Greenway College

How you can help build the school that engineers
OUR SUSTAINABLE FUTURE

Troy McBride

5 Castles on the Ground

> The future is not completely beyond our control. It is the work of our own hands.
>
> —Robert F. Kennedy

> If you have built castles in the air, your work need not be lost; that is where they should be. Now put the foundations under them.
>
> —Henry Thoreau, *Walden* (1854)

Greenway College will be a totally "green," zero-sacrifice learning community that runs entirely on clean, renewable energy, independent of the grid. It will implement zero-waste principles throughout its fabric while providing all the services that one would expect from any top-drawer four-year college, and will do so as reliably, conveniently, and affordably as any grid-connected, waste-producing campus. Although a number of net-zero or energy-independent housing blocks and individual buildings have been built to date—all important early adoptions and test-beds—Greenway will be the first *zero-waste, energy-independent, 100 percent renewably powered college in the world.* It will also be the first college dedicated to the study, advancement, and spread of such technologies.

Any college, no matter how physically green or clean, is nothing without faculty and students. For faculty, Greenway will gather top experts and teachers in alternative energy generation, energy storage, zero-waste systems, and other areas of sustainable engineering. We anticipate that our unique laboratory-campus and ambitious mission will enable us to attract top talent in these fields. Likewise, we expect that Greenway will have no trouble filling its roster with qualified students eager to learn in a stimulating, interactive, directed-study, apprenticeship-based style.

In previous chapters we've shown that in the broad areas of energy independence and zero waste, the technologies needed to build Greenway already exist. Although a full-blown, in-detail campus design will require input from architects, engineers, accountants, faculty, and other experts and stakeholders, including members of Greenway's proposed home community, it is possible to outline a workable vision of Greenway campus right now. The final blueprints will differ, but in detail rather than spirit. So let's put meat on the bones. What will Greenway College actually look like? How will it work?

Land

If faculty and students are the lifeblood of any school, grounds and buildings are its bones. Most fundamental of all is the land on which everything stands. Greenway College could be built on a wide range of landscapes, since most of its green technologies do not depend on special geographic features, but this does not mean that Greenway or any similar enterprise ignores its home place: on the contrary, Greenway's design will be fitted to work with its particular site, making it green literally from the ground up. An example of such a site-friendly design approach has been set by the largest zero-net-energy office building in the United States, the National Renewable Energy Laboratory's 360,000-square-foot Research Support Facility in Golden, Colorado (completed 2010). The new facility was designed to fit into the natural character of the mesa site, minimally disturb the terrain, and conserve water resources.[1]

Greenway could be built on undeveloped land or on a predeveloped or partially developed site. It might retrofit old structures or scrape them off and build from scratch, as needed. The possibilities are endless, but to make this discussion specific, we envision purchase of a closed-down industrial, medical, recreational, or other campus that is adjacent to or includes a fairly large tract of undeveloped land. An ideal site would be in the range of 200 to 1,000 acres, enough to allow for future expansion with permanent preservation of open and forested space. The actual college will occupy a fraction of this land, starting with about 50 acres and eventually expanding to about 100. Purchase of an obsolete, crumbling facility would tend to hold land cost down, preferably under $10 million, and assure that real estate is not a dominant share of overall cost.

For specificity, we can imagine building Greenway on a closed-down college in southwestern Vermont—an actual property that listed a few years ago for under $10 million. (Greenway could be built in any climate and setting within the country.) This particular 400-acre site has a number of desirable features, including existing college facilities, good solar exposure, a combination of land at low elevation and acreage on a moderately elevated ridge, the latter appropriate for both wind turbines and pumped hydroelectric energy storage. Pumped hydro is the lowest-cost, longest-lifetime, most-tested technology for large-scale energy storage presently available, but where it is not feasible, other technologies can be used, including compressed air, hydrogen, thermal, and large batteries.

1 "The Design-Build Process for the Research Support Facility," US National Renewable Energy Laboratory, https://www.nrel.gov/docs/fy12osti/51387.pdf.

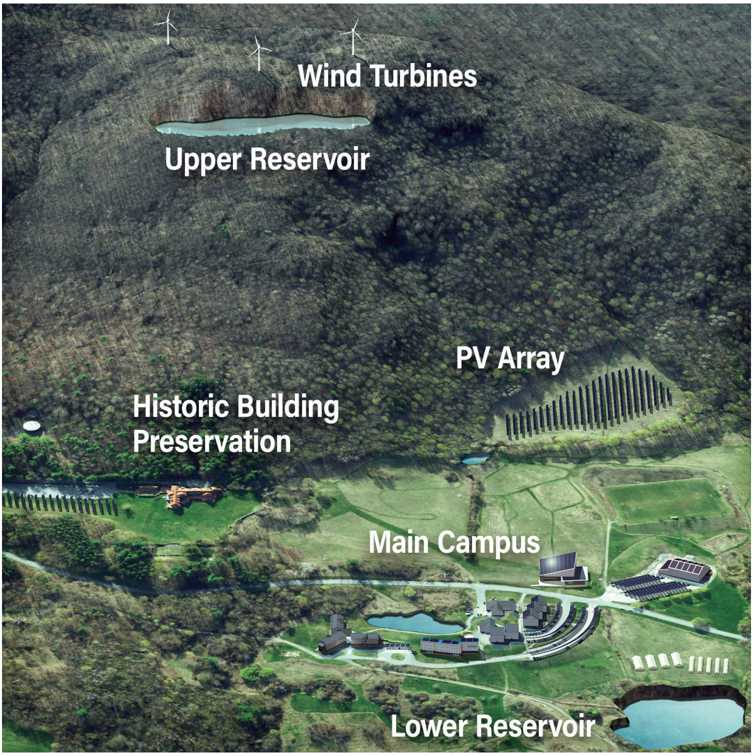

Fig. 5.1. Possible Greenway College layout based on the actual topology of a closed-down, 400-acre college in southwestern Vermont. Wind turbines and buildings are exaggerated in size for visibility.

A high-quality wind resource and siting for pumped-hydro energy storage are not necessary for building a stand-alone, totally green campus, but are offered by many plausible sites and are assumed here. And, although the water and wind resources of this site may make it easier to envisage meeting our clean energy goals, the climate compensates: Vermont has the sixth-coldest winters of any US state.[2] A New Mexico

2 Liz Osborn, "Coldest States in America," Current Results, accessed January 5, 2012, http://www.currentresults.com/Weather-Extremes/US/coldest-states.php.

Greenway campus would have a lot less water to play with, but a lot more solar energy, and (depending on location) perhaps just as much wind. Figure 5.1 shows a possible Vermont Greenway layout based on our exemplary 400-acre site.

The open and wooded lands of the campus wooded portion of the campus will provide fields, gardens, watershed, recreation, habitat, and possibly forestry products such as wood for power generation and liquid biofuel manufacture. A sustainable forestry program could provide many benefits to the campus while also contributing to the local economy.

Buildings

We do not propose upgrading and constructing the best buildings *possible*. Building ideals shift year by year as our know-how grows: the best possible building of today differs in many ways from the best possible building of 1990. Besides, if we already knew how to build Greenway perfectly there would be no point in building it, because we would have nothing to learn. Yet we know enough to begin: we can build a zero-waste, energy-independent, nonideal campus without busting the bank. Our physical plant's ongoing imperfection or non-finality will be a feature, not a bug, for Greenway is intended be a laboratory, a hands-on think tank, a learning and teaching community, a *college*, not a place where students plug their heads in to receive a download of finalized information.

If Greenway is to be a place of learning, it must be built accordingly. While its buildings will incorporate enduring principles of sustainable architecture (self-heating, self-cooling, best siting, optimal solar orientation, and the like), on top of that timeless armature of good design features they will feature as many as possible of the best cutting-edge technologies for generating and using power and light, for handling clean and dirty water, and the like.

Many historical colleges can be traced back to a first building or small set of buildings. These often served as the entire college—dining halls, dormitories, classrooms, laboratories, offices. Greenway will begin this way, too: compact but complete.

The core or original campus will consist of upgrading existing buildings to state-of-the-art, efficient clean-energy-powered buildings and construction of one new building. Existing buildings that will be upgraded include: (1) gymnasium, (2) residence buildings, (3) combined classrooms, residence, and student center, (4) cafeteria, and (5) combined offices, classrooms, and laboratories (see figure 5.2). One new-construction main building will be added with public education facilities, auditorium, and some state-of-the-art teaching-project spaces and laboratories. The core buildings will have about 28,000 square meters (m^2)—about 300,000 ft^2—of floor space and will be upgraded for best performance of their energy, lighting, and other features, such as their windows and rooftop solar panels.

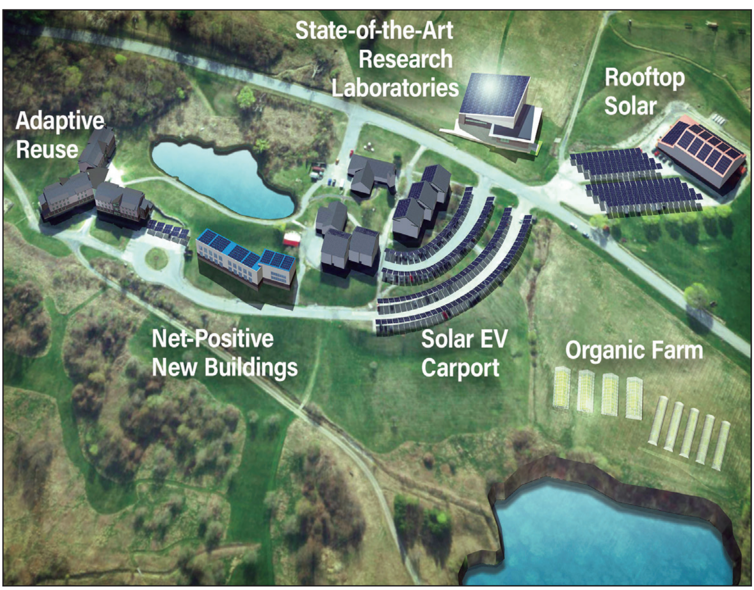

Fig. 5.2. Proposed Greenway College core campus. buildings.

The residence hall will house approximately 180 students, four faculty or staff families, and two caretakers. Remaining faculty and staff will find housing off-campus, as is common at colleges and universities; this will link us to the surrounding community and benefit its economy. There will be about fourteen classrooms, one auditorium, twenty-five offices, and ten teaching laboratories. The teaching laboratories will contain standard equipment in physics, chemistry, electronics, and other disciplines, but in addition will be connected, either directly or electronically, to the working mechanisms and life-metrics of the college: water flows and volumes; brightness and shadow levels; every form of energy generation, usage, and storage; inside and outside temperatures, winds, and light levels; structural loads. All will be treated as functional experiments, subjects for study. The physical fabric of Greenway's campus will, like a spacecraft, be permeated by a veritable nervous system of sensors and links that enable its users to track, learn from, and ultimately improve every aspect of its functioning. The campus will obey the Greek dictum to "know thyself" as few institutions have ever done—and thanks to modern computers and wireless sensors, it will do so at modest cost.

Facilities will include a dining hall and snack bar, student fitness and lounge area, bookstore, public information and display center, administrative offices, restrooms, and possibly a rooftop observatory. All working equipment will be accessible by the faculty for demonstration, examination, and tours. The goal, at Greenway as at any modern university, is simple: comfortable, well-lighted, convenient spaces in which to work, play, live, and learn. Construction costs for the buildings, exclusive of energy generation and other sustainable technology, will be around $50 million.

During and following the upgrade and construction of these first buildings, as well as all of future modifications and expansions, students and faculty will be directly involved in studying them from the standpoints of science, engineering, economics, ergonomics, and all other relevant disciplines. In this way, their lived experience will be a part of their studies of green technologies and engineering.

During and after construction, use of hazardous materials will be minimized. In routine operation, consumer garbage will be eliminated. Reusable or compostable containers will be used for all packaging. Shipments from outside companies will be attached to agreements for return of unwanted excess shipping containers and recovery of obsolete products. All outside purchases will be analyzed for environmental impact during fabrication, use, and recovery/recycling/reuse after their intended lifecycle. All excess food products, as well as other safe and rapidly biodegradable products, including human excrement, will be unobtrusively composted or digested. All excess materials will be completely dealt with on-site or returned to the manufacturer to eliminate waste.

Energy and Waste: Overview

Energy brings buildings to life: it lights, warms, cools, circulates air, and runs computers, phones, elevators, water pumps, and other devices. One form of energy—electricity—can perform all these jobs, but not always economically. Electrical energy is the most refined and most versatile of energy forms—but not necessarily the least expensive or most direct way to perform a function. We will use it—with maximum affordable efficiency—at every point where its use is appropriate, and avoid it wherever there is a more direct, less costly alternative. The result is that Greenway's internal energy economy will be a flexible tapestry adapted to the full range of end uses. Electricity will run computers, communications equipment, artificial light sources, pumps and fans, and other devices that require it. The sun will provide most heating and lighting and virtually all hot water. Insulation, thermal masses, sun shading and reflection, and air circulation will provide all or nearly all of needed space cooling (as these techniques already do at NREL's LEED Platinum buildings in Golden, Colorado, as well as in Europe's tens of thousands of Passivhaus structures). If necessary, additional ground-loop heat pumps (discussed further below) will provide extra heating and cooling capacity to assure that Greenway's buildings remain comfortable at all times, without fail. Gaseous and liquid fuels generated on-site, along with electricity, will be used to run on-campus vehicles, cooking equipment, refrigerators, and other miscellaneous devices.

Electricity will be generated mostly by solar panels and, depending on permitting, a wind-turbine installation, with lesser amounts of additional forms of generation potentially also installed (for example, a biomass-burning system providing combined heat and power, or fuel cells running on hydrogen). Bulk energy storage may be primarily in a two-acre water reservoir located near the wind-turbine installation. A wastewater-treatment greenhouse with artificial wetland and compost facilities—built for strict odor control, as are all good compost sites—will be showcased not far from the main buildings. All facilities will be viewable by tour and designed for maximal accessibility. Gasoline-powered vehicles will be parked at the campus periphery, and a small fleet of electric, hydrogen-combustion and fuel-cell vehicles, charged from on-site power sources, will be available for on-campus transport of materials and mobility-impaired people.

No corners will be cut when it comes to reliability of any campus systems; on the contrary, extra effort and expense will be undertaken to foresee and avoid, or blunt the impact of, possible system failures. All operations will be to some extent overengineered, with backups to compensate for inevitable failures. For example, a hydrogen-burning backup generator will supply power if all else fails. (There will be no grid connection, except possibly a remote laboratory for experimental purposes.) This extra up-front investment will not only serve the Greenway community directly, but ensure the college's long-term success by preventing embarrassing lapses in function. It is up to us, in the design stage, to assure that the headline "Students at Sustainable College Shiver in Dark During Power Outage" *never* sees print.

Next, we review the basic physical systems mentioned above—energy supply and storage and zero-waste design—in more concrete detail.

Solar Power

Solar power, now approaching the least expensive electricity source, will be the leading means at Greenway of generating electricity. Solar could in fact be economically used to generate all of Greenway's power, but for redundancy, experiment, and instruction, we will install multiple technologies, including wind turbines—which balance intermittency to an extent and may reduce energy storage requirements. Solar equipment is very reliable, panels can be stationed atop already-developed land (rooftops, parking lots, and the like), and it raises no concerns about turbine noise, ridgeline development, or other controversies.

Photovoltaic panels turn sunlight directly into electricity. They have no moving parts, produce no noise or pollution during operation, are highly reliable, require little maintenance, and last thirty years or more. They generate the most energy when pointed directly at the sun at all times, but continuous, direct sun pointing is only possible for panels mounted on moving mechanisms, which cost more. In Vermont, tilting a panel at about thirty degrees and pointing it due south produces the most electricity annually for a stationary panel; sun-following trackers add mechanical complications but produce additional annual generation. As shown in figure 5.2, for Greenway we propose solar on most buildings and additional solar over parking lots and in some open spaces. Snow coverage of panels can be a concern in winter in northern latitudes, so ground-based panels will be installed either at a substantial angle or include tracking or seasonal adjustability.

Figure 5.3. At left, a wind farm in Searsburg, Vermont, that generates about 36,000 kWh/day—about five times the wind-power supply we envision for Greenway. Right, the National Renewable Energy Laboratory's Research Support Facility in Golden, Colorado. The facility's dark-blue rooftop solar panels generate about 1,800 kWh/day,[3] making the generation of this 2,800-m^2 system about 25 percent of the size proposed for Greenway.

3 Photo1: http://www.epa.gov/region1/eco/energy/re_wind.html. "Energy and Global Climate Change in New England," EPA, accessed Sept 2012. Searsburg site is approximately 6 MW with approximately a 25 percent capacity factor. Photo2: http://www.nrel.gov/data/pix/Jpegs/19089.jpg, accessed May 25, 2012.

Size and actual kilowatt-hour output of NREL system for all of 2011 used as basis of numbers given here: "System Advisor Model (SAM) Case Study: NREL Research Support Facility (RSF)," US National Renewable Energy Laboratory, 2012, accessed May 25, 2012, https://sam.nrel.gov/files/content/documents/pdf/NREL%20RSF%20Building%20Rooftop%20PV.pdf.

Capacity of solar system 1.6 MW: Heather Lammers, "Solar System Tops Off Efficient NREL Building," US National Renewable Energy Laboratory, September 29, 2010, accessed May 25, 2012, http://www.nrel.gov/news/features/feature_detail.cfm/feature_id=1516.

15.5% photovoltaic capacity factor for Colorado: R. Muren and C. Kutscher. "Analysis of Renewable Energy Deployment in Colorado by 2030," NREL Technical Report NREL/TP-550-42577, US National Renewable Energy Laboratory, December 2007, http://www.nrel.gov/docs/fy08osti/42577.pdf, accessed May 25, 2012.

For Greenway College, we propose a photovoltaic array rated for a maximum output of 1,000 to 2,000 kW. With a 15 percent capacity factor, such a 2,000-kW system would produce an average of 7,200 kWh/day—though all during the daytime and substantially more on sunny days during the summer. This entails around 14,000 m^2 (150,000 ft^2) of panels, an amount that can easily be accommodated on the site on rooftops, parking lots, and dedicated solar areas. At 2020 prices, such a system would cost about $6 million.

Wind

Wind power is highly dependent on wind speed: generation goes up roughly with the cube (third power) of wind speed, so doubling wind speed increases power output eightfold. In many areas, such as the western and central US, excellent wind conditions can be found in flat, wide-open spaces. Wind speed also increases with rotor height above the ground, which is one reason many modern wind turbines are so big. (Some large units have turbine hubs 140 meters—or 450 feet—above the ground, with blades that reach another 60 meters—or 200 feet—or more, making them significantly taller than the 170-meter Washington Monument). In other areas, including the northeastern US, the best wind conditions are found offshore and on ridgetops. Our example site for Greenway includes a ridge that can do double duty for wind turbines and hydroelectric energy storage. Ridgetop installations can have relatively small footprints (primarily for access roads and tower footings), but large turbine installations are often visible for many miles. Therefore, to reduce the visual impact, we propose installing not 200-meter turbines but more manageable midsize turbines rated at 400 to 800 kW with hub heights of at most 45 meters (150 feet) and blades rising another 24 meters (75 feet).

We visualize a nameplate 1,000 to 2,000 kW wind turbine setup with an expected 20 percent capacity factor.

Wind generators typically operate at a capacity factor (actual energy output as a fraction of maximum possible output) of 20 percent to 40 percent, depending on wind conditions, so a minimally well-sited 1,500 kW wind setup would generate, on average, approximately 7,200 kWh/day (sometimes more, sometimes less). Wind turbine costs are currently estimated at $1 to $3 per nameplate watt, installed, for systems less than 5 MW in capacity, making Greenway's expected wind cost somewhere around $4 million.

Combining a wind installation of 1,500 kW capacity and a photovoltaic system with 2,000 kW capacity will generate an around-the-clock average power of about 14,400 kWh/day, enough to run a fully-equipped, zero-sacrifice, energy-smart college campus.

Heat Pump

As noted above, air- and ground-source heat pumps may be used for heating and cooling. Ground-source systems, of which almost three million had been installed worldwide by 2010,[4] exploit the fact that, once you are a meter deep (3 feet) or so, the temperature of the next several hundred meters or so of the Earth is at an almost constant temperature year-round, about the average temperature for that region (e.g. 10–20 °C [50–70 °F] in most of the continental United States). This makes the Earth itself a potential source of heat in the winter and cooling in the summer, if leveraged by a relatively small amount of electric power (which drives the "pump" parts of a heat pump). Although sometimes called "geothermal" heat pumps, ground-source heat pumps have nothing to do with volcanic heat or hot springs; they work most anywhere.

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4 Robert Crowe, "Demand for Geothermal Heat Pumps to Grow 14 percent by 2015," *Renewable Energy World*, January 14, 2011, accessed January 6, 2012, http://www.renewableenergyworld.com/rea/news/article/2011/01/geothermal-heat-pumps-demand-to-grow-14.

The primary space-heating installation will, then, be a ground-source heat pump that recirculates its own water ground-source loop (a "closed loop" system). Such a setup produces about 3 kilowatts of thermal energy for each kilowatt of electrical energy required to run the system. This does not break the laws of physics (which say that energy can only be transformed, not created or destroyed) because the extra thermal energy is extracted from the Earth, whose stock of thermal energy is large and replenished by the sun so that our heat-pump system cannot significantly diminish it.

The approximately 30,000 m^2 of inside space at Greenway will need a 200 kW system, assuming a 7 W/m^2 heating and cooling requirement. This might seem fantastically low to a conventional architect, since it is less than one-tenth the average for *total* energy use in a "commercial"-class space like an office building or hospital,[5] but is quite reasonable for at Greenway. The NREL Research Support Facility in Colorado, in actual operating experience, uses only 5 W/m^2 for heating and a tenth that for cooling.[6] The ground source heat pump system will also provide hot water, supplementing a solar hot water system.

Ground-source heat pump systems are estimated to cost around $1,000 per kW of capacity depending on size;[7] the price of Greenway's system is estimated at about $250,000. Four or five computer-controlled heat-pump units will be

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5 "What is EUI?" US Environmental Protection Agency, accessed January 9, 2012, http://www.energystar.gov/index.cfm?fuseaction=buildingcontest.eui.

6 "NREL's Research Support Facility: An Energy Performance Update," US National Energy Research Laboratory, December 2011 accessed May 24, 2012, http://www.nrel.gov/sustainable_nrel/pdfs/rsf_operations.pdf. This document gives 8.58 $kBtu/ft^2/year$ for heating, and 8.58 $kBtu/ft^2/year$ divided by 8,769 hours per year, which gives .978 $Btu/ft^2/hr$.

7 "Selecting and Installing a Geothermal Heat Pump System," US Department of Energy, 2011, accessed May 24, 2012, http://www.eere.energy.gov/consumer/your_home/space_heating_cooling/index.cfm/mytopic=12670.

installed, each of about 65 kW capacity, allowing for staggering of the heating load and maintaining a lower peak power. Such a system will cover less than an acre, and can go under a small field or parking area.

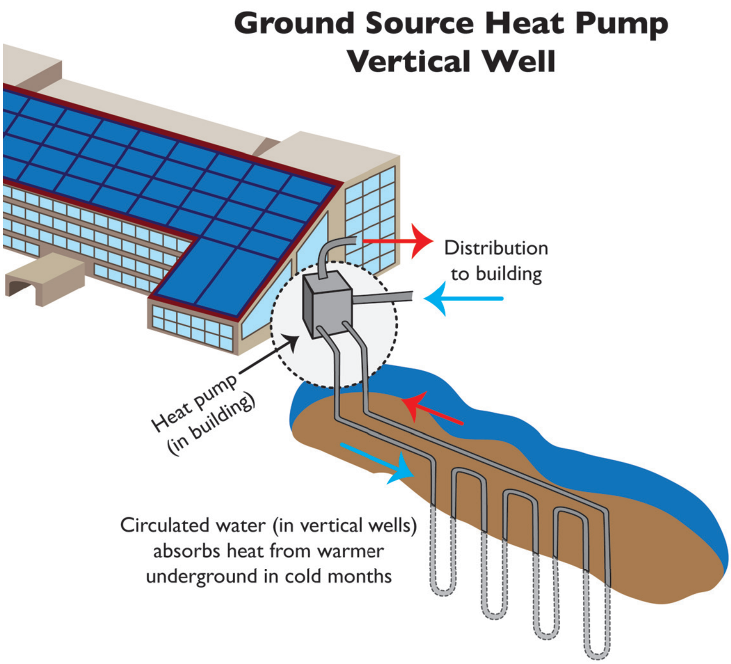

Fig. 5.4. Illustration of a closed-loop vertical-pipe setup for a ground-source heating system.[8]

Direct Solar Heat

Passive solar design is the design of buildings to maximize the use of solar warmth in winter, ventilated cooling in summer, and solar lighting ("daylighting") year round. Overhangs will be constructed above most windows to block

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8 "Geothermal Heat Pumps" at Energy.gov, accessed Oct, 2012, http://www.energysavers.gov/your_home/space_heating_cooling/index.cfm/mytopic=12650.

summer sun and allow autumn, winter, and spring sun to pass through windows facing every way but north. Advanced windows and automated systems for closing insulated curtains can decrease thermal losses at night. Light shelves can bounce daylight up to light-colored ceilings and thence down into workspaces, getting light where it needs to be while eliminating glare. Automatic sensors will dim or brighten overhead fixtures as needed to keep light levels even. Studies show that daylighting not only costs less than electric lighting, but also tends to improve worker mood and productivity.[9] Thermal masses—heavy chunks of the building, perhaps located at its lowest level—will store warmth for cool hours and coolness for hot hours. Costs for all these systems are included in the building budget; notably, although such buildings are marginally more expensive to build, they cost so much less to operate that the original investment pays back tenfold over building lifetime.[10] Money is not only invested but saved up front, as large conventional heating systems need not be purchased.

A moderate-sized active solar collector installation will be used to make hot water in the summer and to preheat water in the winter months. Millions of such systems are in use around the world. The installed cost of a 300 m^2 (3,230 ft^2) solar hot-water system at Greenway will be about \$200,000.

9 “Daylighting Resources—Productivity,” Lighting Research Center, accessed May 24, 2012, http://www.lrc.rpi.edu/programs/daylighting/dr_productivity.asp.

10 Gregory Kats et al., “The Costs and Financial Benefits of Green Buildings: A Report to California’s Sustainable Building Task Force,” report developed for the California Sustainable Building Task Force, October 2003, accessed January 9, 2012, http://www.ciwmb.ca.gov/GreenBuilding/Design/CostBenefit/Report.pdf.

Bioenergy

Today, crude and unhealthy biomass-burning is still a major source of energy for hundreds of millions of poor people around the world, but cleaner, higher-tech ways of generating electricity and heat from crops, forestry products, and organic "wastes" are gaining popularity in industrialized countries. Net carbon dioxide (CO_2) emissions can be nearly zero for such fuels, as approximately equal quantities of CO_2 are absorbed by vegetation during growth as are emitted during combustion. In some cases, such as corn-based ethanol, there has been fierce debate over how much one really gains by making the biofuel, since fossil fuel is used to grow and fertilize the corn: according to the US Department of Agriculture, about 0.5 units of fossil-fuel energy must be invested to produce one unit of corn-ethanol energy. The CO_2 emissions of a gallon of standard corn ethanol are thus not zero, but about half those of a quantity of gasoline yielding the same energy.[11] Other issues with some specialized energy crops, including corn, are soil erosion, fertilizer pollution, and diversion of croplands from food to fuel production, with resulting higher food prices for the world's hungriest people.[12]

Fortunately, some biofuels can be designed and harvested to sidestep these problems. Greenway will implement only fully renewable, sustainable, local biofuel options.

During power generation with direct burning of biomass,

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11 "2008 Energy Balance for the Corn Ethanol Industry," US Department of Agriculture, June 2010, accessed January 9, 2012, http://www.usda.gov/oce/reports/energy/2008Ethanol_June_final.pdf.

12 Environmental Working Group, "The Unintended Environmental Impacts of the Current Renewable Fuel Standard (RFS): A Guide to Common Sense RFS Policy," Fall 2007, accessed January 9, 2012, http://www.ewg.org/files/EWG_Corn_RFS_Fall_07.pdf. Also, "Ethanol Blamed for Record Food Prices," *Technology Review*, March 2011, accessed January 9, 2012, http://www.technologyreview.com/energy/37019/.

CO_2 and some pollutants are inevitably emitted—nitrous oxides (NO_x) and in some cases particulates (smoke and soot)—but overall lifecycle emissions from a new biomass generation installation can be substantially lower than those from a fossil-fuel plant. Biofuel emissions can be lowered and efficiency increased by using clean, dry fuels, gasification systems, and other technologies. Many biomass products can also be converted to methane via biodigesters, then burned or further reformed into hydrogen and reacted in fuel cell systems.

We do not propose installing a biomass generator at this time, although we will look at possibilities to use onsite agricultural and forestry products and eventually test alternative biofuels (e.g., algae-sourced biodiesel, food-industry wastes) produced on campus, offsite, or both.

Bulk Energy Storage

As discussed in detail in chapter 3, storing energy is a crucial aspect of energy independence for Greenway College. Bulk electrical storage and recovery lets us decouple the generation of power from its usage—in our case by storing many hours of energy from wind and solar power for use exactly when needed. Pumping water to a higher elevation for energy storage is the most common large-scale stationary energy storage system in the world; in the United States, about 135 such hydro-pumped storage sites are operational with a total power generation capacity of about 18 GW.[13] Although the most economical storage method will depend partly on the landscape where Greenway is ultimately built, for this estimate we will assume that Greenway's site enables the construction of a 2-acre reservoir at sufficient head to

13 "Inventory of Electric Utility Power Plants in the United States 2000," DOE EIA 2000 report, accessed July 2007, http://www.eia.doe.gov/cneaf/electricity/ipp/ipp_sum.html. This data is specifically from Table 17 (http://www.eia.doe.gov/cneaf/electricity/ipp/html1/t17p01.html).

store 35,000 kWh of electrical energy. This is enough to run the whole campus (assuming an average of 5,000 kWh daily consumption) for seven days—a generous backup supply. We estimate the total cost of such a system at roughly $5 million.

Short-Term Energy Storage

Short-term uninterruptible power supply (UPS) storage provides additional protections for Greenway's power microgrid, reacting to near instantaneous changes in power requirements. Currently, we propose either lithium-ion-based storage or flywheel energy storage. One leading option is for the majority of the UPS backup to come from a long-lifetime flywheel-based system similar to the one from Active Power, Inc. These flywheel systems are commercially available and have superior lifetime environmental performance over battery-based systems, based on both materials (no exotic or hazardous chemicals) and lifetime (thirty-plus years as opposed to closer to five years for most battery-based UPS systems). A 500 kW flywheel system providing about fifteen seconds of coverage (until backup and bulk storage can take over) costs about $75,000.

Backup and Portable Energy Storage

A hydrogen electrolysis, storage, and fuel-dispensing system will be installed at Greenway to provide hydrogen for backup energy storage and portable usage. Hydrogen is sometimes slated as the mobile energy storage medium of the future, because it is low weight and clean burning (when combusted or reacted with oxygen, the only byproduct is water). Hydrogen energy storage has low roundtrip efficiency (20 to 40 percent), but it is a great option for backup generation in place of a diesel generator and for mobile uses. Our hydrogen setup may include an approximately 400 kW power generation unit, providing several hours of backup power. Total cost for such a packaged system (e.g., from Hydrogenics) is about $2 million.

Energy storage for on-campus vehicles will be primarily in the form of on-board batteries with some hydrogen and biofuel vehicles. Electrochemical batteries are currently the best technology for small portable devices and also are used for small and moderate-sized power equipment, including electric vehicles. Proper recycling of battery chemicals and materials is essential to a zero-waste closed-loop system. Currently lead acid batteries claim that "more than 97 percent of all battery lead is recycled",[14] whereas most other batteries have much lower recycle rates. Lithium-based rechargeable batteries—which have a relatively low weight, longer lifetime, and reasonable cost—continue to gain popularity as the technology and costs improve.

Much of the cost of energy storage for transportation will be folded into the cost of buying the vehicular fleet itself. For the initial, core campus, we estimate a fleet of several light trucks, vans, and grounds-keeping vehicles (tractors, mowers, etc.), mostly electrically powered, at a total cost of approximately $1 million.

Altogether, the energy storage systems at Greenway College will provide a highly reliable, totally green stand-alone microgrid and complete working environment, including transportation and maintenance. The systems will be overengineered as they serve not only as a highly reliable working microgrid, but equally importantly as a clean technologies study tool, demonstrator, and campus showpiece. This stand-alone totally green microgrid and complete zero-waste working environment is based on existing technologies but overall will be the first of its kind.

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14 "Battery Recycling," Battery Council International, accessed October 2012, http://batterycouncil.org/?page=Battery_Recycling.

Wastewater and Solid Waste

The average American directly uses about 100 gallons of water a day, about a fourth of this going to blackwater (toilet water).[15] Wastewater treatment will be accomplished using two natural methods. First, in all buildings, blackwater will be separated from washwater (graywater). Toilet waste will be handled by composting toilets whose end product will be useful rather than burdensome or offensive. The Greenway College composting-toilet (blackwater) system will include about twenty fixtures. The graywater system will use a greenhouse with finishing processing done by constructed wetlands and ultraviolet disinfection.

Anything that one might send to a landfill is "solid waste." At Greenway, solid waste will be eliminated largely through preventive nonuse (e.g., elimination of nonessential packaging), reuse (e.g., of essential packaging, washable utensils), use of truly recyclable products (e.g., pure metals, pure glass), use and composting of biodegradable "clean" products, and producer takeback/deposit agreements. Our vision is to use only products that are designed based on life-cycle analysis and zero-waste policies. Experience shows that products can be designed and manufactured in this manner without sacrificing quality and performance, and even, in many instances, with eventual reduction in cost. Companies that collaborate with us in designing and manufacturing such products will likely benefit in the long term—or the not-so-long term.

Costs for a program to eliminate all solid waste from Greenway College are primarily for operations (including personnel). Startup costs include building space for collection

15 "Indoor Water Use in the United States," US Environmental Protection Agency, June 2008, accessed May 25, 2012, http://www.epa.gov/watersense/docs/ws_indoor508.pdf.

and processing of materials to be reused, recycled, or returned to the manufacturer. Much of this space is designed into the initial Plant Operations/Dining Services building, but additional space will be budgeted near the secondary compost facility. Food waste will be composted in an in-vessel system located near the dining hall. A covered building and additional aerated static pile compost facility will be maintained near the greenhouse water-treatment area. These facilities will be landscaped to fit with the natural beauty of the site, will (as mentioned earlier) be designed for strict odor control based on the extensive operating experience of many such facilities around the country, and will provide additional processing and storage space for materials.

The cost of these additional Plant Operations facilities will be on the order of $600,000, depending on the square footage of the site. Overall, solid-waste processing will cost a small fraction of initial construction but will entail an approximate manpower and maintenance cost on the order of $200,000 per year, similar to related activities at a standard institution.

Conservation and Efficiency

The cheapest unit of energy is the one you never use: on a cold day, it is always better to close your windows than to crank up your oil burner. That is why energy experts universally agree that efficient end use is a key part of any rational, cost-effective energy strategy. This is true at every scale, from the household to the nation: dollar for dollar, efficiency investments can reduce cost, emissions, and risk (e.g., exposure to fuel-price volatility) faster than investments in *any* form of energy generation. It is conservatively estimated that the United States as a whole could reduce its energy generation requirements by 23 percent with efficiency and conservation measures that would pay for themselves.[16] Americans presently use about 35 percent more energy to produce each unit of gross domestic product than do Europeans[17]—who intend to increase their already pretty-good energy efficiency by another 20 percent.[18] These numbers matter because higher energy efficiency, far from being a mere amusement for the greener-than-thou, translates to decreased dependence on energy imports, greater resilience against energy price shocks (because of strengthened demand response), lower pollution, lower production costs, and other bottom-line benefits.

At Greenway College, all buildings will feature zero-sacrifice, high-efficiency, long-lifetime systems for lighting, heating, and other technological services that improve efficiency and decrease consumption. Sustainable building practices can affordably reduce energy consumption per square meter (summed over all categories of use) to a small fraction of business-as-usual standards. In general, wise efficiency measures add marginally to start-up costs but more than pay for themselves in reduced operating costs. For reducing electricity consumption, proven zero-sacrifice practices include daylighting and motion-and-light-sensitive, high-efficiency fluorescent and LED lighting; proper sizing of pipes and pumps; thicker in-wall wiring; outside-air ventilation management; proper insulation; passive solar design for heating,

16 "Unlocking Energy Efficiency in the US Economy," McKinsey & Company, 2009, accessed January 9, 2012http://www.mckinsey.com/Client_Service/Electric_Power_and_Natural_Gas/Latest_thinking/Unlocking_energy_efficiency_in_the_US_economy.

17 "World Energy Intensity—Total Primary Energy Consumption per Dollar of Gross Domestic Product Using Purchasing Power Parities, 1980–2006," Energy Information Administration, December 19, 2008, accessed January 10, 2012, http://www.eia.gov/pub/international/iealf/tablee1p.xls.

18 "Action Plan for Energy Efficiency: Realising the Potential," Commission of the European Communities, October 2006, accessed January 10, 2012, http://ec.europa.eu/energy/action_plan_energy_efficiency/doc/com_2006_0545_en.pdf.

cooling, and hot water; computerized power management; and use of high-efficiency appliances.

Start-up Costs, Operating Budget, and Funding

Let's collect the money figures scattered throughout the earlier parts of this chapter. Real estate will be under $10 million; buildings, approximately $50 million; energy generation—including electricity, space heating and cooling, hot water—around $12 million; energy storage, including cost of an electric on-campus vehicular fleet, around $8 million. Total facilities costs are thus in the ballpark of $80 million. A fundraising goal of $120 million will be set for all design, construction, and facilities costs. Greenway could almost certainly be started for a lower figure, but we strongly feel that the facilities cannot be underengineered without compromising the long-term success of the college. Any funds not used for initial construction will be returned to investors or added to the endowment at the option of the specific donors.

Our proposal includes twenty faculty and thirty-five staff at Greenway College, with an additional five researchers paid half salary and two Greenway Institute staff, for a total expected yearly cost of $4.7 million in personnel. With $2 to $2.5 million for supplies, upkeep, and new and replacement equipment, the annual operating budget checks in at about $7 million.

With approximately 175 students paying $30,000 in tuition, we would only have $5 million in annual revenue. This gives a shortfall of about $2 million—not large or unusual for such an institution. This is what endowments are for. Assuming a 4 percent rate of return, a $50 million endowment would return the $2 million per year; an endowment of $175 million would cover all operational expenses for the same rate of return. Funding will be solicited from private donors and corporate sponsors to purchase the land

and build the first state-of-the-art new buildings with power generation, energy storage, and waste treatment facilities.

In sum, we propose to raise $120 million for initial construction and a minimum of $50 million for an endowment. The total is much less than what it takes to build a large amusement park.

Feast or Famine?

Consider two visions of our future world from the popular and scientific press of today: Famine and Feast. Will we doom future generations to Famine—a world depleted of precious natural resources, with reduced biodiversity, polluted by unnecessarily concentrated toxins and waste products, overpopulated and hungry, and with a changed climate due to ever-increasing emissions leading to global warming? Or are we on track for a Feast, in which the world gets better all the time through ever-increasing ingenuity, invention, market forces, and brilliant engineering? One Feast-style forecaster, Julian Simon, predicts that "[t]he material conditions of life will continue to get better for most people, in most countries, most of the time, indefinitely. Within a century or two, all nations and most of humanity will be at or above today's Western living standards."[19]

The Feast forecast is supported by data on health, poverty, hunger, and technology that show long-term improving trends over many generations and even in recent decades. But a Famine fan might counter—recycling an image we introduced in chapter 1—that these data merely document the comfy conditions aboard a car accelerating toward a cliff edge. Are industrial civilization's gains *sustainable?*

Greenway's founders are not qualified to venture a detailed prediction of Earth's planetary future, but we are

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19 Ed Regis, "The Doomslayer," *Wired*, May 2002, accessed May 24, 2012, http://www.wired.com/wired/archive/5.02/ffsimon_pr.html.

confident that that future lies somewhere between the two extremes of Feast and Famine. We argue that industrial civilization will prove sustainable if we *make* it sustainable. This means putting our research, engineering, business, and policy-making powers toward creating a sustainable Feast for the whole world—a goal both worthy and plausible, though not guaranteed or automatic. We do know that through invention, engineering, and technology, we can design products, processes, and communities that are "green"—zero emission, zero waste, and sustainable—while maintaining or improving performance, using fewer resources, and sustaining human well-being.

Never have conditions been more opportune for the founding of such an institution. Never has the importance of sustainability, energy independence, and efficiency been so widely appreciated by private citizens, corporations, and government. Never have so many tested, cost-effective technologies been available with which to weave a sustainable global future. We believe, therefore, that Greenway College, as a uniquely timely and exciting endeavor, will attract superb faculty and students from the US and the world. Highly qualified professionals in clean technologies will be lured by the prospect of educating enthusiastic students in a hands-on, self-directed, apprentice-style setting, working with local and distant communities, corporations, and other organizations to further exciting technologies. They will be lured by the prospect of creating a healthy, fair, and economic workplace for our talented staff and students. Students will be attracted to our unique, hands-on program and the can-do hopefulness of an institution entirely devoted to enacting, developing, and disseminating the techniques of sustainability. We are therefore confident that the *demand* for a Greenway College is out there from all standpoints: faculty, students, corporations, donors, and communities.

As previously outlined in this book, the technology already exists to build a totally green college that sacrifices no creature comforts. We thus look forward to moving from the multi-year process of developing this proposal to the joy of designing, constructing, and working at Greenway College. We foresee that Greenway will become one of the world's most respected, talked-about, and emulated institutions.

Contact information for the Greenway founders' team is given at the back of this book. We hope that you will choose to help us move toward the realization of this vision.