renewables/page/trends/rentrends.html

Geothermal energy is defined most simply as 'heat of the earth.' It is naturally abundant everywhere and is considered a renewable resource because it is generated from continually available sources—either solar radiation striking and stored in the ground or residual heat released from deep within the earth's crust. Different technologies have been developed to use the earth's heat to provide clean, renewable energy options for heating and cooling buildings, and—where conditions are right—the production of abundant electricity.

Geothermal's Potential[1]

There is a vast supply of geothermal energy stored in the earth. According to a 2006 study by the National Renewable Energy Laboratory (NREL), geothermal energy is currently being used in all 50 states. Its potential, however, is far from being realized. There are enough untapped geothermal resources in the United States alone to provide a 30,000-year energy supply at our current domestic rate of demand.

WHY GEOTHERMAL ENERGY?

There are many advantages to using geothermal energy, including rapid return on investment, relatively low cost, and longevity of duration. Compared to other renewable energy sources, geothermal applications have high returns on investment (ROI) as a result of relatively short payback periods. The costs for installing geothermal heating and cooling systems or electric power generation are quickly recouped as a result of significant energy cost savings. The long-term environmental and economic benefits combine to make geothermal energy a very attractive option, especially with the heating, cooling and powering of campus buildings which are responsible for the largest share of higher education's energy consumption and greenhouse gas emissions. This is why government agencies, the commercial renewable energy sector and renewable energy advocates are pushing for increased investment in geothermal energy technologies, which currently contribute to only around five percent of total U.S. renewable energy delivery (see chart).

ABOUT THIS GUIDE

This geothermal energy guide is for higher education administrators, staff, faculty and students who are exploring the implications of climate change and seeking cost-effective solutions. It presents information about various types of geothermal energy projects, and provides many case studies from a diverse group of campuses across the U.S. that are leading the way in the implementation of such projects. The goals of this guide are to inform institutions about geothermal energy's potential to heat, cool and power American higher education, to inspire campuses to consider using geothermal technologies to lower long-term energy costs and energy demand, and to reach greenhouse gas emissions reduction targets.

The Climate Imperative[2]

A commitment to finding solutions to global warming has been central to the mission of the National Wildlife Federation for many years. Wildlife — and all forms of life — will need a habitable planet, which requires a stable climate. How much reduction in greenhouse gas (GHG) pollution is needed? Unfortunately, the number keeps rising because global emissions have been accelerating, not slowing down as scientists have been advising for decades.

In past reports, NWF urged a reduction in the U.S. of 2% per year, including emissions from colleges and universities. But given new understanding of the lag effect of GHGs in the atmosphere, and the likelihood of a higher-than-anticipated global temperature rise that could lead to devastating consequences, NWF is turning up the heat on that timeline. Its current goals:

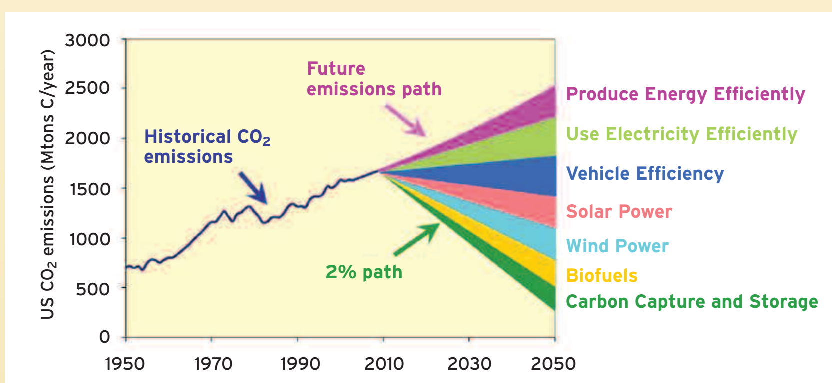
In all sectors of society

- **Emissions reductions of 4% per year over the next 10 years (higher reductions are needed at the start due to the delayed effect of GHGs on atmospheric temperatures)**

Long term emissions reductions needed

- **At least 35% by 2020**
- **At least 80% by 2050 or sooner**

NWF urges readers to keep up with the latest science on climate change through its web portal and blogs (see http://www.nwf.org/GlobalWarming), as well as through widely available information on the internet and elsewhere.



For anyone unfamiliar with the 'stabilization wedges' idea, this image shows how multiple actions will be needed to cut emissions. It will take a lot of people working on technical and behavioral solutions to reduce GHGs fast enough to mitigate the worst effects of climate change. (After Pacala and Socolow, *Science*, 2004)

II. THE OPPORTUNITIES FOR USING GEOTHERMAL TECHNOLOGIES ON CAMPUS

Over the past decade, higher education institutions across the country have invested heavily in geothermal energy. There are now around two hundred American campuses that have implemented geothermal technologies—including earth-integrated buildings—and many more are in the planning process. (See Appendices A and C for lists of schools with geothermal systems and earth-integrated buildings.)

The great majority of installations are geothermal ground-source heat pumps (GHPs) and earth-sheltered buildings, but there are a handful of other successful projects including lake-cooling, direct-use high temperature geothermal, and electricity-generating geothermal. The growth in numbers of systems is largely the result of both rising energy costs and increasing concern about climate change. Explanations and illustrations for each type of system are ahead in section III.

Geothermal resources offer an efficient, renewable alternative for the heating, ventilation and air conditioning (HVAC) systems needed for buildings. Plus, such earth-heat resources are found in virtually every geographical location in the U.S. where campuses have been built. Across the country, decision makers are coming around to the fact that geothermal energy is a smart environmental and economic investment.

A Growing Investment Nationwide[3]

Growth in the national geothermal heat pump industry is measured, by the U.S. Energy Information Administration (EIA), in terms of units shipped and heating/cooling capacity.

- **Shipments of geothermal heat pumps jumped from 35,581 units in 2000 to 115,442 units in 2009.**
- **During the same time period, shipments of geothermal heat pump heating and cooling capacity grew from 164,191 tons to 407,093 tons.**
- **In 2009, domestic shipments went to all 50 states and the District of Columbia. About 52 percent of domestic GHP shipments went to ten states: Florida, Illinois, Indiana, Michigan, Minnesota, Missouri, New York, Ohio, Pennsylvania and Texas.**

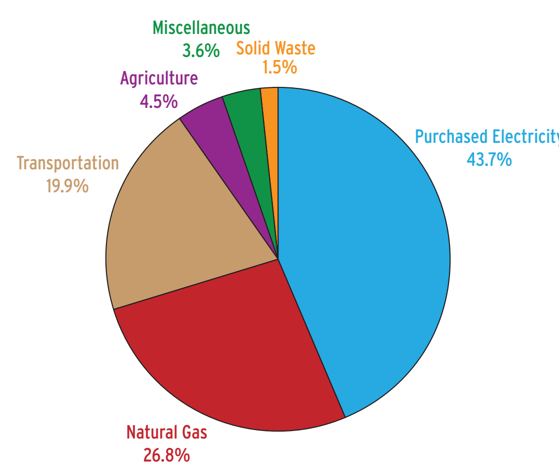
Strategic use of of geothermal energy can be a key component of a climate action plan. While improving energy efficiency and reducing demand are essential approaches to cutting a campus carbon footprint, using carbon-neutral renewables like geothermal can offer significant, long-term reductions. Realizing the savings potential, **Ball State University** (IN) has already broken ground on an ambitious campus-wide geothermal system to provide heating and cooling energy for its entire campus (see story on page 24). And the **University of Minnesota** has cut energy demand by placing major portions of several structures below ground.

There are thousands of colleges and universities in America, and a quarter million individual campus buildings (see box). Since the vast majority are still heated and cooled with fossil fuels, buildings are one of schools' primary sources of harmful emissions. In fact, the coal, oil, natural gas and electricity

Fuel to heat buildings accounts for 22% of **Warren Wilson College's** (NC) greenhouse gas emissions. When combined with electricity, buildings account for 64% of campus emissions.

Chart Credit: Amy Wagner, WWC 2008-09 GHG Inventory author, class of 2011

Warren Wilson College 2008 – 2009 Total GHG Emissions by Source



required to maintain comfortable temperatures throughout the year accounts for fifty to ninety percent of total direct emissions—primarily carbon dioxide (CO_2)—on a typical campus. In addition, fossil fuels are associated with many serious environmental and social costs due to extraction, processing and shipping. Because geothermal energy does not rely on these CO_2-intensive resources or require any offsite extraction, processing or shipping, it provides energy that has a significantly smaller carbon (and overall environmental) footprint. Renewable sources of energy, while not perfect, offer a significantly lesser overall impact and carbon footprint.

Why Higher Education Matters[4]

By the numbers in 2009 –

- **4,350 degree-granting U.S. colleges & universities**
- **19.6 million students (with close to half of undergraduates attending community colleges)**
- **240,000 buildings with 5 billion square feet of floor space**
- **$15-18 billion in new construction and renovation each year**
- **$20 billion annually—and rising—for facilities maintenance, operations and utilities**

The numbers alone are impressive, but perhaps more important is the fact that today's college and university students will become leaders in most areas of the U.S. economy in the years to come. What they see modeled and emphasized during their college years will have an impact on their understanding of sustainability and climate change, and on their future decisions about energy use.

Another advantage to geothermal energy projects is the flexibility of application. Whether constructing new buildings or renovating older structures, schools can design and install geothermal systems to meet part or all of their HVAC heating and cooling requirements. Urban campuses excluded, the majority of colleges and universities are typically situated on campuses that have abundant land where such systems can be hidden from sight. In fact, unlike highly visible installations, such as solar panels or a wind turbine, a school may need to maintain an educational effort to keep the campus—and especially new students and staff—informed about the presence and benefits of their geothermal installations.

FINANCING STRATEGIES

In addition to investing campus resources, administrators drew on one or more of at least ten different sources to finance some of the geothermal systems featured in this guide. This table shows the range of possibilities. See the individual campus stories for details.

College or university	Sources in addition to capital budgets
Ball State University (IN)	State appropriations and Federal stimulus grant
Drury University (MO)	Alumni gifts
Feather River College (CA)	Lease agreement, Private grants
Hamilton College (NY)	State grant
Lake Land College (IL)	Guaranteed energy savings contract and Federal grant
Northland College (WI)	Fundraising campaign
Richard Stockton (NJ)	Utility rebates, State grants
University of Illinois-Chicago	Independent foundation established by utility
University of Maine at Farmington	State bond issue, Alumni gifts

Are Geothermal Systems Worth the Investment?

A viewpoint by John Kelly, Chief Operating Officer of Geothermal Exchange Organization (GEO), the non-profit trade association of the geothermal heat pump industry

"Economic analysis of alternative HVAC systems is a complex area, and 'simple payback' is often a misleading metric for the benefits of ground-source heat pump systems (GHPs), as well as for other renewable energy and energy efficiency projects. GEO, recommends a more sophisticated approach to the economic analysis: for example, net present value over the estimated 50+ year projected life of the in-ground geothermal loop. Although the ground loop represents a significant portion of the initial cost of a GHP system, it lasts well beyond the projected service life of the above-ground heat pump equipment. That is, if the mechanical equipment is replaced after 25 years, it does not require the expense of replacing the ground loop. Experienced geothermal design engineers can provide these and other comparative metrics to show how alternatives to conventional HVAC systems can be a sound, long-term investment."

PUTTING THEORY INTO PRACTICE

The rest of this guide focuses on the practical applications of earth-based thermal resources, both geothermal technology and earth-integrated architecture, for colleges and universities. This vast renewable resource—possibly the best means to effectively displace fossil fuels currently used for heating and cooling buildings—holds great promise as one of the key solutions needed to put a halt to greenhouse gas pollution, not just from campuses but from the built environment nationwide.

III. REVIEW OF GEOTHERMAL TECHNOLOGIES

WHAT IS GEOTHERMAL ENERGY? A TECHNICAL EXPLANATION

Geothermal energy originates from one of two sources:

1. Solar energy stored in ground or water near the surface and
2. Heat from the earth's inner mantle that is accessible relatively near the surface (within a few miles).[5]

A thermal geyser at Yellowstone National Park.

Source: U. S. National Park Service
http://www.nps.gov/history/worldheritage/yell.htm

Five technological processes are commercially available to capture this abundance of renewable energy, and each is reviewed below:

1. Geothermal heat pumps (also called ground source heat pumps)
2. Aquifer thermal energy storage
3. Direct-use geothermal
4. Geothermal electricity
5. Earth-integrated architecture

Geothermal heat pumps and earth-sheltered buildings can be used nearly anywhere in the country. Geothermal electricity, direct-use geothermal and aquifer thermal storage have special geologic requirements and hence are more site-specific. Although each of these technologies comes with a higher upfront cost than traditional heating and cooling and electricity generation systems, payback periods can be as short as one to seven years and the long-term energy savings can be worth millions. See Section IV, Campus Case Studies, for examples of campuses across the country that are reaping the economic and environmental benefits of geothermal energy.

Drill rig at the **University of Wisconsin-Madison** drilling through 300 feet of soil and bedrock to make one of 75 boreholes for a closed loop GHP system.

Photo: David J. Eagan

Geothermal's Savings Potential[6]

According to a 2008 report by the DOE's Oak Ridge National Laboratories, if ground-source heat pumps were aggressively deployed, the accompanying reduced demand for electricity could prevent the need to build 91–105 gigawatts (GW) of electricity generating capacity. This is nearly half (42–48%) of the 218 GW of net new capacity projected to be needed nationwide by 2030. In addition, $33–38 billion annually in reduced utility costs (at 2006 rates) could be achieved.

1 Geothermal Heat Pumps – Nationwide possibilities

Geothermal Heat Pumps (GHPs) are the most accessible, cost effective, widely used and fastest growing type of geothermal energy. GHPs take advantage of the fact that the surface of the earth is a large solar collector. Stored heat from the sun maintains a relatively constant temperature below the surface (around 50º F) from just a few feet down to as deep as 1,500 feet. In a GHP system, a network of water-filled pipes brings heat up from the ground in the winter, where an electrically driven compressor and a heat exchanger concentrate the warmth. The building's HVAC then distributes the heat as needed.

Coil of 600 feet of plastic tubing needed for one 300-foot deep loop in a GHP system. Inset shows the U-shaped end that goes to bottom of the borehole.

Photos: David J. Eagan

In summer, the heat pumps reverse the process. They draw unwanted warmth from the interior—similar to the way a refrigerator works—and then use water in the underground tubing to disperse the heat into the ground. But unlike refrigerators and conventional air conditioners which use the air around them as a heat sink, a GHP system uses the relatively cool soil underground, which is much more efficient.

For closed-loop GHP systems (see types below), the boreholes or trenches contain a flexible loop, typically of 1-1/4 inch diameter plastic pipe. Soil or thermal bentonite clay is backfilled around the piping to enhance heat conductivity. The fluid in the pipes (typically water) does not ever come into contact with groundwater.

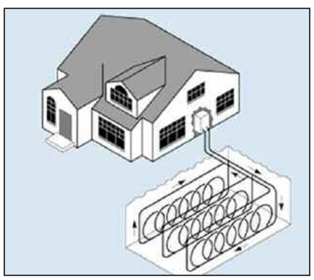
This readily available heat source and sink can be integrated into a building's HVAC system to boost heating and cooling efficiency, save energy costs and reduce greenhouse gas emissions. They function like traditional heat pumps—much like those in a home refrigerator—but instead of relying on the variability of external air temperature to provide interior heating and cooling, GHPs gain efficiency by utilizing the superior heat transfer properties of water combined with the earth's natural insulating properties.

Geothermal Heat Pump Efficiency[7]

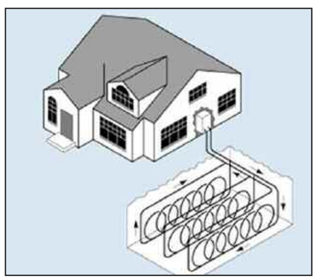
According to the Energy Efficiency and Renewable Energy (EERE) program of the DOE:

- **Heat pumps that circulate water through a geothermal system use 25%–50% less electricity than conventional heating or cooling systems.**
- **Geothermal heat pumps can reduce energy consumption and greenhouse gas emissions by as much as 44% compared to air-source heat pumps and 72% compared to electric resistance heating with standard air-conditioning equipment.**
- **A secondary benefit of geothermal heat pump systems is relative indoor humidity control, which systems maintain at about 50%.**

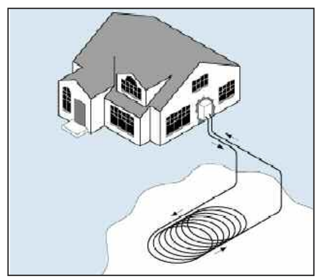
Most GHPs circulate water to and from buildings through pipes that are buried either deeply or shallowly underground. There are three types of closed loop GHP systems (horizontal, vertical and pond/lake) in which the fluid in the loops never mixes with groundwater. An open loop or well-based system, however, does take advantage of groundwater, using its naturally cold temperatures to operate the heat exchangers. (See drawings and descriptions.)[8]



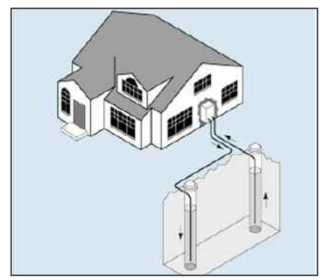
Closed Loop Systems
Horizontal



Closed Loop Systems
Vertical



Closed Loop Systems
Pond/Lake



Open Loop Systems

Horizontal closed loop systems are popular and cost effective for residential and commercial installations because no deep drilling is required. These systems, however, can require access to a greater amount of land because the system's hundreds of feet of pipes are coiled or laid horizontally in trenches dug four feet or more deep.

Vertical closed loop systems work well for residential or commercial use, especially for larger scale installations because they often require significantly less land surface than horizontal systems, and can be used where soil is not deep enough for trenching. For these systems, boreholes that are four to six inches in diameter are drilled 100–500 feet deep. The long parallel "loops" of piping from each hole are linked together and connected to the heat pump inside the building. Vertical systems can be appropriate for HVAC retrofits where available land around the building is minimal.

Geothermal Heat Pumps Keep Maintenance Costs Down

The high-density polyethylene pipe typically used in loop fields is made to flex and resist breaking. This is the same material often used in natural gas pipelines. The loop fields are estimated to last approximately 50 years. That is comparable to the life-span of any well-built heating and cooling system. The heat pumps themselves are located indoors and have similar maintenance requirements and costs as any space-heating or cooling device.

Pond or lake closed loop systems, in which the loop field is placed underwater, rely on the heat storage capacity of water. Where there is access to a body of water that meets minimum volume, depth and environmental criteria, pond/lake systems can be installed at less cost than other types of systems because no drilling or trenching is required.

Open loop systems typically use standing-column wells which pump groundwater to the surface where it is cycled through a heat exchanger and returned to the well. Open loop systems require specific hydrogeological conditions with adequate water flow. The wells are usually drilled much deeper than the boreholes of closed loop systems, ranging from 1,000 to 2,000 feet. Standing column wells are often installed in places with limited surface space, such as in cities and urban campuses. Local codes and regulations dictate whether the water must be returned to recharge the groundwater or can be discharged elsewhere. Ecosystem and aquifer impacts must be carefully assessed before implementation, and ongoing monitoring will be required because groundwater contamination is always possible. A variation on open loop geothermal is lake or ocean loop systems which pump cold water from deep underwater, extract the 'coolness' via heat exchangers, and return the warmed water to the upper layers of the water body. **Cornell University** (NY), featured in this guide, has such a system using Lake Cuyuga.

How Long Will They Last?

John Kelly,Chief Operating Officer of Geothermal Exchange Organization (GEO), the non-profit trade association of the geothermal heat pump industry, sheds some light on the often wide fluctuations in longevity estimates of ground-source heat pump (GHP) geothermal systems reported in the campus examples above.

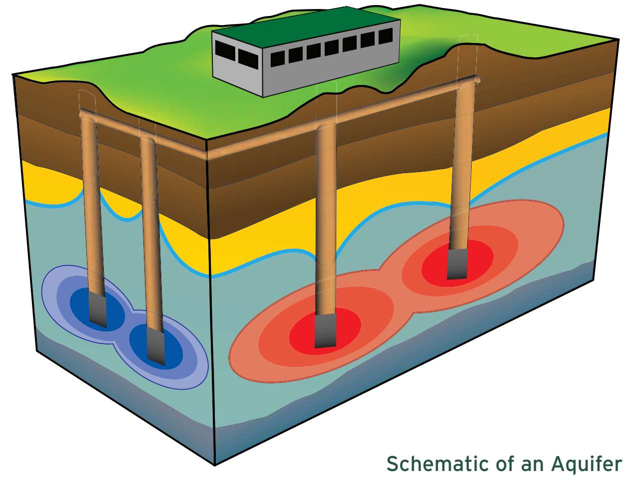
"The projected service life of geothermal heat pump systems (GHPs) is significantly longer than that of conventional heating and cooling equipment. The reason for such outstanding performance is that GHPs don't experience the same extremes of environmental operating conditions as conventional systems. Most GHPs are typically located inside the facilities they serve, rather than having components located outside with exposure to the elements. Further, GHPs don't experience the extreme temperature stress associated with fuel-burning equipment.

The U.S. Department of Energy[9] estimates GHP service life at 25 years for the inside components and 50+ years for the ground loop and this example provides insight into the 20 to 50 year range of estimates of service life seen in the campus case examples. Due to a wide variety of system configurations and maintenance practices, different campuses may experience significant differences in GHP service life. For example, some may have installed their heat pump equipment outside, and some campus practitioners may be referring to the inside GHP equipment while others may be referring to the ground loop. It is not unusual for heat pumps to perform for over 30 years, but the greatly improved performance of new machinery can justify the economic replacement of older equipment even if it is still operating within design parameters."

2 Aquifer Thermal Energy Storage – A promising geothermal frontier

Aquifer Thermal Energy Storage (ATES) is a variation on the open loop ground-source heat pump technology and is one of several methods of underground thermal energy storage. The difference from other GHP methods is that ATES systems rely on the presence of a stable, deep aquifer large enough to store both warmed and cooled groundwater.

To operate, the system has two sets of wells (see diagram). In summer, water drawn from the cool water wells (blue color) is used to cool interior spaces. The resulting warmed water is returned via injection wells to a different area in the aquifer. The summer heat stored in that area (red color) is then drawn out in winter, cooled in the process of giving up its heat, and returned to the cool part of the aquifer storage to be used again the following summer. Groundwater that is brought to the surface is returned to the aquifer, so there is minimum net loss. Aquifer temperatures near the wells are altered seasonally by the heat exchange process, so when the added heat in summer is combined with added cold in winter the thermal balance of the aquifer is maintained.[10] Mechanical components and wells must be carefully designed to prevent groundwater contamination.



Schematic of an Aquifer Thermal Energy Storage system

Image: Joel Black-Beatty

Hundreds of ATES systems are in use in Europe and Canada, but the technology has not been significantly used in the United States since research and development was halted in the early 1980s due to a shortage of funding from the Department of Energy and other public funding. **Richard Stockton College** (NJ) installed the nation's first commercial-scale ATES system in 2008 (described below in Campus Case Studies). According to Stockton physics professor Lynn Stiles[11], 'this technology has great potential in the U.S. because many of our population centers sit atop deep aquifers that are suitable for ATES.'

3 Direct-Use Geothermal – Hot groundwater at the ready

Direct-use geothermal is the most straightforward and cost-effective application of geothermal energy. Naturally-occurring reservoirs of warm to very hot groundwater (temperatures 68ºF-300ºF), primarily in the western half of the U.S., can provide heat for a variety of residential and industrial purposes. The typical use of this energy is for district and space heating in buildings, but also for such places as greenhouses, fish farms and swimming pools. Direct-use systems save thirty to eighty percent in heating costs over fossil fuels, with no greenhouse gas emissions.[12] The **Oregon Institute of Technology** in Klamath Falls currently heats its entire campus using a direct-use geothermal district heating system, with the first installation dating back to1964 (see Campus Case Studies section).

Thinking Big, Thinking Hot

The Oregon Institute of Technology sits atop a large reservoir of scalding hot water. The school is poised to become the only campus in the world to meet nearly all of its energy needs (heating, cooling and electricity) by accessing this on-site geothermal resource. To achieve this, OIT will continue to use its 45-year old direct use geothermal district heating system while completing a new power plant to tap hot water a mile below the surface to generate electricity. OIT is one of only four higher education institutions known to have direct use geothermal systems. The others are College of Southern Idaho and New Mexico Institute of Mining and Technology, with Boise State University under construction and Cornell University in the planning phase.

The technology is relatively simple. A well is drilled into the underground reservoir, tapping the supply of hot groundwater. The water is pumped through pipes into buildings where it can radiate heat into interior spaces, or be processed through a heat exchanger similar to other heat pump technologies. Once the water cools, it is either returned underground via a different well or discharged on the surface.

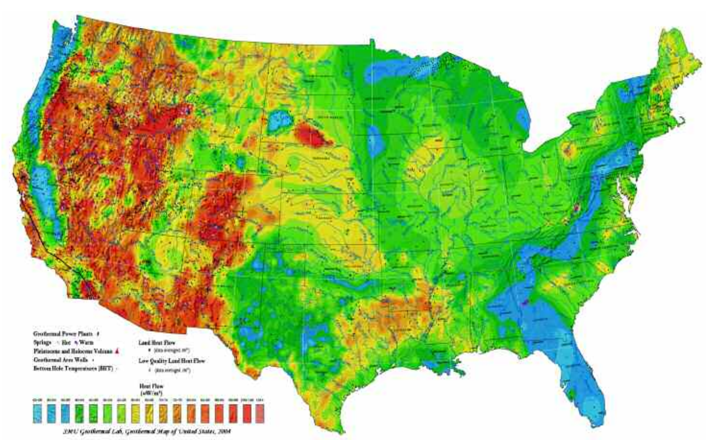
The Nation's Hotbed for Geothermal[13]

A recent survey cited by the U.S. Department of Energy identified the potential of direct-use geothermal in 10 western states:

- **The study found more than 9,000 thermal wells and springs, and over 900 low- to moderate-temperature geothermal resource areas.**
- **There are hundreds of direct-use geothermal systems already installed.**
- **270 cities within five miles of a resource hotter than 122º F have excellent potential for near-term direct use.**
- **If geothermal resources were used in those cities only to heat buildings, they could provide the energy equivalent of 18 million barrels of oil per year.**

4 Geothermal Electricity – A rising renewable energy star

Creating electricity by using underground heat resources to spin turbines can contribute to a local power grid, at least in geologically favorable areas (see map). As tallied by the U.S. Department of Energy, geothermal electricity production ranks a distant third among currently implemented renewable energy technologies — but its potential is huge.[14]



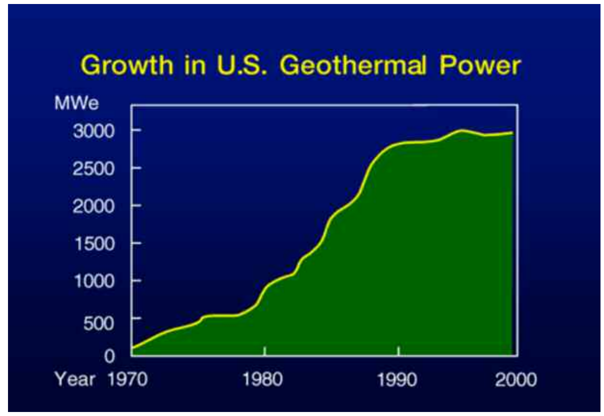
Geothermal Map of the U.S. Shades of red show where the potential for geothermal electricity is greatest.

Southern Methodist University, Geothermal Lab, 2004

Making electricity requires high temperature rock formations and water (greater than 300º F) heated by magma deep within the earth. This naturally occurring energy heats water flowing through fractures and porous rock within the crust. In some places, hot water reaches the surface creating geysers and hot springs. In most regions, the heat remains trapped deep beneath a cap rock layer. Areas of the world with good geothermal electricity production potential, such as the western United States, have abundant hot water within one to two miles of the surface.

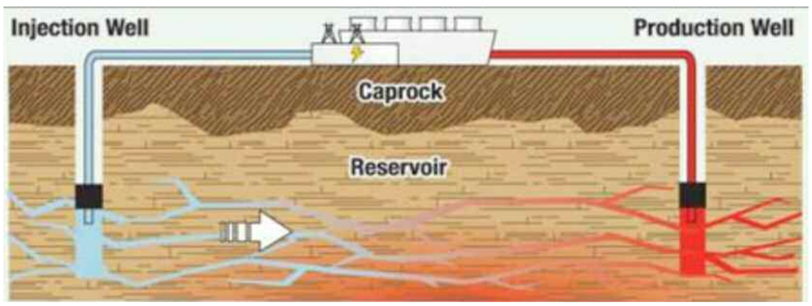
As of 2010, the International Geothermal Association[15] reports that 10,715 megawatts (MW) of installed geothermal power capacity is producing 67,000 gigawatt-hours (GWh) of renewable energy annually in 24 countries including Iceland, New Zealand, Indonesia, Japan, Mexico, Italy, the Philippines and the United States (the world's largest geothermal electricity producer). These numbers represent a twenty percent world-wide increase since 2005 in both capacity and generation. IGA reports that 70 countries currently have projects under active consideration or development. In the US, geothermal plants both large and small are operating in Hawaii, Idaho, California, Alaska, Utah and Nevada. Currently there are 188 geothermal power plants under development in 15 different states.

Geothermal electric plants have several designs. Some use steam piped from below ground to spin electric turbines. Others, such as the facility planned for the **Oregon Institute of Technology** (see Campus Case Studies section), pump hot groundwater through a heat exchanger where it vaporizes a low-boiling-point fluid, typically a hydrocarbon. This steam-like vapor creates the thrust to power a turbine. In this type of geothermal plant, two closed-loop systems keep the water and hydrocarbons separate, allowing clean groundwater to be pumped back down to replenish the reservoir. It is expensive to build a power plant and drill wells—but once in place, the energy is free, abundant, renewable and, unlike other forms of renewable energy, available around-the-clock. (See Appendix E for diagrams and explanation of different types of geothermal power plants.)



New federal laws requiring utilities to buy electricity from independent power producers led to a period of rapid growth in geothermal capacity from 1980 to 1990.

Source: http://geothermal.marin.org/geopresentation/sld066.htm



In **Enhanced Geothermal Systems**, water is injected deep into hot rock layers causing them to fracture and form a hot water reservoir. This reservoir is then tapped through a production well and its steam is used to create electricity.

Image: U.S. Dept. of Energy

A new cutting-edge technology called **Enhanced Geothermal Systems**[16] (EGS) is being developed because of its promise to produce geothermal energy in areas that have high below-ground heat, but lack naturally heated groundwater. An EGS creates geothermal reservoirs by pumping water down 5,000 to 10,000 feet or more where extremely hot, dry rock layers can heat it to temperatures exceeding 300° F. Once heated, the injected water is pumped via different wells back to the surface where it turns to steam and can be used to generate electricity. A 2006 study by the **Massachusetts Institute of Technology**[17] says EGSs could provide 100,000 megawatts of electricity by 2050, enough to satisfy ten percent of the nation's energy needs. In 2008, the U.S. Department of Energy pledged $10 million to research EGS.

The Geysers, near San Francisco, is the largest complex of geothermal power plants in the world. It produces enough electricity to power 725,000 homes. Its geothermal reservoir is partially recharged with treated wastewater pumped 7,000 to 10,000 feet below ground.

Photo: Don Follows, National Park Service

5 Earth-Integrated Buildings – Life in the underground

Greater numbers of campuses around the country are tapping into an ancient way to use the earth's below-ground temperatures for heating and cooling — by building underground. There are at least 145 such college and university buildings on 77 campuses in 32 states and the District of Columbia, many of which date back to the energy crisis of the early-1970s (see list in Appendix C).

Types of earth-integrated buildings

Sloping entry plaza leads into the Civil Engineering Building at the **University of Minnesota.** Only five percent of this five-story structure is above ground. The triangular tower directs sunlight 100 feet deep into the lowest levels.

Photo: Loretta Hall

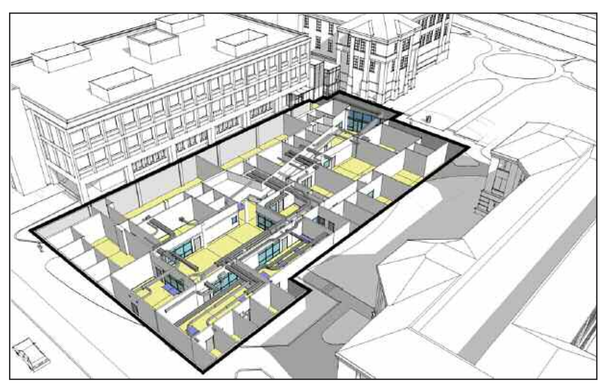
Any structure with a basement reaps some of the thermal advantages of being below grade. But true earth-integrated buildings go beyond that simple measure, maximizing ways to incorporate earth-sheltering in their design. Earth-bermed buildings, for example, use soil piled up along exterior walls and sometimes on rooftops to cut energy costs and shield the structure from wind, storms, rain and intense sunlight. But putting all or the majority of a building below grade offers the greatest benefits of going underground.

While the tops of subterranean buildings may be at ground level, they often have ingeniously designed entryways, sunken courtyards, banks of windows and skylights to let in fresh air and natural light (see photo). It takes a different sort of architectural thinking to create elegant, efficient buildings that will mostly be out of sight—but that kind of thinking readily finds a home on a college campus.

With space for new buildings at a premium on many campuses, going underground makes sense. It preserves open space and protects treasured views of historic buildings and landscape features. Using the earth's steady temperatures and insulating properties, underground buildings require approximately fifty percent as much energy for heating and cooling as conventional buildings, significantly lowering GHG emissions.[18] Due to the thermal buffering properties of the soil, they require lower capacity HVAC equipment when built. By being covered in soil, there is less need for expensive building exteriors or conventional roofing. Also, they are quieter and more vibration-free—a characteristic that was essential in the **University of Oregon's** decision to build its new Nanoscience Research center underground[19] (see images).

Bird's eye view of the Lorry I. Lokey Laboratories, under the oval-shaped courtyard at the **University of Oregon.** Opened in 2008.

Photo: (Skyshots Aerial Photography, courtesy of Lease Crutcher Lewis)



Cutaway drawing of the Lorry I. Lokey Laboratories.

Credit: (SRG Partnership, Inc.)

Earth-Sheltered Buildings Offer Many Advantages*

- **Vegetated "roofs" at ground level offer opportunities for recreation, plus wildlife habitat and seasonal migration corridors.**
- **Significant energy savings for heating and cooling, especially over the building's life cycle.**
- **Lower building shell maintenance costs.**
- **Open space preservation.**
- **Noise and vibration protection.**
- **Greater security from fire and break-ins.**
- **Protection from severe weather and earthquakes.**

* *See Appendix D"Top Ten Reasons to Bury a Building"*

What are some of the downsides? According to author Loretta Hal[20] who has done extensive research on earth-sheltered buildings, the chief problem is psychological; people tend not to like being underground. As **University of Oregon** campus planner Fred Tepfer put it, "The trick is, everyone wants daylight and views." A wide variety of solutions have been devised to brighten underground spaces, but overcoming users' potential aversion to subterranean life is essential. Another common problem is water leakage from precipitation, floods and groundwater. But with today's modern waterproofing materials and technologies, moisture and drainage problems are largely an issue of the past. Hall also reviews air quality issues in her book (see box), pointing out that earth-sheltered structures need to address the same issues—such as adequate ventilation and minimizing volatile organic compounds—as tightly sealed aboveground buildings. One exception may be radioactive radon gas found in some soils, but effective measures can be taken to minimize risk in areas with high radon levels.

Huge Energy Savings Potential

"Generally, building below the surface produces energy savings ranging from 50 – 80%. Considering that buildings consume about 1/3 of all energy used in U.S., including nearly 2/3 of the nation's electricity production, subsurface structures offer enormous potential for energy conservation."

Underground Buildings: More Than Meets the Eye, **by Loretta Hall 2004**

Fire safety is also a concern, but new detection and suppression systems minimize the risks. Plus, by being constructed mainly of concrete and steel, the frameworks of underground structures are essentially fireproof. There are a number of libraries and archives that take advantage of the steady environmental conditions of underground space, including **Harvard University's**[21] three-story underground Pusey Library whose Halon gas system for fire suppression is harmless to both books and people.

IV. CAMPUS CASE STUDIES – GEOTHERMAL TECHNOLOGIES IN PRACTICE

Despite the moderate temperatures found only a few feet below ground level, colleges and universities are finding that geothermal is hot! There are over 75 installations in place or under construction on campuses across the country, with more in the pipeline. Plus, at least 145 earth-integrated structures have been built on campuses. (See Appendices A & C)

Just as each school is unique, so too are their geothermal systems. This section features schools, large and small, with projects for both new structures and building renovations. Some projects were motivated by anticipated energy cost savings, some by student and employee demand, and others to help meet climate change commitments such as the American College and University Presidents Climate Commitment (ACUPCC). Overall, campuses report high satisfaction with the technology and a desire to increase their geothermal capacity.

Each case study summarizes key elements of a school's geothermal systems or underground buildings. These include:

- **System** – Type, size and year installed.
- **Highlights** – Costs, funding sources, savings plus noteworthy features and successes.
- **Challenges** – Concerns or problems that arose during or after installation.
- **Takeaway** – Valuable lessons and inspiring stories.

Note: For these case studies, the authors compiled information from a number of higher education institutions that have built geothermal systems and earth-integrated buildings. The aim was to capture a diversity of campus examples and show the range of possibilities. Details came from official online college or university sources, as well as from phone and email conversations with campus personnel. Financial data, especially accurate cost-savings numbers, were often hard to secure so readers are invited to explore the nitty-gritty of geo-based installations on campuses or elsewhere to learn more and glean insights for projects they may be considering.

The campus examples below are organized into five categories:

1. Geothermal Heat Pumps
    - A) Whole Campus Systems
    - B) Retrofits for Existing Buildings
    - C) Geothermal in New Buildings
2. Aquifer Thermal Energy Storage
3. Lake-Source Cooling (a variation of pond/lake geothermal)
4. Hot Spots: Direct Thermal Use and/or Electricity Generation
5. Earth-Integrated Buildings

1 Geothermal Heat Pumps

A) WHOLE CAMPUS SYSTEMS

At most schools, ground-source heat pumps handle part or all of the heating/cooling demands of just one or two buildings. Scaling a system to meet the needs of an entire campus, however, takes bold thinking and a major investment, but several schools have risen to the challenge—and its many benefits.

The three examples in this section show the adaptability of ground-source heat pumps in quite different campus settings. **Richard Stockton College** (NJ) has a sprawling main building with 14 wings plus a new arts and science building, which together serve 6,300 students. **Lake Land College** (IL), a two-year public college with 7,200 students, is a third of the way toward converting all of its 12 campus buildings to geothermal. **Ball State University** (IN), with 45 buildings and a population of 22,500 students, faculty and staff launched its project in 2009. When complete, its geothermal system will be the country's largest. A fourth whole-campus system is found at the **Oregon Institute of Technology**, which takes advantage of its location over a geologic hot spot. Its application of direct-use geothermal is covered in section 4 ahead.

Richard Stockton College led the way for major GHP installations in higher education. Its 16 year-old system continues to provide the majority of the heating needs to the campus. This utility building holds the cooling towers for the experimental ATES system, described below on page 39

Photo: Office of External Affairs, The Richard Stockton College of New Jersey

Richard Stockton College[22] (NJ)

System – Installed in 1994, this is one of the largest ground-source geothermal systems in the U.S. Its closed loop system has 400 boreholes drilled to a depth of 425 feet and linked together with 64 miles of underground pipe. Providing 1,741 tons of installed heating/cooling capacity, the system handles 480,000 square-feet of classroom, office and lab space.

Highlights – The installation cost $5.1 million, but because most of the expenditures were covered by utility rebates and state grants, the campus got a return on its investment in only about six years. The savings numbers say it all: approximately $400,000 in annual fuel and maintenance savings, twenty-five percent reduction in electricity, seventy percent reduction in natural gas, and seventeen percent reduction in campus greenhouse gas emissions. International delegations from around the world have visited to learn about the system.

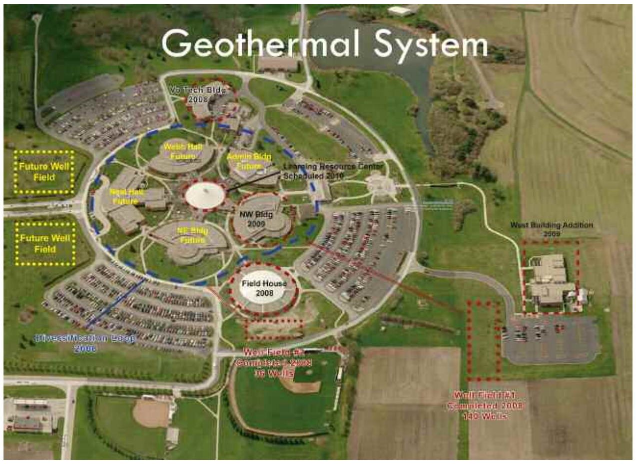
Challenges – The school monitors aquifer temperatures regularly to track 'heat creep' — the tendency of GHPs to warm the borehole region over time and diminish performance. Soil and aquifer microbes are also analyzed regularly to ensure that the extra heat from the loops does not encourage pathogen growth in surrounding groundwater. (Read more on this issue in the Benefits and Challenges, Section IV.)

Takeaway – The system remains one of the largest in the world. According to physics professor Lynn Stiles, "The Stockton project was groundbreaking due to its size and circumstances. Because of its uniqueness and use of test versions of some of the equipment, our lessons learned do not translate well to other institutions." Stiles makes this point to emphasize the fact that geothermal knowledge and technology have advanced significantly since Stockton's system was installed. He does, however, have a key piece of advice for other institutions interested in geothermal. "Payback for a properly engineered system should be 5-8 years," he notes, "the most important thing to do is to hire an engineer who has successfully designed a 5-8 year payback system."

Lake Land College[23] (IL)

System – Lake Land College (LLC) is one-third of the way toward its goal of meeting one hundred percent of its heating and cooling needs with a closed loop ground-source heat pump network. It currently has two GHP systems installed, both completed in 2008. The first, a group of 30 boreholes drilled 200 feet deep, serves the 10,000 square-foot Fitness Center. A second system with 140 boreholes 300 feet deep, provides most of the heating and cooling needs for three other buildings totaling 124,000 square-feet. Because LLC has circular layout, it will integrate its current and future geothermal installations in a 'hub and spoke' arrangement, distributing heating and cooling energy throughout the overall system as needed (see aerial photo). Eventually, the college plans to install enough borehole loops—as many as 470 in all—to provide the HVAC demands for its entire 386,000 square-feet of building space.

NOTE: Principal engineer for **Lake Land College's** project, Kirk Mescher, P.E., also participated in early discussions about **Ball State University's** geothermal system (see next campus example). When Ball State heard of Lake Land's whole-campus retrofit plans, it was inspired to look into the possibilities for replacing its own heating and cooling systems. Campus planners – along with engineering firm MEP Associates – came up with a scheme for a geothermal installation nearly ten times the size of Lake Land's. These two projects have raised the bar for schools considering geothermal heat pump technology as a way to cut their dependence on fossil fuels —and achieve significant cost savings.



Lake Land College geothermal plans. Red lines show progress to date. Yellow lines outline future installations.

Image: CTS - Control Technology and Solutions

"Savings come primarily from the incremental cost difference between replacing our HVAC systems with geothermal versus conventional. We're continuing on a holistic-approach, looking at every possible way to reduce the use of electricity. Once we get things running and people see the amount of electrical power we're saving, then we'll start looking into behavioral components—which will have even more impact on our demand. We're taking it one step at a time."

–Raymond Rieck, Vice President for Business Services, Lake Land College

Highlights – Several years ago, faced with an aging infrastructure and rapidly rising energy costs, the college studied various long term renovation solutions for its 35-40 year old classroom and office buildings. After careful analysis, it developed a comprehensive strategy in collaboration with an engineering firm, Control Technology and Solutions (CTS), to gradually replace all heating and cooling systems with geothermal. Under a 'guaranteed energy savings' contract between the college and CTS, the $16.8 million project was launched with completion targeted for around 2012. Payback is estimated at seven to eight years for the extra costs required for the higher priced geothermal systems over what it would have cost to install conventional boiler/chiller systems. If savings targets are not met, CTS will cover the difference. One of the pieces of funding came from U.S. Congressman Tim Johnson who secured a $1.3 million grant from the Department of Energy to help pay for the system.

Savings have already been significant. Buildings retrofitted with geothermal (and other efficiency measures) require only about one-third as much energy per square-foot as they did in the past. The Field House currently shows savings of $32,000 a year, and the newly renovated Northwest Classroom Building boasts savings of around $50,000 a year. So far, the campus is getting more production out of its current geothermal system than the models predicted—which may reduce the total number of boreholes eventually required. Its 170 boreholes heat and cool 140,000 square-feet, though were designed to handle around 90,000 square-feet. A newly-opened 50,000 square-foot addition to the West Building was added to the existing system, requiring an average of only three watts of electricity per square-foot.

Challenges – The new HVAC and energy efficiency upgrades all have to take place without seriously affecting the normal operation of the campus, so major projects occur during the summer. To minimize disruptions to students and staff, they are making changes one building at a time. Once the geothermal system is fully operational, Lake Land will retain enough conventional gas-fired boiler and chiller capacity to ensure that the campus can meet demand during extremes of hot and cold weather. But even this peaking capacity will be decommissioned if the geothermal system proves its ability to handle any weather situation, as it is expected to.

Takeaway – Over the next ten years, Lake Land hopes to fully implement its ambitious plan to use renewables for nearly all of its energy needs. Along with its geothermal systems, it intends to erect four wind turbines and photovoltaic panels on its 300 acre campus, cutting its use of purchased electricity and natural gas—and its carbon footprint—to a bare minimum. Their goal is eventually to be completely off the grid. According to Raymond Rieck, Vice President for Business Services, the college expects to avoid or offset over 42,000 therms of natural gas and at least 580,000 kWh of electricity per year by the project's completion. "When finished," Rieck notes, "this project will revitalize the facilities and provide quality learning and working environments for students and staff in a timely, cost effective manner."

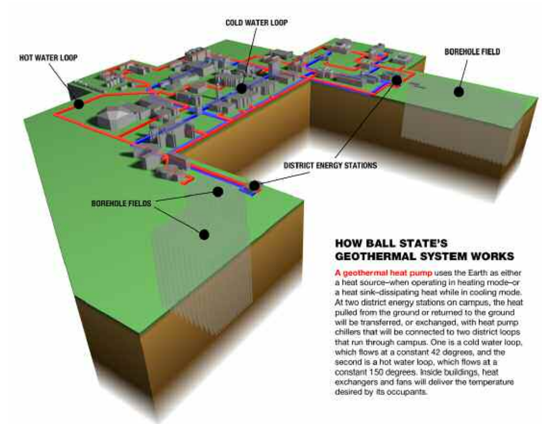
Ball State University[24] (IN)

System –When completed, this vertical closed-loop system will be the largest in the country. Its 4,100 boreholes, drilled 400 feet deep, will provide all the heating and cooling needed for Ball State's 45 buildings and 22,500 students, faculty and staff. The borehole fields will supply two energy stations that will supply an existing cold water loop and a new hot water loop running throughout campus. Using high performance heat pumps, the energy stations will 'source' or 'sink' thermal energy from—or to—the borehole fields (where underground temperatures average 55° F). The heat pumps will generate 150° F distribution water for heating or 42° F distribution water for air conditioning. During the swing seasons of the year the campus requires simultaneous heating and cooling, so based on daily temperatures and building load requirements the distribution system will be used largely as an energy management device 'swapping' heat and coolness building-to-building (without requiring a geothermal exchange). During the peak heating and cooling seasons, the geothermal borehole fields will be called upon to 'source' (deliver) or 'sink' (store) energy.

2010 Update

Launched in 2009, Ball State's geothermal project is midway through Phase 1. By April 2010, they had completed 1,300 out of the first 1,800 boreholes. By fall 2011 the first phase of the project will be complete, two York-brand heat pumps will be in place (with 2,500 tons of cooling capacity each), and about half of the campus will be hooked up to the system allowing Ball State to shut down two of its four coal-fired boilers. According to Jim Lowe, Director or Engineering, Construction and Operations, Phase 2 with its 2,300 boreholes and two additional York heat pumps, is "funding dependent." They are working hard to secure funds to complete the project and fully replace the current wasteful—and carbon-intensive—boiler/chiller system.

Highlights – This project will replace the university's worn out coal-fired heating/cooling system which was slated for a multi-million dollar upgrade. With $40 million committed from the state and another $5 million in federal stimulus money, the system will require another $20-25 million to cover its projected $65-70 million cost. By eliminating coal, it will reduce campus greenhouse gas emissions by roughly 50% or some 80,000 tons annually—an impressive accomplishment. It is planned that components of the system will be American-made and the project will add many jobs to the local economy. Estimates call for a net savings of $2 million per year with additional savings anticipated due to a reduction in operation and maintenance costs compared to the current district heating/cooling system.



Cutaway view of **Ball State University's** campuswide geothermal heat pump system.

Image: Courtesy of Ball State University

Challenges – The installation cost of the system was the primary hurdle, but the university persuaded the Indiana legislature that the $45 million dollars they had appropriated to replace the aging boilers would be better spent on a revolutionary large-scale geothermal system, whose tangible benefits include long-term energy cost savings as well as GHG emission reduction, job stimulation and technology demonstration. Another challenge was to engineer the system properly so that the two massive loop fields would not alter the local hydrogeology. According to experts, the large number of boreholes will ensure that the system will yield the energy required without altering average underground temperatures. Finally, while the borehole fields are being created on the edges of campus away from congestion, a much more visible challenge will involve disruptions to traffic and pedestrians during the 're-piping' of the campus core. This will require tearing up walkways, streets and lawns to lay the necessary piping, including installing several underground house-sized vaults for valves and other equipment.

Takeaway – The economic and energy savings are not the only significant innovations of this system. As Robert J. Koester, Professor of Architecture explains, "Because of the scale of this geothermal system and the fact that it is integrated into the entire campus building stock, we will be able to effectively trade energy from one building to another. We can pull heat out of a warmer building and deliver it to a colder one and vice versa. Hence, the geothermal network becomes an energy management system rather than just an energy sourcing system. The campus will operate as one big organism for its heating and cooling functions."

B) RETROFITS FOR EXISTING BUILDINGS

At **Drury University's** Stone Chapel, borehole drilling made a muddy mess of the grounds around the building, but only temporarily.

Photo: Drury University

Geothermal heat pump technology is replacing conventional heating and cooling systems in renovations as well as in new buildings. Both closed loop and open loop systems have proven effective on many campuses when retrofitting older buildings (see Appendix A), though each has technical and environmental considerations that must be tailored to specific installations. 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. Examples in this section are primarily single-building systems such as at **Drury University** (MO), **Hamilton College** (NY), **Harvard University** (MA), **Northland College** (WI) and **Feather River College** (CA), plus a multiple-building system at the **University of Illinois-Chicago**.

Drury University[25] (MO)

System – Installed in 2008, this closed loop vertical system with 20 boreholes drilled 250 feet deep provides heating and cooling for the renovated 600-person capacity historic Stone Chapel.

A year after completion, **Drury's** geothermal system is out of sight underground, consistent with historic preservation goals.

Photo: Drury University

Highlights – The Stone Chapel GHP project cost $295,000 which included expenses related to installing duct work in the historic building. This price tag was around $100,000 above the cost of conventional air conditioning. A $1.3 million donation from two alumni families covered the costs of this and many other building improvements. Based on a rough comparison of utility bills before and after the installation, savings in electricity and natural gas in the first year of operation were around $30,000, which translates into a 3–4 year payback for the cost difference for geothermal.

Challenges – Prior to the renovation, the chapel was heated inefficiently by old steam radiators supplied by a gas boiler that also supplied heat to three other buildings. In addition, this iconic building previously lacked an air conditioning system, which meant that in the uncomfortably hot summer months it was frequently underused. This makes it complicated to determine savings attributed to the GHP system. Although it will take several more years and careful calculations to get solid numbers, the first year's savings look promising.

Takeaway – The Stone Chapel project is one of many sustainability steps being taken at the school. As reported in a press release about the project quoting the university's president Todd Parnell, who is a signatory to the American College and University Presidents Climate Commitment, "This system shows that Drury University is serious about its commitment to sustainability and is working to reduce its production of greenhouse gases." The geothermal system also shows how this technology is compatible with preserving historic structures. Once in place, such installations are out of sight, quiet, and easily integrated with available interior spaces of a building.

"We were looking to sustain the environment as well as the building by installing a cutting edge technology into one of the most historic buildings in town."

–Wendy Anderson, Director of Campus Sustainability and Associate Professor of Biology, Drury University

Harvard University[26] (MA)

System – Geothermal heat pump projects have been installed for eight Harvard buildings (see table). Of these, Blackstone, QRAC, Radcliffe Gym, Francis Ave and Byerly Hall were retrofits. Open loop standing-column wells are used for seven buildings, requiring from two to five wells per building. The 19 wells, most drilled to a depth of 1,500 feet, provide partial heating and cooling for these structures which contain classrooms, labs, administrative offices and student residences. The university recently completed its first closed-loop system with 88 boreholes, drilled 500 feet deep, for the 27,000 square-foot Weld Hill Research and Administration Building.

Harvard Well Inventory

	Wells	Depth (feet)	Designed to Bleed	Pump Depth (feet)	Pump Capacity (GPM)	VFDs*
Blackstone	2	1500	Yes	110	180	Yes
QRAC	2	1500	Yes	100	180	Yes
90 Mount Auburn	3	450 - 650	Yes	100	270	Yes
Radcliffe Gym	2	1500	Yes	100	160	Yes
2 Arrow St (condo).	3	1500	No			Yes
1 Francis Ave.	2	750, 850	Yes	100	160	Yes
Future Projects						
Byerly Hall	5	1500	No	100	410	Yes
Weld Hill (Closed Loop)	88	500	No	N/A	680	Yes

©Harvard UOS, 2007 * Variable Frequency Drives allow a pump to run at partial capacity, reducing energy cost

All but one of **Harvard's** geothermal projects are open loop standing-column systems, drawing 52-57° F water from a deep aquifer.

Image: Harvard Office of Sustainability

Highlights – For the retrofits, the GHP systems added summertime air conditioning to buildings that previously lacked central cooling. These open-loop systems have cut an estimated 20-50% in energy costs over conventional HVAC. The system at Blackstone South—Harvard's first GHP project—helped it attain LEED, leadership in energy and environmental design, Platinum certification for existing buildings when it opened in 2003. And with ongoing adjustments to air handling, heat pump operation and other factors, the building systems are outperforming energy efficiency expectations. An added bonus: the systems are well suited to preserving the look and character of the university's historic buildings.

Challenges – Because the five existing buildings did not have central AC before the retrofits, nor was energy-use metering as comprehensive as it is now, it is not possible to calculate the actual savings due strictly to the geothermal systems. Performance of the open-loop wells has diminished somewhat over time due to the tendency of the aquifers to heat up in summer, providing less cooling capacity and reducing system efficiency. The open-loop systems are also prone to corrosion due to brackish groundwater, plus minerals in the water clog filters requiring added maintenance. The systems were also expensive to install. The Office of Sustainability's Assistant Director, Nathan Gauthier, reports that a single 1,500 foot well cost around $80,000, which is about $50 per foot. With a payback of over 40 years, they were not installed for their cost-effectiveness but for other benefits.

Takeaway – Harvard chose open-loop wells partly because of limited space. "In a city, there is little space for a large closed-loop borehole field," says Tony Ragucci, Associate Director of Facility Maintenance Operations. In addition, they are well-suited to the university's urban location, especially in summer, because the ground-source heat pumps are much quieter than conventional rooftop air conditioning equipment. On the benefits, Gauthier notes: "The systems are reliable, long-lasting and produce comfortable heat."

Lessons Learned at Harvard

Harvard has posted an informative 50-slide presentation that outlines the lessons it learned about operating open-loop systems—essential reading for anyone considering an open-loop standing column installation. See: http://www.green.harvard.edu/sites/default/files/attachments/oe/GSHPSharable3-08.pdf

Feather River College[27] (CA)

System – Currently, there are eight separate geothermal installations at this northern California campus, with a ninth under construction. In 1998, a group of four projects were completed: three horizontal closed loop systems with a total of 192 pipes laid in trenches up to 300 feet long, and one vertical loop system with 10 boreholes drilled 125 feet deep. They heat and cool 75,000 square-feet of space in four structures: the library, gymnasium and two classroom/office buildings.

More recently, four horizontal loop systems have been added. The children's daycare center uses a six-pipe system, installed in 2008, buried five feet below grade in a 500 foot trench. The maintenance building is heated and cooled with a 900 foot trench system, installed in 2008. There are another two ball-field clubhouses with similar systems coming online in 2010. See box for the ninth project—a novel idea that called for some creative engineering.

Artesian Well Prompts Innovative Geothermal Approach

Construction of the new 21,000 square-foot Learning Resource Center at Feather River College was two-thirds complete by fall 2010 and is scheduled to open in April 2011. During the drilling of a test borehole to determine heat conductivity for its planned closed loop geothermal system, an artesian well was discovered, flowing at a generous 130 gallons per minute. Rethinking its options, the college designed a one-of-a-kind scheme to tap that unexpected resource. Plans call for a 20,000 gallon storage tank to hold the clean well water which will be piped to and from the building's heat pumps. Its large size will act as a heating and cooling buffer for the water. New water from the artesian well will be added as required to keep the tank temperatures in the proper range, adjusted for each season. The spent water from the tank will be used to supply the school's fish hatchery—at the proper temperatures—and also to irrigate the fields of the equestrian studies program.

Highlights – So far, around eighty percent of campus building space has already been converted to geothermal. With the exception of just three buildings (including two temporary classrooms), Feather River soon will be close to one hundred percent geothermal for its heating and cooling. The four closed loop systems installed in 1998, which were chosen to replace the original outdated HVAC equipment, cost $512,000—which was $218,000 more than the price of installing less efficient air-source heat pumps or other conventional technology. Those geothermal systems reduced the college's electricity consumption by 421,000 kWh per year and resulted in annual energy cost savings of $50,000 and CO_2 reduction of roughly 280 tons. The newer systems contribute additional savings. The daycare center saves around 21,470 kWh and the maintenance building saves 18,890 kWh annually. And on a practical matter, Feather River also realized it could save substantial sums by using its backhoe—which it already owned—to do the digging for horizontal loop projects.

Challenges – When drilling boreholes for the vertical loop system in 1998, unexpected problems with mud, granite and other geological features meant changing plans to avoid increased drilling costs. Instead of 250 feet deep as originally planned, some loops could only extend down a little over 100 feet. Typically, deeper loop fields provide more heating and cooling.

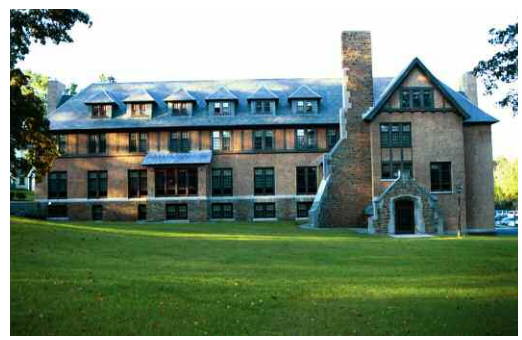
Grid Neutral by 2020 in California[28]

California's Global Warming Solutions Act of 2006 will require many public buildings—including schools and community colleges—to become grid-neutral by 2020. As explained by Bonnie Smith, Facilities Administrative Assistant at Feather River College, "The reason we've launched so many geothermal projects is to get ahead of curve on the upcoming grid neutrality date." While FRC's geothermal systems don't produce electricity and require electric pumps to power them, their net demand for electricity has been significantly lowered. Discussions are underway for a photovoltaic installation that will be another step toward grid neutrality.

Takeaway – Feather River College provides lessons in creative financing. In 1998, administrators arranged a lease agreement with Princeton Development Corporation, the system designer, to repay a $120,000 loan with proceeds from energy savings, allowing the school to put no money down. In addition, the system received $35,000 from the Geothermal Heat Pump Consortium and $300,000 from the State of California for being a clean energy demonstration project. Thanks to this suite of funding sources, the college got a five-year return on investment for its original geothermal projects. Recent systems have been funded with state Energy Efficiency Grants and through participation in the Investor Owned Utility / California Community College Chancellors Office rebate programs aimed at increasing energy efficiency on California community college campuses.

Hamilton College[29] (NY)

Systems – Three campus buildings use ground-source geothermal for heating and cooling. For the historic Skenandoa House, a closed loop system with 16 boreholes drilled to 400 feet was completed in 2004. A water-to-water radiant system warms the slab of this 21,000-squre-foot dormitory, built in the 1920s, while thermostat controlled water-to-air heat pumps in each dorm room allow occupants to adjust temperatures to their individual preference.



When the Skenandoa House at **Hamilton College** was renovated, a geothermal heat pump system contributed both to historic preservation and energy efficiency goals.

Photo: Philip Scalia

In 2005, Hamilton installed a second closed loop system, comprised of 15 vertical loops each 370 feet deep, to heat and cool only the atrium of its new Science Center. The atrium project also has an educational mission; an interactive electronic kiosk provides real-time data about energy output. Most recently, Emerson Hall was renovated into a student union with the addition of a new structure similar in size and linked to the historic original. Opening in fall 2010, the new Sadove Student Center is heated and cooled by a closed loop system with 28 boreholes drilled to 500 feet.

Highlights – The Skenandoa House system cost $90,000 more than the college would have spent on a conventional heating/cooling system retrofit, but with over half of the extra cost covered by a grant from the New York State Energy Research and Development Authority (NYSERDA), the payback was only three years. The system shows the economic potential of GHP: a sixty percent decrease in energy use, $11,000 annual energy savings and $330,000 life-cycle savings based on the system's projected 30-year lifespan. It is the school's most energy efficient building.

Emerson Hall has been another model project. Its 30,400 square-feet are entirely heated and cooled by geothermal. Although costing more than a conventional HVAC system, one-third of the outlay was covered by a NYSERDA grant. An added benefit: the mechanical system required

"At Skenandoa House, students set the temperatures in their own rooms. After years we finally realized it makes more sense to let them control it. And they're much more energy-efficient than we first figured they would be. We thought 'if we let students have their own thermostats they'll turn them up to 80!' Well, actually they don't. Some even turn their units off because the building now is well insulated and stays warm."

–William Huggins, Associate Director of Physical Plant, Construction, at Hamilton College

for geothermal requires much less space than a typical system, so the building needed 500 fewer square-feet, cutting the overall construction bill.

Challenges – Space heating in the Skenandoa House is gradual and does not provide the blast of hot air some students are accustomed to. "It's an oxymoron, but geothermal heat is cool heat. You have to get used to it," explains Steve Bellona, Associate Vice President for Facilities. Another downside is the large size of the individual heat pump units which are similar in size to temperature control units in hotel rooms. They also tend to be noisy when operating.

At the Science Center, one of the underground pipes sprung a leak in an inaccessible spot—so the college bypassed the area and connected two borehole loops into a double-length loop and avoided compromising the high efficiency of the overall system. The anti-freeze chemical in the loop field fluid is a food-grade propylene glycol, so no harm to groundwater is expected.

Takeaway – Hamilton hired the most experienced local building designer with GHP experience, a crucial step for anyone installing geothermal. The Skenandoa system passed a tough test its first winter when temperatures dipped below zero for two weeks. According to Bellona, Skenandoa House was the only building on campus that didn't have any complaints.

Northland College[30] (WI)

System – The campus has two closed loop vertical ground-source heat pump systems. The first, with 60 boreholes drilled 275 feet deep, was installed to heat and cool the 48,500 square-foot Ponzio Campus Center, built in 2002. Its geothermal system was added retroactively in 2004, but as of 2010 only the cooling capacity of the system has been used. A second GHP system, with 30 boreholes drilled 230 feet deep, was added during the 2008 renovation of the 19,000 square-foot Dexter Library.

Well drilling rig outside the Ponzio Campus Center at **Northland College** in 2004.

Photo: Tom Fitz

Highlights – The loop system at Dexter Library cost $550,000 to install. It was part of a $2.5 million renovation of the entire building, a sum raised entirely through a fundraising campaign. Geothermal provides all-season temperature control for the library. In its first two winters of operation—in far northern Wisconsin—the system worked so well that the backup boiler remained idle. Based on past utility bills, the geothermal system is saving around $12,000 in natural gas, according to Rick Waligora, Director of Facilities. Expenditures for electricity, however, have doubled due to added demands from the geothermal system, though approximately twenty percent of the electric bill is offset by a 14 kW photovoltaic (PV) array mounted on the roof. The net carbon footprint for Dexter is significantly lower than in the past because the local utility burns sixty percent wood to generate electricity—and plans to burn all wood in the future. The building is on track to earn LEED-Gold certification.

Challenges – The Ponzio Center geothermal system is taking longer than expected to become fully operational. Since it needed to be designed to work with the building's existing heating system, the project was very complex and during installation would have benefited from more solid engineering expertise and careful monitoring.

Students use the campus as a renewable energy laboratory

As explained by Clare Hintz, Northland's sustainability coordinator, the college strongly encourages students to participate in practical sustainability. "We think about our campus as a lab where students can witness the successes and failures of new technologies, asking and answering tough questions about leadership for mitigating climate change. Tackling the challenges of technological innovations, and the human systems in which they are embedded, is at the heart of the work of environmental leaders."

Takeaway – Students at Northland are actively engaged in bringing climate change solutions to campus—and use their own money to make it happen. Partial funding for the Ponzio GHP system came from the college's Renewable Energy Fund whose resources derive from a self-assessed fee that students voted to pay for. Starting in 2000 the fee was $20 per semester but it doubled to $40 a semester in fall 2008. A committee of students evaluates and decides which renewable energy projects the fund will support, working in collaboration with college staff.

University of Illinois at Chicago[31]

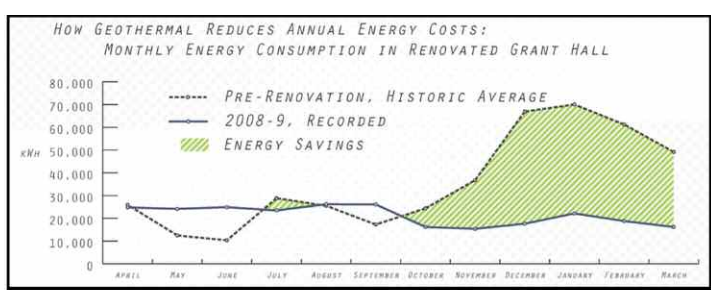
System – A large vertical closed-loop field provides heating and cooling for two renovated buildings on campus, and a third structure will soon be added to the system. In total, the system is calculated to satisfy eighty percent of the maximum load of all three buildings. It started with Grant Hall, a 15,000 square-foot office and classroom building which was renovated in 2007. Its loop field required 14 boreholes drilled 500 feet deep. Based on Grant Hall's success, a 50-borehole loop field drilled 500 feet deep was added in the same area and hooked up to the newly renovated 25,000 square-foot Lincoln Hall. This 1960s-era classroom building reopened in late 2009. The loop field also was designed to accommodate nearby Douglas Hall, the 25,000 square-foot home of the business school which is undergoing renovation in 2010.

Grant Hall at the **University of Illinois-Chicago** installed geothermal heat pumps as part of a comprehensive energy efficiency retrofit.

Photo: James Steinkamp, Steinkamp Photography

Highlights – Grant Hall's $190,000 geothermal system cost was primarily funded by the Illinois Clean Energy Community Foundation, with the remainder from UIC funds designated for renovations of classroom and laboratory space. (The subsequent 50 wells cost approximately $650,000 to install.) To date, the Grant Hall system is performing better than originally expected, achieving an estimated eighteen percent in energy savings over the former heating system and contributing to a fifty percent cut in overall energy use for the building since the renovation (see box). As reported by Cynthia Klein-Banai, Associate Chancellor for Sustainability, the geothermal HVAC equipment provides more comfortable heating and cooling than was delivered previously by the central heating plant. With geothermal, it is easy to maintain a 72° temperature year-round. In the past, complaints about inconsistent temperatures were common, especially during the transition seasons of spring and fall.

Challenges – Proving that adding the geothermal systems provided an economic benefit was a challenge with each of the three buildings. Savings were calculated based on energy models for Lincoln Hall, but the data has been inconclusive, due in part to the fact that, in the past, the buildings were not metered individually for the steam or chilled water coming from the central plant. Also, the combined square footage of the three buildings adds up to only about one percent of the total 7,000,000



"The geothermal system is a good example of how the three interlocking circles of sustainability work together; environmental—by reducing fossil fuel consumption and carbon emissions, social—by making a better learning environment, and economic—by saving money."

–Cynthia Klein-Banai, Associate Chancellor for Sustainability

square-feet on campus. While it is clear that overall energy consumption in the buildings is lower, electricity use has increased somewhat due to running the geothermal pumps and compressors.

Takeaway – Asked about the future of geothermal at UIC, Klein-Banai noted that "UIC has a mandate from campus administration and the University of Illinois Board of Trustees to reduce its energy consumption. Now that we have seen the success of geothermal, the board would like to see it used to the extent possible on all three University of Illinois campuses." The success of geothermal systems is also helping propel the university's sustainability dialog among students, faculty and staff. UIC currently is developing a formal policy on green building and energy through the Chancellor's Committee on Sustainability and Energy which will be an integral part of UIC's climate action plan.

C) GEOTHERMAL IN NEW BUILDINGS

With new construction, every aspect of a building's design and HVAC system can be integrated and right-sized for the expected heating and cooling performance required of the geothermal installation. As with retrofits, the majority of these new-building installations have been closed loop GHP systems. Examples in this section range from single building systems at **Rice University** (TX), **University of Maine at Farmington**, **Warren Wilson College** (NC), **Wilson Community College** (NC) and **Yale University** (CT), to multiple building systems at **Allegheny College** (PA) and **Lipscomb University** (TN).

Completed in August 2006, the North Village Phase I residence hall at **Allegheny College** achieved LEED certification. Its buildings were designed and constructed to optimize natural ventilation and lighting, regulate temperature with a geothermal heat pump system, reduce water and energy consumption and incorporate local, recycled and reused materials.

Photo: Bill Owen

Allegheny College[32] (PA)

System – A vertical closed-loop system installed in 2006 provides heating and cooling to the three buildings, totaling 45,000 square-feet, which comprise the LEED Certified North Village Phase I with 30 boreholes, 500 feet deep. A similar system was added to the recently completed North Village Phase II, a 75,000 square-foot residence hall. Its loop field includes 48 wells at a depth of 500 feet. A third vertical closed-loop system serves the recently renovated 14,000 square-foot 454 House, home to Admissions and Public Affairs, with 17 wells also about 500 feet deep.

Highlights – North Village Phase I's three buildings use eighty percent less fossil fuel energy during the heating season compared to the campus average—only .01 ccf/ft^2 of natural gas versus an average of .057 ccf/ft^2. When natural gas savings are added to the electricity savings from geothermal cooling—compared to conventional HVAC—the extra costs for the geothermal system will be paid back in 4–6 years, according to estimates by Ken Hanna, Director of Physical Plant.

Challenges – "During the first year of operation there were a few glitches to work out, of course, but this is often the case with a new energy system," says Brian Gillette, Assistant Director of Physical Plant. Adjustments were needed in the system controls and a couple of circulation pumps had to be replaced. Overall, the campus community has been pleased with the comfort and performance of its geothermal systems.

Takeaway – "Geothermal… is now taken as a serious option for all new construction and major renovation projects since it has been so successful," notes Kelly Boulton, Sustainability Coordinator. For several years the college had been exploring various ways to achieve greater energy efficiency and reduce its overall energy consumption. "Geothermal was initially introduced by the Physical Plant and administration as a means of achieving these goals," says Boulton. Allegheny is considering installing geothermal for the upcoming renovation of Carr Hall, an academic building. "While this project is still in the design phase," says Boulton, "geothermal will be installed if appropriate within the budget and the building's logistics. And we will explore adding more geothermal systems to buildings across campus, where feasible."

Lipscomb University[33] (TN)

System – Three vertical closed-loop systems serve eight buildings at Lipscomb. The first loop field was installed in 2006, with 144 boreholes drilled 300 feet deep. It heats and cools the 77,000 square-foot Ezell Center, a new office and classroom building. Another new construction project—the Village Apartments—consisting of four structures with a total of 48,000 square-feet was opened in summer 2008. It has 46 boreholes drilled 500 feet deep. A third geothermal installation serves an interconnected trio of buildings: the Burton Health Science Center (44,000 square-feet), Thomas James McMeen Music Center (10,000 square feet) and Willard Collins Alumni Auditorium (15,000 square-feet). For this renovation project, also completed in 2008, a 70 borehole, 500 foot deep loop field was installed.

Highlights – The cost of the Ezell Center geothermal system was $1.2 million, with $500,000 covered by a U.S. Department of Energy grant. The Burton and Village systems cost $750,000 and $430,000 respectively. At the Ezell Center energy use is around sixty-five percent less than if heated and cooled with conventional HVAC, cutting utility bills by an estimated $70,000 per year. In addition, maintenance calls are a small fraction of those for other campus buildings, saving money on labor. Back when it opened, administrators anticipated a multi-year return on investment but spiking energy prices cut the payback to 16 months.

Challenges – Although comparatively few maintenance calls have been needed for the Ezell geothermal system, its in-room heat pumps are mounted above the ceilings which are harder for maintenance staff to access.

Takeaway – The new geothermal system has proven itself to outperform Lipscomb's previous traditional HVAC systems. The Ezell Center system got a trial by fire during the scorching Tennessee summer of 2008, when temperatures topped 100 degrees for 16 days, but despite the heat, "It was the coolest building on campus," said Don Johnson, director of facilities. "The system has performed beyond our wildest expectations." When asked why Libscomb installed geothermal, Dodd Galbreath, executive director of the Institute for Sustainable Practice says, "Initially it was to reduce energy costs. Later, when our sustainability academic program began, it also became a 'walking the talk' issue." Galbreath notes that "all future new construction and major renovations on campus will incorporate geothermal systems."

Rice University[34] (TX)

System – A vertical closed loop system with 10 boreholes drilled 250 feet deep heats and cools the 1,400 square-foot control room and conference room spaces within the South Plant, Rice's new utility plant which opened in 2008.

Rice University's new South Utility Plant has a small closed loop system that serves the building's glass-enclosed high-tech control room.

Photo: Richard Johnson

Highlights – Richard Johnson, Director of Sustainability, notes that the geothermal system is a small demonstration project intended to help the campus "learn more about the potential for on-site renewable energy technologies to plan for Rice University's future energy supply." Its costs were folded into the larger construction project of South Plant's 14,400 square-foot total. According to Johnson, "after two years of operation, the system has worked quite well." So well, in fact, that the university commissioned a feasibility study for using geothermal in a proposed new building and initial feedback suggests that a building-scale system could be cost-competitive with conventional HVAC approaches.

"We like to see the buildings and HVAC systems we install last and perform at peak efficiency for as many years as possible, so naturally we looked at the idea of a geothermal system for the utility plant very critically. Thus far I'm happy to report that the geothermal-specific parts of the system have been maintenance free, and it continues to perform exactly as it was designed."

–Douglas Wells, Director of Central Plant, Rice University

Challenges – The project was designed to demonstrate the geothermal equipment, so no cost savings have been calculated. Rather, the main challenge was to successfully convince skeptical campus engineering, operations and maintenance personnel—through this pilot project—that geothermal technology could play a meaningful role in Rice's energy future.

Takeaway – Rice's story shows how geothermal heat pumps can serve as a renewable energy 'gateway' technology. As has been true of many campuses described in this guide, one geothermal project often leads to more. Johnson concludes, "We are exploring the potential for wide-scale applications of geothermal technology on campus, which is a conversation that would have been far more difficult had we not taken the initial small step of a demonstration-scale installation to prove to ourselves that it works." Educational tours of the South Plant include the geothermal system, as well as its other green features: photovoltaic panels, high-efficiency chillers and boilers, condensate recycling, fly ash concrete, native landscaping and a vegetated green roof.

University of Maine at Farmington[35]

System – A 42 borehole closed-loop system drilled 400 feet deep heats and cools the new 44,000 square-foot Education Center, which opened in 2007. The building, home to the College of Education, Health and Rehabilitation, earned LEED-Silver certification in 2008. Elsewhere on campus, a 29 borehole closed loop system was part of the 2009 renovation of 1960s-era Preble Hall, whose 42,700 square-feet houses the university's biology, chemistry and physics programs. Geothermal energy completely replaced its fossil fuel-based HVAC system.

Highlights – The Education Center system cost $280,000, with half the funding coming from a state bond issue and the remainder from gifts. According to Rob Lamppa, Director of Facilities Management, "We have followed the energy consumption for the Ed Center over the last three years, comparing it to a 1970s campus facility of similar size and use." Based on those numbers, UMF calculates that the building consumes about seventy five percent less energy, saving the campus approximately $60,000 and 325 metric tons of carbon emissions per year, with a payback of around six years. Thanks to the success of the Education Center system, plans are underway for geothermal to be used to heat and cool the new campus Emery Community Arts Center, which broke ground in spring 2010, and potentially several other buildings.

The **University of Maine** at Farmington's Education Center during construction shows the borehole drill rig and the paired ends of some geothermal loops protruding from the ground.

Photo: UMF Photo

Challenges – Evaluation of the Education Center system is difficult due to the fact that energy comparisons were made with an older, inefficient building. As with most construction projects, the geothermal drilling added to the disruption of traffic in the vicinity of the site.

Takeaway – The Education Center is a showpiece for sustainability. UMF faculty and students received a grant from the U.S. Green Building Council's Excellence in Green Building Curriculum program to develop and provide public tours of the building and its green technologies. For these tours, education students serve as spokespersons for sustainability. The goal is to increase community knowledge and awareness about the benefits of building green.

Warren Wilson College[36] (NC)

System – Installed between 2004 and 2007, three vertical closed loop systems provide heating and cooling for three campus buildings. The new Orr Cottage, a 6,800 square-foot LEED-Gold certified structure, has four boreholes drilled 300-350 feet deep. The renovated Jenson building, a 27,750 square-foot classroom building, has14 boreholes drilled 300 feet deep. And the renovated 5,155 square-foot Lauren administrative building installed four boreholes drilled 300 feet deep.

Highlights – The geothermal system at Orr Cottage, combined with a very tight building envelope and efficient lighting, results in the building using an estimated 56% less energy than the industry standard (based on ENERGY STAR *Portfolio Manager*). This translates to 1,650 tons of greenhouse gas emissions avoided over the GHP system's estimated 50 year lifespan. Based on energy savings alone, the building's total 'green' investments, costing an additional nine dollars per square foot, are expected to be paid back within 12 years by deferring roughly $5,000 annually in energy costs.

Challenges – While the Orr Cottage is performing well, the Jensen GHP system is not achieving its anticipated savings. Its geothermal system was installed to replace an antiquated electric radiant heat system. The building's electricity use, however, has actually risen slightly since the loop field was installed. Additional system commissioning is underway to determine whether or not the problem is equipment or design related.

Takeaway – Asked why he favors geothermal heat pumps, facilities director Paul Braese reports, "For the most part they are very problem free." Further, he added, "With these systems you can have a lot of heating and cooling zones. There are 10 in the newly constructed Orr Cottage, so people are more comfortable and energy is distributed more efficiently." Warren Wilson is motivated to use geothermal as one of many strategies to reach its goal of carbon neutrality—required as a signatory of the Presidents Climate Commitment—as well as to demonstrate renewable energy alternatives to its neighbors in the region. "Our commitment to renewable energy and energy conservation," Braese explained, "is increasingly expressed through our green buildings, which shows we are serious about walking our talk."

Outside Warren Wilson's Jensen building, plastic piping that interconnects the loop field is laid out in a trench and then buried below the frost line.

Photo: Stan Cross

Warren Wilson College LEED-Gold Orr Cottage is fully heated and cooled with geothermal energy.

Photo: Stan Cross

Wilson Community College[37] (NC)

System – Installed in 2008 to heat and cool the new 16,000 square-foot Student Services Building, the closed-loop ground source geothermal system uses EarthLinked© technology that circulates refrigerant through a copper pipe loop field instead of the usual plastic pipe loops. The system uses nine separate loop and heat pump units, one of which provides hot water for restrooms on an as-needed basis. Called 'direct exchange geothermal,' this approach improves efficiency by piping the loop field refrigerant directly to the heat pumps without needing to transfer heat from a separate water-based loop field. The refrigerant is a non-toxic, non-polluting, ozone-safe product that is EPA approved.

Highlights – According to college president Rusty Stephens in a 2009 press release, "The building is operating on one-third the energy used in a typical building of its size." In 2009 it was awarded LEED-Gold certification. The system's half-inch copper pipes were buried in 75-foot long boreholes at a 45-degree angle instead of vertically, which is another innovation of this technology." You get more pipe-run for a given depth of drilling," explains project engineer Chuck Ladd of Williard Ferm Architects, which designed the building.

The lawn in front of the Student Services Building at **Wilson Community College** has regrown over the land where geothermal boreholes were drilled.

Photo: Cameron C. Sargeant, Wilson Community College

Challenges – A cathode protection system was installed to prevent corrosion of the copper pipes. This was required by state law, but the due to the chemistry of soil (within the acceptable pH range of between 6 and 11) it should be little needed. The long-term performance of this system, especially with its corrosion-fighting features, should meet or exceed its 20 year warranty.

Takeaway – In a typical GHP system, water from the loop field is circulated to the heat pumps, where a refrigerant draws heat from the water and then transfers it to the building's HVAC system. In contrast, "an EarthLinked system has no middle man," explains EarthLinked

"The geothermal system is performing as designed and expected. We are seeing reduced energy consumption for the building and are very pleased with its operation."

–Rob Holsten, Dean of Continuing Education and Sustainability, Wilson Community College

technician John Webster—no intermediary transfer step which wastes 15 to 25% of the energy value. Heat (and cooling) from the ground loops is transferred via heat exchangers directly to the forced air HVAC system in the building.

Yale University[38] (CT)

System – The new award-winning Kroon Hall, which houses the Yale School of Forestry and Environmental Studies, draws heating and cooling energy from four 1,500 foot deep open-loop standing column wells. Yale chose a standing column system because of limited space on its 300-year old urban campus. The 58,000 square-foot building opened in 2009 and earned LEED Platinum certification in 2010.

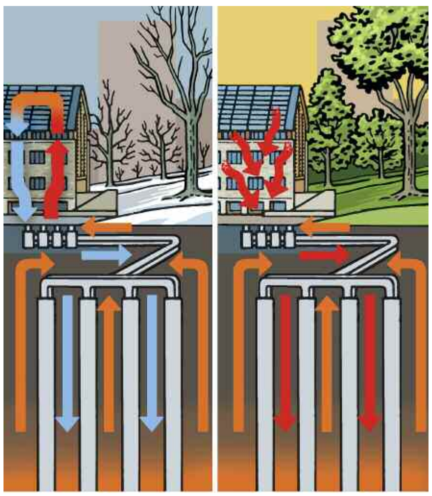


Diagram shows how **Yale University's** four open loop wells at Kroon Hall operate in both winter and summer.

Image: Illustration by Gregory Nemec

Highlights – The system provides one hundred percent of Kroon Hall's cooling and twenty-five percent of its heating. The geothermal system is one of many strategies used in the building both to cut energy demand and produce its own energy and heat. For only a two point four percent 'green premium' in overall project costs, the building uses approximately fifty percent of the energy needed by a conventional structure of similar size and function.

Challenges – Because of local ordinances on well drilling, the original plan to put the four wells next to the building had to be scrapped. With its commitment to keeping Kroon as emissions-free as possible, the university agreed to pay the extra $500,000 required to locate the wells in nearby Sachem's Wood.

Takeaway – Kroon Hall was designed to be carbon-neutral and now ranks as the flagship building in Yale's campuswide effort to cut greenhouse gas emissions forty-three percent from 2005-2020, even after accounting for campus growth. Besides the geothermal system, there is a 100 kW photovoltaic array on the roof that provides twenty-five percent of the building's electricity, a solar hot water system, abundant daylighting, an east-west orientation for maximum solar gain, and fan-free circulation of fresh air throughout the tall, barn-like structure. Fittingly, the building stands in a space formerly occupied by the fossil fuel-burning Pierson-Sage Power Plant.

Oberlin College incorporated a ground source heat pump geothermal system into the design of its 13,600 square-foot Adam Joseph Lewis Center for Environmental Studies, built in 1999. Its 24 boreholes, each costing $90,000 (for a total of $2.16 million), supply one hundred percent of the building's heating and cooling needs.

From *The Business Case for Renewable Energy: A Guide for Colleges and Universities*

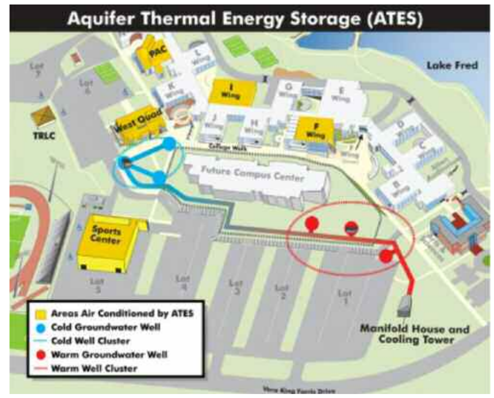
By Andrea Putman and Michael Philips, 2006, page 42

"We hired an experienced geotechnical firm to design the system and dig a test well to determine the precise geothermal conditions underground—which is essential for anyone doing a standing column system. Wells must be drilled to the proper specifications or you won't get the performance required."

–Thomas Downing, Senior Energy Manager, Yale University

2 Aquifer Thermal Energy Storage (ATES)

‘Banking’ warmth or coolness in underground aquifers and then drawing it back when needed in another season is the principle behind ATES. (Another storage technology is Borehole Thermal Energy Storage—BTES—which stores heat or coolness in borehole fields in soil or rock.) Only one such ATES project is in operation today at **Richard Stockton College**, though such technologies may be well-suited for other college and university campuses that possess the right hydrogeologic conditions underground.



Richard Stockton College's ATES system has three cold groundwater wells and three warm groundwater wells.

Richard Stockton College ATES Research Laboratory http://intraweb.stockton.edu/eyos/energy_studies/content/docs/ATES_map.pdf

Richard Stockton College[39] (NJ)

System – The college (featured above for its whole-campus closed loop geothermal system) completed the nation's first commercial-scale Aquifer Thermal Energy Storage (ATES) system in 2008. This ‘seasonal cold storage’ technology works by chilling groundwater using winter's naturally cold temperatures and then returning it to the aquifer until needed in summer. The heat exchange system protects the groundwater from contact with the air and other contaminants and is returned to the aquifer unchanged except for temperature. The system has six large wells—located in two clusters of three wells drilled 950 feet apart—along with piping, pumps and a cooling tower.

Highlights – “This is the next generation of geothermal,” explains physics professor Lynn Stiles. The system pumps 55° water up from the aquifer in winter and circulates it through a cooling tower, chilling it to 41° before returning it underground. In summer, this 41° water is pumped back up to chill buildings that are not connected to the older geothermal system. They conserve nature's winter cold by storing it until summer's heat arrives.

Challenges – ATES technology is under-explored in the United States. “There is not any funding in the U.S. Department of Energy for underground thermal storage,” notes Stiles who also works with the International Energy Agency. By comparison, Sweden currently has over 50 large scale ATES installations.

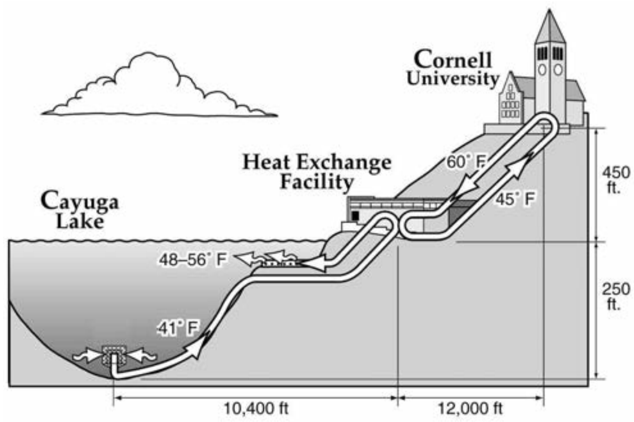
Takeaway – The ATES system is still in a trial period, but it seems to be passing the test. The cooling tower will be linked to the nearby geothermal well field that needs cooling to balance the excess heat build-up over the years. Stiles notes, “Stockton students and faculty are evaluating the ATES system in detail. Meters and other instruments were added to the project to facilitate analysis of energy savings. Our goal is to collect data so other institutions can plan similar systems with the confidence of knowing what the benefits will be.” Stiles points out that ATES is especially promising in the U.S. because a significant number of population centers are above adequately deep and abundant aquifers.

3 Lake-Source Cooling (a variation of pond/lake geothermal)

Taking advantage of a naturally-occurring thermal resource—the frigid waters of a deep northern lake—has been achieved by only one campus. Cornell University in the Finger Lakes region of upstate New York developed a one-of-a-kind system to tap into the low temperatures needed to air condition its campus in summer.

Cornell University[40] (NY)

System – Cornell's Lake Source Cooling (LSC) project, which began operating in 2000, uses an innovative open-loop-to-closed-loop system that pumps the deep 39°-41° F waters of Cayuga



Cornell University's Lake Source Cooling system provides cooling to the campus by using cold lake waters as a heat sink.

Image: Jim Houghton

Lake from 250 feet below the surface and two miles from shore to a heat exchange facility on the lake's edge. There, it transfers its cold temperatures through stainless-steel plates to water circulating to campus in a closed loop. After absorbing warmth from the campus loop, the lake water is discharged close to the surface.

Highlights – This large-scale system cost around $58 million and led to an 86% reduction in energy needed for campus cooling. This is the equivalent to the electricity required to power around 2,300 homes annually. Savings linked to the LSC system have varied with the cost of electricity, according to Bert Bland, Cornell's Energy and Sustainability Director. "In periods of high electric cost," he notes, "the project has generated significant net savings of over $1 million per year, after debt service. LSC has reduced the uncertainty in the cost of cooling by reducing our dependence on variable electric rates."

The Lake Source Cooling system also reduced Cornell's CO_2 emissions associated with purchased electricity by around 10,000 tons a year, which represents approximately five percent of the central energy plant emission footprint. As an added benefit, several buildings in the city of Ithaca tap into the system to reduce community-wide energy use, cost and emissions. The LSC system has an anticipated life span of 75–100 years versus the 30–35 years of conventional chillers.

"In 2002, the LSC received the Ecological Society of America's Award of Special Recognition and Merit. Scientific studies, based on extensive lake sampling for the ten years of operation, have shown there is no significant negative impact on the lake water quality."

–Robert R. Bland, Energy and Sustainability Director, Facilities Services, Cornell University

Challenges – Potential impacts on the lake's ecosystem were explored in an environmental impact assessment that took four years. Effects of the system on lake water temperatures and aquatic life were determined to be negligible. The extra heat added to surface waters is the equivalent of an extra five hours of sunlight falling on the lake, and all the heat is shed in winter. During installation, measures were taken to minimize sediment disturbance and near-shore ecology.

Takeaway – The benefits of the LSC have outweighed its extra initial cost. In the mid-1990s, Cornell was faced with an immediate need to replace most of its refrigerant-based chillers due to their age and new laws banning ozone-depleting chlorofluorocarbons. Not only did it cut a significant part of its annual electrical bill and CO_2 emissions, but eliminated the need for chemical refrigerants and opened the way for handling the cooling loads of an expanding campus at minimal cost.

4 Hot Spots: Direct Use Geothermal and Electricity Generation

A) DIRECT USE GEOTHERMAL

Parts of the U.S. are underlain with accessible hot groundwater resources occurring near the surface to a mile or more underground. (See the 'Geothermal Map of the U.S' on page 16.) These regions have the potential to provide campuses with heat energy in winter without the need for heat pumps to boost temperatures. The **Oregon Institute of Technology** and **College of Southern Idaho**, featured here, are two of four schools with direct-heat systems in place or under construction.

Oregon Institute of Technology[41]

System – Energy required for district space heating and domestic hot water has been abundant and cheap thanks to the Oregon Institute of Technology being situated over a geothermal hot spot, which was first tapped in 1964 when the school was built. The system for the entire campus is supplied by three wells drilled 1,300-1,800 feet deep with a combined capacity of 980 gallons per minute. This geothermal source has been used for more than 45 years with no change in temperature or flow rate. The hot groundwater—emerging at 192º F—is first pumped into a holding tank and then piped across the campus to devices that distribute the heat. Two injection wells were added around 1990 to recharge the geothermal reservoir because disposing of spent groundwater into surface waters is no longer permitted by city code.

Hot groundwater pumped from wells at the **Oregon Institute of Technology** provides heating energy for the whole campus.

Photo: Geo-Heat Center

Highlights – This system provides heat for all of OIT's buildings, roughly 828,000 square-feet, and sidewalk snow melting for approximately 40,400 square-feet. (Distribution pipes are in tunnels below the sidewalks, keeping them warm in winter.) A 1996 report on the system noted that, over its first 30 years, annual operating costs were about $35,000, or about a nickel per square-foot per year. This includes maintenance salary, equipment replacement and cost of pumping. In all, this renewable resource saves OIT an estimated $1 million dollars per year in energy costs and avoids the release of 10,000 tons of CO_2.

Challenges – As would be expected with a 45-year old system, pumps and other mechanical parts have worn out and needed replacement. The original steel distribution pipes that were buried in the ground corroded over time and were replaced by fiberglass pipes in the 1970s.

Takeaway – Direct use systems are the most efficient application of high-temperature geothermal energy—if a school is lucky enough to have the right geology underfoot. Although electric pumps are still needed to move hot groundwater through the system, they eliminate the need for heat pumps, which saves both electricity and maintenance costs. OIT has long understood the educational value of its geothermal system and established the Geo-Heat Center back in 1975 to conduct research and provide outreach on geothermal energy.

One of three wells that provides 192º F groundwater for the OIT system.

Photo: Geo-Heat Center

Hot groundwater heats the College of Southern Idaho — for more than 30 years.[42]
An article — "Hot and Steamy" — in Campus Ecology's September 2009 *ClimateEdu* newsletter tells how two 1,800 foot deep wells, drilled in 1979 at the College of Southern Idaho and drawing 100º F water, provide heating for more than 663,000 square feet in 17 buildings. The system even uses heat pumps to pull extra heat energy from the spent water before returning it to the aquifer. With this highly efficient hybrid setup, they get about $4 worth of heat from every dollar spent on electricity to run the system.

B) ELECTRICITY GENERATION

In the U.S., tapping high temperatures underground to generate electricity has been achieved only in the geothermal regions of the West. Only the Oregon Institute of Technology has had the right combination of geography and institutional commitment to develop generating capacity on its campus lands.

Steam rises from the new 280 kW geothermal power plant at the **Oregon Institute of Technology.**

Photo: John Lund

Oregon Institute of Technology[43]

System – The state of Oregon's first geothermal electric power plant began operating in April 2010 on the Klamath Falls campus of OIT. Although this one is small, only 280 kW, it leads the way for a much larger plant that is in the planning stage. The current installation is a combined

"It's expensive to drill the wells and build a power plant, but once the infrastructure is in place you've got almost free energy. It runs when the sun doesn't shine and where the wind doesn't blow."

–John Lund, Former Director, Geo-Heat Center, Oregon Institute of Technology

heat and power (CHP) binary cycle plant that uses the 192º F hot water from the three existing wells. Although below the boiling point, the water is hot enough to make a hydrocarbon refrigerant vaporize, which then spins the turbines of the generator. After giving off some of its heat to power the generator, the still-hot water is used in heating applications including greenhouse and aquaculture projects, before being injected back into the aquifer.

A new well for the larger plant was drilled in 2009 and pumping tests were completed in summer 2010. It is a mile deep (5,300 feet), has a capacity of 2,500 gallons per minute, and taps into a geothermal area where the water is around 198º F, though it was originally hoped that temperatures in the new well would approach 300°. The larger plant will also use a binary system to create electricity but because of the lower temperatures may only be able to produce around 700–800 kW of power. OIT is looking into a plant design that could create up to 1.2 MW if hotter aquifer sources are found in the future. See Appendix E for descriptions about various technologies used in geothermal power plants.

Highlights – The small plant produces 280 kW of power, or around ten percent of campus needs. Estimates made by summer 2010, after six months of operation, show that savings for electricity may run as high as $52,000 a year. The larger plant, when built and combined with the smaller plant, is expected to produce around seventy percent of campus electrical power needs.

Drilling the new well cost close to $4 million, and power plant construction is expected to cost about the same. This larger plant will produce roughly same amount of electricity that is produced by a commercial-sized wind turbine. It will supply sixty percent of OIT's electrical demand and take a big bite out of the campus carbon footprint. Funding for the project comes from a U.S. Department of Energy grant and from Oregon state bonds and grants. Additional support may come from the Energy Trust of Oregon and Oregon Business Energy Tax Credit. "This power generation system will be the first of its kind on a campus and will be able to supply more than half of the base electrical load for campus, once both plants are operating," notes John Lund, former director of OIT's Geo-Heat Center. "Savings will be around $400,000 per year in electric bills alone." In addition, OIT will be able to make use of the plant's effluent before it is recharged back underground. Notes Lund, "The spent water could be used to backup the campus heating system, or sold to adjacent land owners for additional income estimated at about $200,000 annually."

Challenges – The new well tapped into a much deeper part of the aquifer, but due to unexpected permeability of the underground fault structures, temperatures at a mile deep (198º F) were almost the same as the three existing shallower wells. Due to new campus buildings recently added to the system and lower well temperatures, the original goal of producing one hundred percent of OIT's electricity likely will not be met.

Takeaway – In addition to generating renewable energy, Lund notes that these two power plants will be monitored remotely in real time, "so students on our campus and elsewhere can observe temperatures, flow rates, 'parasitic' loads such as pumps and fans, and then calculate efficiencies and energy output." These systems will become a "classroom" for engineering and business students and for OIT's new Renewable Energy Engineering program. The plants are also expected be a hot spot for visitors who will come to see and learn from the facility. Lund explains, "We already have given many tours for people from all over the world showing them our geothermal heating system, so the electric plants will complete the picture."

5 Earth-Integrated Buildings

Earth-sheltered buildings are experiencing something of a resurgence on campus. There are many under construction right now and more in the planning phase.[44] In the past, earth-sheltered buildings enjoyed energy savings as a side benefit. Most were built as a way to keep a low profile on campuses running out of room for new structures, or as demonstration projects.

McAfee Memorial Library at **Park University (MO)** opened in 1988. Underground space for this building was mined into limestone bedrock.

Photo: Loretta Hall

The majority of earth-sheltered campus buildings or parts of buildings use a "cut and cover" method of construction, with a large excavation dug either into soil, bedrock or both. The structure is built within the excavation, covered with soil and then a plaza of vegetation or other surface material forms the top, at approximately ground level. Earth-bermed buildings use a variation of cut and cover, in which soil is sloped up against the walls and sometimes on the roof.

Other buildings create their underground space by mining into bedrock. The cavity required for the McAfee Library at **Park University**[45] in Missouri was mined from limestone, with the sale of the quarried stone used to partially offset the cost of the building. Mining left the forested hillside above the library intact, preserving its habitat value for populations of deer, turkey and other wildlife. A building at the **University of Minnesota** (see below) used both cut and cover, and mined bedrock in its construction.

"Basically, you're using the geothermal advantages of the earth without having to use all the piping because your whole building is immersed in it."

–Loretta Hall, Author, *Underground Buildings*

More than 140 campus buildings around the U.S. use some form of underground construction. For a list, see Appendix C. The following examples highlight the variety found on campuses today.

University of Arizona – Integrated Learning Center (ILC)[46]

Opened – 2002
Square-footage – 119,000
Cost – $21 million
Underground levels – 1

Highlights – Thanks to its earth-integrated design, the Manuel Pacheco Integrated Learning Center occupies a unique setting on UA's campus that both lends character to the building and makes it a great example of how the school is putting sustainability into practice. Built in the heart of campus below a palm tree-lined boulevard, it is all but invisible from even a short distance away. Two stairway plazas lead from the surface into the building and a large, open air courtyard only hints at the massive building hidden from view. The lawn that was restored over parts of the building lying beneath the campus mall has been described as "the state's first green roof" on a public structure.

Open air courtyard of **The University of Arizona's** Integrated Learning Center, located below the central campus mall.

Photo: C. Balf Walker / Chris Mooney

Challenges – Putting a major building in the middle of the busiest part of campus led to significant, though temporary, disruptions to pedestrian and car traffic flow. A huge volume of excavated material—100,000 cubic-yards equaling thousands of truckloads—had to be hauled away, but was cleared mostly at night to ease traffic congestion and neighborhood concerns. Waterproofing and designing the structure to handle 100 year flood events (of which two have happened since it was built) required double waterproofing and high-volume pumps to handle potential breaches. And two mundane, ongoing issues—due to the building's placement on the mall and under two campus roads—have been to keep festival tents from driving their stakes into the mall lawn (potentially piercing the water barrier) and to reroute heavy vehicles from certain stretches of roadway. Brian Dolan, project manager of the ILC construction, states that these concerns have required constant vigilance by facilities staff,.

Takeaway – Thanks to being underground, the building saves about forty percent of the energy that would have been lost to heat exchange through the walls of a conventional campus building. Savings are especially significant in summer months when daily temperatures exceed 100o F aboveground because energy needs are buffered by being 26 feet (on average) below ground. Lighting costs are also reduced during the day due to the windowed walls of the courtyards and four skylights that allow much natural light to brighten interior spaces.

Bowdoin College – Museum of Art[47] (ME)

Re-opened – 2007
Underground levels – 2

The new underground space outside **Bowdoin College's** Walker Art Building now houses the visitor services department.

Photo: Bowdoin College Museum of Art

Square footage – Renovation of the Walker Art Building (which contains the college Museum of Art) added 12,500 square-feet—most of which was underground—for a new total of 32,500 square-feet.

Cost – Total project cost $18 million but because the underground portion was part of a larger renovation and space enhancement, separate costs for the underground structure and geothermal cooling system are not available.

Highlights – This project was a renovation and expansion of a historic 1894 building, and came 30 years after a 1976 expansion which put a second level below the original basement. In the recent renovation, the lowest floor was dug down a bit more to improve gallery space, and a large single-level underground space was added outside the building footprint. This structure contains the main entryway, visitor services and museum gift shop and is topped by a glass-enclosed pavilion set several feet away from the original building. Geothermal wells were added as part of the project.

Challenges – Integrating the new space with the old, and keeping the original building steady while its foundation was lowered posed unique engineering challenges. According to Suzanne Bergeron, Assistant Director of Museum Operations, coming up with the right design for the renovation was a complicated process. "We spent a lot of time figuring out how to blend the historic with the new."

Bowdoin College Museum of Art with the new glass-walled visitor entry pavilion.

Photo: Bowdoin College Museum of Art

Takeaway – By going below-grade, the museum added new space while visually complementing the original landmark structure. The innovative design earned it one of the 2008 American Architecture Awards. The Walker Art Building is also Bowdoin's fourth geothermal building. Its five standing-column open loop wells provide heating and cooling using heat pumps. Prior to the renovation there was no cooling system, which was hard on both the staff and works of art.

University of Oregon – Lorry I. Lokey Laboratories[48]

(See photo and floor plan above, on page 19)

Opened – 2007
Square-footage – 26,500
Cost – $16 million
Underground levels – 1

"Being underground definitely improved Lokey Labs' energy performance compared to what would've been a typical above-ground research building of the type we needed."

–Fred Tepfer, Project Planning Manager, University of Oregon

Highlights – Lokey Laboratories is a signature research center of the Oregon Nanoscience and Microtechnologies Institute (ONAMI), a consortium of schools and high-tech companies. The floor of the building lies as much as 20 feet below the surface and is embedded seven feet into the underlying sandstone. Lawn and landscape vegetation cap the site at ground level, preserving the area's status as a dedicated open space.

Challenges – During the excavation of bedrock, the noise and vibrations negatively affected nearby research projects involving zebra fish and small mammals, but only temporarily. As the future home of $25 million worth of high-tech research equipment, extra care was given to waterproofing the building. The methods used included redundant systems with extra pumps and emergency power backup. So far, only small leaks have occurred where the new structure joins an existing building. Providing natural light in Eugene's often gray climate is important, and a skylight offers a chance for occupants to keep tabs on the weather.

A skylight brings daylight into part of the Lokey Labs building at the **University of Oregon.**

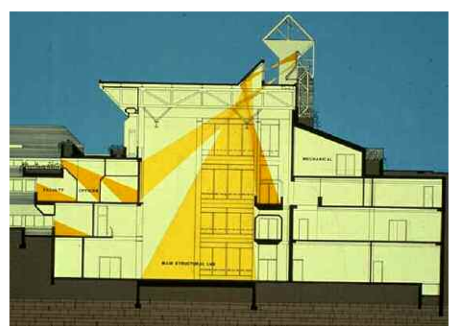
Photo: Fred Tepfer

Takeaway – By being both underground and anchored into bedrock, the building is one of the quietest, vibration-free nanoscience research centers in the world. It is also insulated from electromagnetic and radio frequency fields along with being very energy efficient. There are no external solar heat loads, and the internal loads are about the same as any building. Though it was an expensive structure to build, going underground "saved us a bunch of money," according to campus planner Fred Tepfer.

University of Minnesota-Twin Cities – Civil Engineering Building[49]

(See photo above, on page 18)

Opened – 1982
Square-footage – 150,000
Underground levels – 5

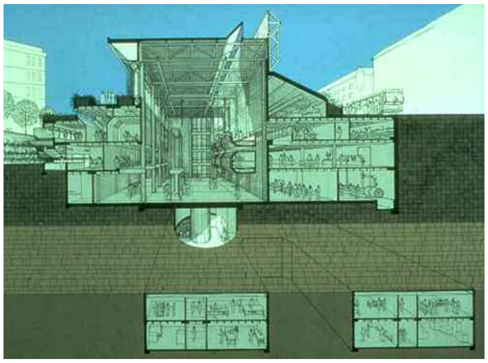


Innovative daylighting strategies channel sunlight to all levels of the **University of Minnesota's** Civil Engineering building.

Image: David J. Bennett, DJB Architects

Highlights – Originally conceived during the energy crisis of the 1970s, UM's Civil Engineering building was both a demonstration for energy conservation and a showcase of new technologies developed for underground spaces. It contains classrooms, labs, offices, commons areas and a four-story atrium for large civil engineering experiments. It was constructed using both cut-and-cover and mining techniques. The lowest two levels (of five) were mined from soft sandstone located beneath 30 feet of harder limestone. More than ninety-five percent of the building is below the surface, with the lowest level 112 feet deep.

Challenges – Sunlight-tracking mirrors in the above-ground heliostat did not function well in the beginning, but were replaced in 1987 and now channel daylight down to the lowest level. Special fire-safety features were required for the bottom levels, including two separate stairwells that automatically pressurize during a fire to keep out smoke.



All but five percent of the Civil Engineering building at the **University of Minnesota** is underground, with the lowest levels mined deep into bedrock.

Image: David J. Bennett, DJB Architects

Takeaway – This building, plus Williamson Hall (opened 1977) were demonstration projects of the now disbanded Underground Space Center. Much research was conducted and published on these innovative structures. A more recent addition underground is the Andersen Library which opened in 2000 and holds the university archives in space mined deep below the larger, above-ground part of the building.

Oklahoma City Community College – Health Professions Center[50] (OK)

Opened – 2008
Square-footage – 46,000
Cost – $5.8 million
Underground levels – 1

Highlights – The first floor of this two-story building is earth-bermed on three sides and landscaped primarily with drought-resistant Bermuda grass. According to Director of Facilities J.B Messer, it operates at a thirty percent lower energy cost than comparable campus buildings. OCCC's first building, which opened in 1972 and is still called the Underground Building, is also earth-bermed. In 2007 a second story was added.

The first floor of the Health Professions Center at the **Oklahoma City Community College** is earth-bermed.

Photo: Kim Holding, Marketing and Public Relations

Challenges – The campus area experiences high rainwater runoff during storms, so during construction the campus staff closely monitored the installation of waterproofing and drainage systems. Quality assurance is the key to preventing leaks, says Messer. "It becomes a real fiasco if you don't get the waterproofing right the first time."

Takeaway – Because of its strong walls and earth-bermed sides, this building has been designated a tornado and storm shelter—in a state prone to severe summer storms.

University of Wisconsin-Green Bay – Instructional Services & Student Services Buildings[51]

Opened – Instructional Services 1969; Student Services 1972
Square-footage – Instructional Services 66,000; Student Services 44,000
Cost – Approximately $4 million each
Underground levels – 1

Student Services building at the **University of Wisconsin-Green Bay.**

Photo: Tony Rajer

Highlights – The Instructional Services building was one of three original buildings when UW-Green Bay opened in 1969. It and the Student Services building are on opposite sides of the nine-story campus library and were designed to create an open space around the library. Each of these one-story structures is topped by a ground-level paved plaza, with planters for shrubs and other ornamentals. Banks of windows on the south and north sides let in daylight from dug-out courtyards. Retired facilities director Les Raduenz said the underground design creates a work environment that compares well with other campus buildings. "You don't get the feeling of being in a cave thanks to all the daylight coming in."

Challenges – Over the years, the roofs developed leaks which required the replacement of waterproofing membranes and drains. The main problem turned out to be a breakdown of the adhesive that joined the seams of the rubber membranes. Newer adhesives used in the retrofit are expected to last much longer.

Underground walkways link all buildings at **UW-Green Bay.**

Photo: Tony Rajer

Takeaway – To allow students and staff to move about the campus in comfort despite Green Bay's northern climate, all campus buildings are interconnected by a series of underground or below-grade concourses—'the tunnels.' Many have windows on one or two sides, excavated to access daylight. Since everyone uses them, they foster much interaction and community spirit among students, faculty and staff. And because a lot of equipment and supplies also travel between buildings through the tunnels, they result in significantly less campus vehicle use and air loss through doorways. In 2001, the three-story, 130,000 square-foot Mary Ann Cofrin (MAC) building was added to the campus. As part of the project, five classrooms were built underground (totaling 12,000 square feet), flanking the underground concourse that connects the MAC building with the library. Natural light is provided by a dugout along one side of the concourse walkway and skylights over the classrooms.

St. John's University – Seton Apartments[52] (MN)

Opened – 1982
Square-footage – 4,500 per building
Cost – $225,000 per building
Underground levels – 2

Above-ground view of the Seton Apartments at **St. John's University.**

Photo: Loretta Hall

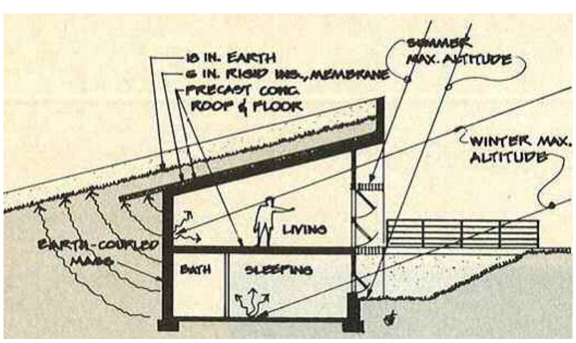
Highlights – Each of the five identical Seton Apartment buildings contains four student apartments which each follow the same efficient plan. The top floor is partially below grade, with a wall of windows facing south that floods the interior with direct and reflected sunlight. The second level is fully underground. The lawn-covered roof, which faces north and deflects cold winter winds, is covered with 16 inches of soil underlain with waterproof membranes and insulation. The turf requires no additional watering.

Challenges – In recent years, the buildings developed mold problems due to leaks. A complete renovation was required, including excavation of the walls and roofs, re-waterproofing, tuck-pointing, replacing blocks and cleaning the drain tile. The work was completed in 2008 and there were no complaints from residents in the 2008-09 school year. To keep humidity in check, bathroom exhaust fans run 24/7.

Grass-covered roof on the Seton Apartments at **St. John's.**

Photo: Loretta Hall

Takeaway – It is extremely important to ensure proper initial waterproofing and choose cleanable drain tiles, according to Buildings and Facilities Manager Gary Jorgensen. "It's expensive and laborious to do repairs on underground buildings because they have to be dug out to get at the walls and roof." Due to combined costs for ventilation, dehumidifiers and electric heating, the buildings have not been any cheaper to run than other residences on campus—though when built in 1982 they were expected to cost half as much. For two years St. John's experimented with native grasses on the roofs, but people thought they looked unkempt and the vegetation trapped wind-blown trash which was a maintenance concern. They are now planted with turf grass and mowed.



Cross section of the Seton Apartment buildings at **St. John's** from a 1984 article in *Solar Age* magazine.

Aerial view of the five Seton Apartment buildings at **St. John's University.**

Photo: St. John's College

Going Underground Can Lead to LEED[53]

Currently, the U.S. Green Building Council's LEED (Leadership in Energy and Environmental Design) rating system standards have little to say about the sustainability virtues of underground buildings. But in *Digging for the Green: Underground Architecture and Sustainable Design*, Loretta Hall lists eight ways that subsurface buildings can contribute to LEED certification and provide up to 22 of the 26 points required for green certification. These include:

- **Controlling erosion, sedimentation, and stormwater runoff by covering much of the site with vegetation.**
- **Reducing the environmental impact from the building location by having a minimal footprint.**
- **Conserving existing natural areas or restoring damaged areas, improving habitat and biodiversity.**
- **Reducing heat islands (temperature increases due to development) that can alter the microclimate and affect human and wildlife habitat.**
- **Cutting energy use. Underground structures typically save fifty to eighty percent.**

V. GEOTHERMAL TECHNOLOGIES ON CAMPUS: PRESENT AND FUTURE

The future of geothermal energy and earth-integrated architecture on college and university campuses looks promising indeed. The snapshots above of 35 campuses with either geothermal installations or underground buildings are just a modest percentage of the total of 77 schools and 230 buildings across the country (see Appendices A and C) that are teaching—by example—the art of the possible. But these are just a hint of what's to come.

In this final section we explore several important themes that bear further emphasis. First, renewable energy technologies on campus not only have financial, environmental and societal benefits, they also can yield significant educational value. Most schools, it seems to us, appear to have under-utilized those potential learning opportunities and so we encourage all schools to do more.

Next, we look briefly at the potential for careers in geothermal technologies. There is, of course, massive job growth anticipated in all renewable energy fields—and community colleges in particular have heeded that call. Finally, we raise the question that must always be asked by a wildlife protection organization: can we move forward with minimal impact on the environment and on the animal and plant life which depend on it for their long term survival? The National Wildlife Federation's mission is to protect wildlife and natural systems for our children's future. College and university campuses offer a shining hope to instill that value in the next generation of national leaders.

1 An Extraordinary Educational Opportunity

Geothermal systems and earth-sheltered architecture, regardless of their respective scales of installation or technology type, may be mostly hidden from view underground—but lessons about them can be lifted up and brought into educational programming within and beyond the classroom. As Professor Koester mentions in his foreword, students who study engineering, energy technologies, green buildings and other disciplines have much to learn about systems-based energy design especially on campuses that use district (multiple buildings) or whole-campus heating/cooling systems.

As part of their educational experience, students on campuses with geothermal, solar or other types of clean energy systems can be asked to track system performance over time, evaluate returns on investment and educate the wider campus and public communities. At places such as the Oregon Institute of Technology and Richard Stockton College, students sometimes give tours to show their geothermal installation to peers and visitors. When geothermal systems are metered and incorporated into real-time energy monitoring, students and building occupants can begin to visualize energy and resource use, compare operational performance and follow trends across monthly climate variation and/or building types.

And educational options aren't only for an individual college or university. Thanks to the internet, schools can educate not only their campus community but also the world beyond by showcasing their campus geothermal systems and other sustainability initiatives with descriptive narratives and real-time performance 'dashboards' posted to campus websites. Creating and updating such information sources is a perfect opportunity for students to make a far-reaching and lasting contribution. In short, as with any project on campus that conserves resources, the benefits beyond the purely environmental or financial aspects can be substantially educational—for students, faculty, staff and the wider community.

2 Expanding Career Pathways in Renewable Energy

The geothermal industry—in the electricity-generating sector alone—saw an estimated twenty-six percent surge in domestic geothermal projects since 2009, according to a recent U.S. Department of Energy report.[54] This is good news for colleges and universities, as the report notes: "This substantial growth will require an educated and trained workforce to locate new geothermal resources, develop new reservoirs, and build and administer the power plants." The Geothermal Energy Association (GEA) estimates that geothermal energy employed 18,000 people in 2008—5,000 direct and 13,000 supporting positions, not including those employed in the manufacture or installation of geothermal heat-pumps.[55] Employment in geothermal energy is expected to continue to increase in coming years.

Energy analysts hold that geothermal technologies offer more and better jobs than conventional fossil fuel technologies. For example, total employment for a 500 MW natural gas plant is around 2,500 workers versus around 27,000 for a geothermal energy plant.[56] In its 2010 study, "Green Jobs through Geothermal Energy," the GEA notes that geothermal industries offer relatively higher-paying and longer-term jobs than local averages and that one plant can involve as many as 860 different people with a broad range of skills.[57]

Career pathways in the geothermal power industry will be open to skilled workers in a wide variety of fields. The GEA green jobs study offers detailed charts on types of jobs involved and education levels required at each phase of project implementation from start-up to exploration, to feasibility (test) drilling, installation drilling and site construction, to operations and maintenance. Roles include degreed professionals such as engineers, geologists and geophysicists as well as 'green collar' laborers who work as drill rig operators, welders, mechanics and safety managers. In support positions, geothermal development will also require greater numbers of lawyers, project managers, archeologists, sales people, assembly workers and administrative staff.

Job opportunities and career paths in the ground-source geothermal heat pump (GHP) industry, similarly, are expected to increase. The use of GHP technologies represented four percent of new single-family home HVAC heating/cooling tonnage[58] in 2008 rising to six percent in 2009, according to GEO. It cites the U.S. Department of Energy's goal for industry growth of one million GHP installations annually by 2017—a cumulative total of 3.3 million GHP installations—creating an estimated 100,000 new jobs and reducing U.S. annual CO_2 emissions by approximately 26 million metric tons.[59]

Among the professions and trades benefiting from the GHP industry are water well drilling companies that have entered the market for drilling boreholes to install loop fields and wells. HVAC companies have expanded their business to include installation and maintenance of geothermal heat pumps and related equipment. Architects and design firms have embraced geothermal alternatives, working with clients on GHP and direct-heat projects at all levels.

To meet the increasing demand for education and training, programs in renewable energy technologies, including geothermal, at community colleges and other postsecondary institutions across the U.S. have been going strong.[60] An internet search quickly brings up geothermal courses and programs at dozens of schools. And places like the Energy Center of Wisconsin[61] are meeting the needs of working building industry technicians and professionals with courses on commercial and residential geothermal systems.

Occupational Information Network (O*NET)

The Occupational Information Network (O*NET) is a national database of information about the evolving world of occupations, created with sponsorship from the U.S. Department of Labor. It provides resources for job searchers and employers through interactive applications for exploring and searching occupations.

Among its features, O*NET highlights 'Green' occupations as well as those having a 'Bright Outlook.' Green economy activities and technologies have increased the demand for green workers, including geothermal technicians, geothermal production managers and other occupations involved in renewable energy fields. The O*NET database provides current information about both geothermal electrical generation and heat pump occupations. Bright Outlook occupations (including emerging occupations) are jobs expected to grow rapidly in this decade. Geothermal jobs are among those predicted to multiply faster than most occupations over the period 2008-2018, with a significant increase in numbers of openings.

3 Protecting Wildlife and the Environment

No energy source is free of environmental impacts. Although geothermal systems can dramatically reduce energy use and greenhouse gas emissions associated with heating and cooling buildings, they are not a panacea and must be carefully designed and monitored to safeguard environmental values such as biological diversity and water quality. As documented in many of the case studies within this guide, campus leaders are evaluating these impacts and devising best practices to avoid or reduce them. Schools employing open loop and aquifer-based systems, in particular, are evaluating the impact of underground water temperature changes on microbes and other life forms, aiming to maintain normal seasonal water temperatures, protect freshwater resources and prevent any harm to wildlife.

The use of antifreeze or refrigerants in some geothermal systems that may mix with groundwater or release ozone-depleting chemicals and greenhouse gases (CFCs and HCFCs) is another issue of concern, yet little is known about these impacts. By optimizing building efficiency, campus designers can reduce the required quantity of bore-holes (and resulting closed loop system field size) or minimize open loop well-withdrawal requirements, further reducing environmental changes. In the final analysis, however, any geothermal technology impacts must be evaluated and balanced against the alternative environmental harm that would be caused by other sources of heating and cooling , primarily those that require the extraction, transport and burning of fossil fuels. It always should be the case that conservation and efficiency measures are the first priority before a campus chooses to employ geothermal technologies or any type of clean energy system for buildings.

VI. APPENDICES

This table names colleges and universities using geothermal energy*—either through ground-source heat pumps (open or closed loops), direct heating, aquifer thermal storage systems (ATES) or to generate electricity.

As of February 2011, the list contains **86 schools** from **38 states.**

**Our apologies to any schools using geothermal technologies missing in this list. NWF will periodically post an updated list on the Campus Ecology website, so if your school belongs here please let us know its name and type of system. Send an email to campus@nwf.org.*

APPENDIX A

College and University Geothermal Systems – Completed or Under Construction

SCHOOL	STATE	SYSTEM
Yavapai College	AZ	Closed Loop Vertical
Feather River College	CA	Closed Loop Vertical and Horizontal, and Artesian Well Cooling
Ohlone College	CA	Closed Loop Horizontal
Colorado Northwestern Community College, Craig campus	CO	Closed Loop Vertical
Eastern Connecticut State University	CT	Open Loop - Standing Column
Fairfield University	CT	Closed Loop Vertical
Yale University	CT	Open Loop - Standing Column
University of Central Florida	FL	Open Loop
Georgia Institute of Technology	GA	Closed Loop Vertical
University of Hawaii at Manoa	HI	Open Loop - Injection well return
Luther College	IA	Closed Loop Vertical
Maharishi University of Management	IA	Closed Loop Horizontal
University of Northern Iowa	IA	Closed Loop Vertical
Boise State University	ID	Direct Heat - under construction
College of Southern Idaho	ID	Direct Heat Open Loop
Columbia College	IL	Closed Loop Vertical
Heartland Community College	IL	Closed Loop Vertical
John Wood Community College	IL	Closed Loop Vertical
Lake Land College	IL	Closed Loop Vertical-Hybrid
University of Illinois, Chicago	IL	Closed Loop Vertical
University of Illinois, Rockford	IL	Closed Loop Vertical
Western Illinois University	IL	Closed Loop Vertical
Ball State University	IN	Closed Loop Vertical
Goshen College	IN	Closed Loop Vertical
University of Kansas	KS	Closed Loop Vertical
Berea College	KY	Closed Loop Vertical
Harvard University	MA	Open Loop - Standing Column and Closed Loop Vertical
Harford Community College	MD	Closed Loop Vertical
McDaniel College	MD	Closed Loop Vertical
Bowdoin University	ME	Open Loop - Standing Column
Colby College	ME	Closed Loop Vertical
University of Maine Farmington	ME	Closed Loop Vertical
University of Southern Maine	ME	Open Loop - Standing Column
Davenport University	MI	Closed Loop Vertical
Grand Valley State University - Allendale	MI	Closed Loop Vertical
Lansing Community College	MI	Closed Loop Vertical
Lawrence Technological University	MI	Closed Loop Vertical
University of Minnesota Arboretum	MN	Closed Loop Vertical
Drury University	MO	Closed Loop
University of Montana	MT	Open Loop - Injection well return
University of North Carolina Chapel Hill	NC	Closed Loop Vertical

SCHOOL	STATE	SYSTEM
Warren Wilson College	NC	Closed Loop Vertical
Wilson Community College	NC	Closed Loop Vertical
Turtle Mountain Community College	ND	Closed Loop Vertical
Plymouth State University	NH	Closed Loop Vertical
Drew University	NJ	Closed Loop Vertical
Richard Stockton College	NJ	Closed Loop Vertical and Aquifer Thermal Storage System (ATES)
New Mexico Institute of Mining and Technology	NM	Direct Heat
Adelphi University	NY	Closed Loop Vertical
Bard College	NY	Closed Loop Vertical
Columbia University	NY	Open Loop - Standing Column
Cornell University	NY	Open Loop - Lake source
Hamilton College	NY	Closed Loop Vertical
Ithaca College	NY	Closed Loop Vertical
Paul Smith's College	NY	Closed Loop Vertical
Skidmore College	NY	Closed Loop Vertical
SUNY Sullivan County Community College	NY	Closed Loop Vertical
SUNY Brockport	NY	Closed Loop Vertical
SUNY Dutchess Community College	NY	Closed Loop Vertical
The General Theological Seminary	NY	Open Loop Standing Column
Vassar College	NY	Closed Loop Vertical
Oberlin College	OH	Closed Loop Vertical
Rogers State University	OK	Closed Loop Vertical
Oklahoma State University	OK	Closed Loop Vertical
Oklahoma State University Institute of Technology at Okmulgee	OK	Closed Loop Vertical
Lane Community College	OR	Closed Loop Horizontal and Open Loop
Oregon Institute of Technology	OR	Direct Heat (since 1964) and Electric Generation (since 2010)
Portland State University	OR	Closed Loop Vertical
University of Oregon	OR	Closed Loop Vertical
Allegheny College	PA	Closed Loop Vertical
California University of Pennsylvania	PA	Closed Loop Vertical
University of Pennsylvania Morris Arboretum	PA	Closed Loop Vertical
Mercyhurst College	PA	Closed Loop Vertical
Mercyhurst College - North East	PA	Closed Loop Vertical
West Chester University	PA	Closed Loop Vertical
Furman University	SC	Closed Loop Vertical
Medical University of South Carolina	SC	Closed Loop Vertical
Lipscomb University	TN	Closed Loop Vertical
Rice University	TX	Closed Loop Vertical
University of Utah	UT	Underground thermal storage system
Champlain College	VT	Open Loop - Injection well return
Pacific Lutheran University	WA	Closed Loop Vertical
College of Menominee Nation	WI	Closed Loop Vertical
Northland College	WI	Closed Loop Vertical
University of Wisconsin-Madison	WI	Closed Loop Vertical
Laramie County Community College	WY	Closed Loop Vertical

APPENDIX B

Additional Resources on Geothermal Systems

Government Sites

U.S. Department of Energy (DOE) – Geothermal
The Department of Energy offers a gateway to resources on geothermal energy and encourages diversification in domestic energy supply options.
http://www.energy.gov/energysources/geothermal.htm

U.S. Department of Energy – Energy Efficiency and Renewable Energy program
The DOE provides general information about all types of geothermal energy and links to additional sources.
http://www1.eere.energy.gov/geothermal

Federal Geothermal Research Program Update, Fiscal Year 1999
This 500-page collection of research papers by the nation's leading geothermal energy experts includes topics on all types and aspects of geothermal energy.
http://geothermal.inel.gov/publications/doeid-10743-fy99.pdf

Trade Organizations

Geothermal Energy Association
GEA provides information on current and potential applications of U.S. geothermal power plants and cost/benefit analyses of geothermal energy production.
http://geo-energy.org

Geothermal Exchange Organization (GEO), the non-profit trade association of the geothermal heat pump industry – Geothermal +Heat Pump Consortium
GEO, the non-profit trade association of the geothermal heat pump industry has extensive links to geothermal heat pump professionals across the country and up-to-date information about current technology.
http://www.geoexchange.org

Geothermal Resources Council
The GRC is a professional educational association for the international geothermal community. It works with national and international academic institutions, industry and government agencies to encourage economically and environmentally sound development of geothermal resources.
http://www.geothermal.org

Research and Education Centers

Geo-Heat Center
The Geo-Heat Center at the Oregon Institute of Technology is a research facility and information source for consultants, developers, potential users and the general public on the development of direct heat utilization of geothermal energy.
http://geoheat.oit.edu

Great Basin Center for Geothermal Energy
The Great Basin Center at the University of Nevada, Reno, conducts research towards the establishment of geothermal energy as an economically viable energy source within the Great Basin.
http://www.unr.edu/geothermal

Geothermal Education Office
This nonprofit organization based in California produces and distributes educational materials about geothermal energy to schools, energy/environmental educators, libraries, industry and the public.
http://geothermal.marin.org

Articles

Universities Lead the Charge to Mine the Heat Beneath Our Feet
by Paul Tolmé, *ClimateEdu*, September 30, 2008
http://www.nwf.org/campusEcology/climateedu/geothermal.cfm

The Heat Movers
by Paul Tolmé, *ClimateEdu*, November 13, 2008
http://www.nwf.org/campusEcology/climateedu/articleView.cfm?iArticleID=29

Ground-Source Heat, from Lipscomb to Yale
by Paul Tolmé, *ClimateEdu*, December 9, 2008
http://www.nwf.org/campusEcology/climateedu/articleView.cfm?iArticleID=37

Hot and Steamy: Ground-Source on Campus
by Maryruth Belsey Priebe, *ClimateEdu*, September 15, 2009
http://www.nwf.org/campusecology/climateedu/articleView.cfm?iArticleID=102

Geothermal Energy: Tapping the Potential
by Bill Johnson, APPA Facilities Manager, November/December 2008
http://www.appa.org/files/FMArticles/FM111208featureJohnson.pdf

This table, which lists earth-integrated campus buildings, is drawn from a compilation of over 675 earth-integrated public and commercial buildings in the U.S.[63] These buildings represent the range of underground campus structures.* Some are completely subsurface, while others have a significant portion underground or are built with earth-bermed sides and roofs.

As of February 2011, the list contained 145 structures on 77 campuses in 32 states and the District of Columbia. Where known, construction dates are given.

**Our apologies to any schools using earth-integrated technologies missed from this list.*

APPENDIX C

Earth-Integrated Campus Buildings – Completed or Under Construction

AZ

Hayden Library (1989), Arizona State University, Tempe
Nelson Fine Arts Center (1990), Arizona State University, Tempe
Manuel Pacheco Integrated Learning Center (2002), University of Arizona, Tucson
Bear Down Gym shooting range, University of Arizona, Tucson

CA

Bechtel Engineering Center (1980), University of California, Berkeley
Law School library and academic building (under construction; 2011), University of California, Berkeley
Northwest Animal Facility (1991), University of California, Berkeley
Student Athlete High Performance Center (under construction; 2011), University of California, Berkeley
University Art Museum (1970), University of California, Berkeley
Main Library addition (1994), University of California, Berkeley
Geisel Building addition (1993), University of California, San Diego
Love Library (1971, addition in 1996), San Diego State University, San Diego
Beckman Hall (1993), Harvey Mudd College, Claremont
Student Health Services building, San Francisco State University, San Francisco
Music Center (1996), University of California, Santa Cruz
Cancer Treatment Center (2004), Stanford University, Stanford
James H. Clark Center auditorium (2003), Stanford University, Stanford
Lucas Center expansion (2000), Stanford University, Stanford

CT

Cross Campus Library (1971), Yale University, New Haven
Beinecke Library (1963), Yale University, New Haven
Child Study Center's Child Development Unit (1976), Yale University, New Haven
Ingalls Hockey Rink (1958, addition in 2009), Yale University, New Haven

DC

Yates Field House (1979), Georgetown University, Washington, D.C.

DE

Rodney Fitness Center (1997), University of Delaware, Newark

FL

Auditorium (1980), University of Florida, Gainesville
J.C. Dickinson Jr. Hall (1970), University of Florida, Gainesville
Science building (1958), Florida Southern College, Lakeland

IA

University Union (1960), University of Northern Iowa, Cedar Falls
Carver-Hawkeye Sports Arena (1980), University of Iowa, Iowa City
School of Art and Art History Building, University of Iowa, Iowa City
Ballou Library addition (1996), Buena Vista University, Storm Lake
Siebens Forum (1985), Buena Vista University, Storm Lake

IL

Assembly Hall addition (1999), University of Illinois, Urbana-Champaign
Undergraduate Library (1969), University of Illinois, Urbana-Champaign
Interdivision Research building (2004), University of Chicago, Chicago
Mansueto Library (under construction; 2010), University of Chicago, Chicago

IN

Library expansion (1989), Anderson University, Anderson
Simon Hall (2007), Indiana University, Bloomington
Fitzpatrick Hall of Engineering (1979), University of Notre Dame, South Bend
John Hicks Undergraduate Library (1982), Purdue University, West Lafayette
PRIME Lab (1969), Purdue University, West Lafayette

KS

Anderson Family Football Complex (2008), University of Kansas, Lawrence

LA

Museum of Natural History Research facility (1968), Tulane University, Belle Chasse

MA

Du Bois Library (2005), University of Massachusetts, Amherst
Bauer Laboratory building (2002), Harvard University, Cambridge
Cabot Science Center (1970), Harvard University, Cambridge
Countway Library (1960), Harvard University, Cambridge
Fogg Art Museum addition (under construction; 2013), Harvard University, Cambridge
Integrated Science & Engineering Library (2006), Harvard University, Cambridge
New College Theater (2008), Harvard University, Cambridge
Northwest Science building (2007), Harvard University, Cambridge
Pusey Library (1976), Harvard University, Cambridge
Lyman Conservatory expansion (2002), Smith College, Northampton
University Club and food court (2003), Smith College, Northampton
Higgins Hall (2000), Boston College, Chestnut Hill
Five-College Library Repository (Amherst College, Hampshire College, Mount Holyoke College, Smith College and University of Massachusetts-Amherst) (2002), Hadley

MD

Greenfield Library annex (1996), St. John's College, Annapolis
Peabody Institute (1980), Johns Hopkins University, Baltimore

ME

Museum of Art expansion (2007), Bowdoin College, Brunswick
Hawthorne-Longfellow Library expansion (1983), Bowdoin College, Brunswick

MI

Margaret Dow Towsley Center organ studio (1985), University of Michigan, Ann Arbor
Law Library addition (1979), University of Michigan, Ann Arbor

MN

Seton Apartments student housing (1982), St. John's University, Collegeville
Solon Campus Center (1995), University of Minnesota, Duluth
Anderson Library (2000), University of Minnesota, Minneapolis
Civil Engineering building (1982), University of Minnesota, Minneapolis
Williamson Hall (1977), University of Minnesota, Minneapolis

MO

McCafee Library (1988), Park University, Parkville

NC

Media Center (1980), Mars Hill College, Mars Hill

NJ

East Pyne addition (2003), Princeton University, Princeton
Firestone Library (1970, addition in 1990), Princeton University, Princeton
Marquand Art Library addition to McCormick Hall (2003), Princeton University, Princeton
McDonnell Hall (1998), Princeton University, Princeton
Robertson Hall addition (2002), Princeton University, Princeton
Fine Hall (1969), Princeton University, Princeton
Jadwin Gym (1969), Princeton University, Princeton
Math-Physics Library (1970), Princeton University, Princeton
Whitman Theater & Servery (2007), Princeton University, Princeton

NM

Centennial Science & Engineering Library (1986), University of New Mexico, Albuquerque
Parish Library (1987), University of New Mexico, Albuquerque
Regener Hall (1972), University of New Mexico, Albuquerque
Zimmerman Library addition (1993), University of New Mexico, Albuquerque

NY

Physics Laboratory, State University of New York (SUNY), Albany
Heimbold Visual Arts Center (2004), Sarah Lawrence College, Bronxville
Facilities Management building, State University of New York (SUNY), Fredonia
Sage Hall addition (1998), Cornell University, Ithaca
University Campus Store (1970), Cornell University, Ithaca
Undergraduate Library (1980), Cornell University, Ithaca
Johnson Museum of Art addition (under construction; 2010), Cornell University, Ithaca
Kroch Library (1992), Cornell University, Ithaca
Campus Bookstore, Ithaca College, Ithaca
Textor Hall (classrooms), Ithaca College, Ithaca
Garden Apartments (one building is earth sheltered), Ithaca College, Ithaca
Tully Hall (1969), The Juilliard School, Manhattan
Main building expansion (2009), New York Law School, Manhattan
Wellness Center (2008), College of New Rochelle, New Rochelle
Avery Hall addition (1974), Columbia University, New York City
Marcellus Hartley Dodge Physical Fitness Center (1974), Columbia University, New York City
Classrooms beneath Gould Plaza (2009), New York University, New York City
Law Library addition (1986), New York University, New York City
Performing Arts Center (2008), Rensselaer Polytechnic Institute, Troy

OH

Shoker Science Center (1978), Bluffton College, Bluffton
Aronoff Center (1996), University of Cincinnati, Cincinnati
Health Sciences building (1998), Cleveland State University, Cleveland
Library addition (2007), Cleveland Institute of Music, Cleveland
Wexner Center for the Arts (1989), Ohio State University, Columbus
Library (1972), Sinclair Community College, Dayton
Dana Center (1980), Medical College of Ohio, Toledo

OK

Jones Museum of Art (2005), University of Oklahoma, Norman
Original main building (1972), Oklahoma City Community College, Oklahoma City
Health Professions Center (2008), Oklahoma City Community College, Oklahoma City

OR

Lokey Laboratories Building (2007), University of Oregon, Eugene

PA

Dalton Hall addition, Bryn Mawr College, Bryn Mawr
Rhys Carpenter Library, Bryn Mawr College, Bryn Mawr
Thomas Library addition (1997), Bryn Mawr College, Bryn Mawr
Houston Hall addition (2000), University of Pennsylvania, Philadelphia
Penn Museum addition (2005), University of Pennsylvania, Philadelphia
Roberts Proton Therapy Center (2009), University of Pennsylvania, Philadelphia
Posner Family Collection Gallery (2004), Carnegie Mellon University, Pittsburgh

RI

Multidisciplinary Teaching Lab (1969), Brown University, Providence

SC

West Quad Learning Center (2004), University of South Carolina, Columbia
Strom Thurmond Institute (1989), Clemson University, Clemson

TX

University Center Satellite (1973), University of Houston, Houston
University Center Underground (1973), University of Houston, Houston
Law Library, University of Houston (1969), Houston
Cullen Performance Hall Annex (1988), University of Houston, Houston
Law School Library addition (1992), Texas Tech, Lubbock

UT

Eyring Science Center addition (2003), Brigham Young University, Provo
IT building (2001), Brigham Young University, Provo
Lee Library addition (2000), Brigham Young University, Provo
Marriott Library addition (1996), University of Utah, Salt Lake City
Utah Museum of Natural History (under construction; 2011), University of Utah, Salt Lake City
Student Services building, University of Utah, Salt Lake City

VA

Burchard Hall (1998), Virginia Tech University, Blacksburg
Special Collections Library (2004), University of Virginia, Charlottesville

WA

Intramural Activities building (IMA) addition (1982), University of Washington, Seattle
Law Library (2003), University of Washington, Seattle
Medical Center Surgery Pavilion (2003), University of Washington, Seattle
Mueller Hall (1990), University of Washington, Seattle

WI

Sigurd Olson Environmental Institute (1981), Northland College, Ashland
Instructional Services building (1969), University of Wisconsin-Green Bay, Green Bay
Student Services building (1972), University of Wisconsin-Green Bay, Green Bay
Mary Ann Cofrin building (2001), University of Wisconsin-Green Bay, Green Bay
Computer Services Department, Western Wisconsin Technical College, La Crosse

WY

Science Library (1970), University of Wyoming, Laramie

APPENDIX D

Top Ten Reasons to Bury a Building[64]

Because they are unconventional, underground buildings seem like eccentric creations that would appeal only to an impractical segment of society. But today in the United States, more than 500 public and commercial structures and 5,000 private homes nestle within the earth. At least 20 major subterranean structures are currently under construction or are in the planning process in this country. For what earthly purpose? Read on for a countdown of the ten best reasons.

10. It can't upstage its neighbors if it's built downstairs.
Putting a new building or an expansion of an existing structure below ground minimizes its impact on views of historic facades or scenery.

9. If heat rises, we're all pretty cool down here.
Depending on the climate and the use of the underground space, heating and cooling costs can be as much as eighty percent lower than in an aboveground building.

8. It's not nice to fool Mother Nature!
Compared to aboveground buildings that blanket the earth with a waterproof layer, underground buildings covered with vegetation reduce rainwater runoff and help replenish subsurface water resources. Rooftop plants also improve air quality by converting carbon dioxide to oxygen.

7. If you can't get around the rules, get under them.
Some zoning rules such as required amounts of parking and landscaped areas are easier to meet if the building's roof can be used to accommodate them. Other surface rules like minimum setbacks from property lines are less applicable to underground buildings.

6. Not a whole lotta' shakin' goin' on.
Trying to think near an airport or a busy highway? Trying to manufacture precision parts with your factory floors being shaken by nearby traffic or your own machinery? Insulate your building with soil and anchor it in the earth.

5. Don't make a mountain out of a molehill, make a mansion out of a mountain.
Invest in a bargain-priced lot that's too steep to build on, burrow horizontally into the hillside and enjoy the view!

4. No more handwriting on the wall.
Because of limited points of entry and small amounts of exposed walls or windows, underground buildings can be more secure from vandals, thieves and even terrorists.

3. Forget battening down the hatches—batten down the building!
Properly designed underground buildings resist not only wind and fire, but flooding and earthquakes as well.

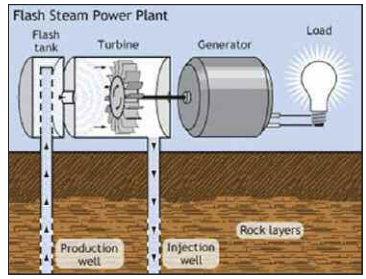
2. Maintenance is dirt cheap.
Lack of exposure to wind, sunlight, precipitation, and temperature extremes virtually eliminate the need to reshingle roofs or to maintain exterior walls by repainting, resurfacing or installing aluminum siding.

1. If you can't see the forest for all the trees, how are you ever going to see the building?
Parks and gardens built on top of underground buildings are great ways to create or preserve open space in downtown areas.

APPENDIX E

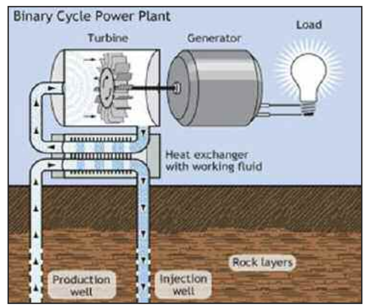
Electricity-Generating Geothermal Technologies

Flash Steam Power Plants



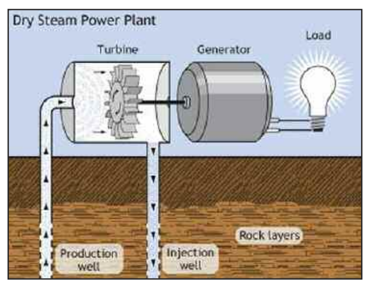
Water above 360° F can be used in flash plants to make electricity. Water is sprayed into a tank held at a much lower pressure than the fluid, causing some of the fluid to rapidly vaporize, or 'flash.' The vapor then drives a turbine, which drives a generator. If any water remains in the tank, it can be flashed again in a second tank to extract even more energy.

Binary-Cycle Power Plants



Most geothermal areas contain moderate-temperature water (below 400° F). Energy is extracted from these fluids in binary-cycle power plants. Hot water plus a secondary 'working' fluid with a much lower boiling point than water—hence a 'binary' system—pass through a heat exchanger. Heat from the water causes the secondary fluid to boil (flash to vapor), which then drives the turbines. Because this is a closed-loop system, no pollutants are emitted to the atmosphere.

Dry Steam Power Plants



Steam plants use steam, rather than hot water, that comes from deep underground. The steam goes directly to a turbine which drives a generator that produces electricity. The steam eliminates the need to burn fossil fuels to run the turbine. This is the oldest type of geothermal power plant. It was first used at Lardarello in Italy in 1904, and is still very effective. Steam technology is used today at The Geysers in northern California, the world's largest single source of geothermal power. These plants emit only excess steam and very minor amounts of other gases.

Source: U.S D.O.E, Energy Efficiency and Renewable Energy

NOTE: Coverage of programs or initiatives at schools named in this publication ranges from a brief mention to detailed case examples. Page numbers in *"From the Ground Up"* follow the school name below.

APPENDIX F

Schools Included in this Guide by State
TOTAL: 154 Schools, 42 States, and the District of Columbia

AZ
Arizona State University
University of Arizona
Yavapai College

CA
Feather River College
Harvey Mudd College, Claremont
Ohlone College
San Francisco State University
Stanford University
University of California, Berkeley
University of California, San Diego
University of California, Santa Cruz

CO
Colorado Northwestern Community College, Craig campus

CT
Eastern Connecticut State University
Fairfield University
Yale University

DC
Georgetown University

DE
University of Delaware

FL
Florida Southern College
University of Central Florida
University of Florida

GA
Georgia Institute of Technology

HI
University of Hawaii at Manoa

IA
Buena Vista University
Luther College
Maharishi University of Management
University of Iowa
University of Northern Iowa

ID
Boise State University
College of Southern Idaho

IL
Columbia College
Heartland Community College
John Wood Community College
Lake Land College
University of Chicago
University of Illinois, Chicago
University of Illinois, Rockford
University of Illinois, Urbana-Champaign
Western Illinois University

IN
Anderson University
Ball State University
Goshen College
Indiana University
Purdue University
University of Notre Dame

KS
University of Kansas

KY
Berea College

LA
Tulane University

MA
Boston College
Harvard University
Smith College
University of Massachusetts, Amherst
Five-College Library Repository (Amherst College, Hampshire College, Mount Holyoke College, Smith College and University of Massachusetts-Amherst)

MD
Harford Community College
Johns Hopkins University
McDaniel College
St. John's College

ME
Bowdoin College
Colby College
University of Maine Farmington
University of Southern Maine

MI

Davenport University
Grand Valley State University, Allendale
Lansing Community College
Lawrence Technological University
University of Michigan

MN

St. John's University
University of Minnesota Arboretum
University of Minnesota, Duluth
University of Minnesota, Minneapolis/St. Paul

MO

Drury University
Park University

MT

University of Montana

NC

Mars Hill College
Warren Wilson College
Wilson Community College
University of North Carolina Chapel Hill

ND

Turtle Mountain Community College

NH

Plymouth State University

NJ

Drew University
Princeton University
Richard Stockton College

NM

New Mexico Institute of Mining and Technology
University of New Mexico

NY

Adelphi University
Bard College
College of New Rochelle
Columbia University
Cornell University
General Theological Seminary
Hamilton College
Ithaca College
Juilliard School
New York Law School
New York University
Paul Smith's College
Rensselaer Polytechnic Institute
Sarah Lawrence College
Skidmore College
State University of New York (SUNY), Albany
State University of New York (SUNY), Brockport
State University of New York (SUNY), Dutchess Community College
State University of New York (SUNY), Fredonia
State University of New York (SUNY), Sullivan County Community College
Vassar College

OH

Bluffton College
Cleveland Institute of Music
Cleveland State University
Oberlin College
Medical College of Ohio
Ohio State University
Sinclair Community College
University of Cincinnati

OK

Oklahoma City Community College
Oklahoma State University
Oklahoma State University Institute of Technology at Okmulgee
Rogers State University
University of Oklahoma

OR

Oregon Institute of Technology
Portland State University
University of Oregon

PA

Allegheny College
Bryn Mawr College
California University of Pennsylvania
Carnegie Mellon University
University of Pennsylvania
Mercyhurst College
Mercyhurst College, North East
University of Pennsylvania Morris Arboretum
West Chester University

RI

Brown University

SC

Clemson University
Furman University
Medical University of South Carolina
University of South Carolina

TN

Lipscomb University

TX

Rice University
Texas Tech University
University of Houston

UT

Brigham Young University
University of Utah

VA

University of Virginia
Virginia Tech University

VT

Champlain College

WA

Pacific Lutheran University
University of Washington

WI

College of Menominee Nation
Northland College
University of Wisconsin-Green Bay
University of Wisconsin-Madison
Western Wisconsin Technical College

WY

Laramie County Community College
University of Wyoming

NOTE: Details and text for many of the campus geothermal stories were drawn in part from three articles by Paul Tolmé previously published by the National Wildlife Federation in *ClimateEdu:* News for the Green Campus. A fourth *ClimateEdu* article by Maryruth Priebe is also an excellent resource.

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