Greenway College

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

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Zero Waste

> In our workshops we pride ourselves on discovering a use for what had been previously regarded as waste, but how partial and accidental our economy compared with nature's. In nature nothing is wasted. Every decayed leaf and twig and fiber is only the better fitted to serve in some other department, and all at last are gathered in her compost heap.
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> —Henry Thoreau, *Journal*, January 13, 1856

> You [shouldn't just] filter smokestacks or water. Instead, you [should] put the filter in your head and design the problem out of existence.
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> —William McDonough, *Cradle to Cradle*

Zero waste is a goal now being seriously discussed by companies, universities, governments, and other institutions around the world. On the surface, it is simple: emulate nature by either returning all used materials to nature *or* repurposing them without causing net harm to people or the environment. This means no landfilling; no spewing smoke, toxins, or greenhouse gases; leaving water as clean as or cleaner than one found it; total recycling, reforming, or repurposing of all sewage, food leftovers, paper, metal, plastic, glass, and other materials; and high-efficiency products and processes of all kinds. Admittedly, zero waste is a visionary goal, yet a growing technical literature, backed by real-world experience, shows it to be practical.

At Greenway we will aim not at marginal, halfhearted improvements, but at the total elimination of waste. We will design our campus and activities to result in no harmful effluent, no solid waste, and no harmful emissions, while maximizing energy efficiency. In addition, we will seek to design, develop, test, and promote systems and initiatives to allow industries, homes, and other stakeholders to operate with zero waste at zero sacrifice. That last term is, as we have emphasized in previous chapters, crucial: any zero-waste program that asks people to live in sacrificial misery is bound to be a nonstarter. When we say zero waste, we emphatically mean *zero waste at zero sacrifice.*

Questions

What, exactly, do we mean by "waste" and "zero"?

Waste may broadly be defined as anything that is thrown away. Some advocates of zero waste advocate replacing the idea of "waste" with that of *residual product* or *potential resource*. These terms highlight the fact that in a perfectly rational industrial system, maximum value would be extracted from 100 percent of resource.

"Waste" is not only a lost opportunity, but is often positively harmful, in which case we call it "pollution." Indeed, since all resources require energy for their extraction and processing, and all energy production—even from renewable sources—entails some degree of pollution or other environmental harm, there is no such thing as truly harmless waste.

As for the "zero" part of "zero waste," it is not as simple as it sounds. Two basic senses or limiting cases of "zero" waste can be defined, which we might call *everywhere zero* and *net zero*. An *everywhere-zero* system produces no waste at any point. For example, it produces no combustion products anywhere—any of its exhausts could be routed safely into a child's bedroom. A *net-zero* system, on the other hand, may produce waste outputs at some points, but makes up for them at other points. If it burns fuel in one place, it creates fuel in another, perhaps by biodigesting food and sewage to yield methane, or by growing trees or other biofuel feedstocks, or by using wind or solar electricity to make hydrogen.

A net-zero system might be easier to build, but an everywhere-zero system might be easier to keep honest. Strict accounting is needed to assure that a system is truly net-zero, and apples-to-oranges comparisons may be unavoidable. Carbon offset or credit systems, which attempt to cancel the net emissions of far-flung enterprises, have been notoriously hard to verify.[1]

On the other hand, strictly net-zero systems can actually be built, while strictly everywhere-zero systems cannot. To take just one example, each of us exhales carbon dioxide, a greenhouse gas, and we prefer to not stop breathing. Our CO_2 output is trivial, but not *zero*.[2]

Greenway will aim at “zero,” however defined, because all waste is an opportunity turned into a burden. Wasted material is discarded resource, and discarding resources is economically irrational; and on a finite Earth, zero waste is the only standard that we can uphold indefinitely. Mines will eventually play out, gas or oil wells will run dry, arable soil will wash to the sea, if we continue on our current one-way path: the timing is debatable but the outcome is inevitable.

And in the long run, why settle for zero? Why should not Greenway ultimately be a *negative*-waste system, producing more clean water, energy, and food than it takes in, with an

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[1] Mark Schapiro, “Conning the Climate: Inside the Carbon-Trading Shell Game,” *Harper’s*, February 2010, accessed May 23, 2012, http://citizensclimatelobby.org/files/Conning-the-Climate.pdf.

[2] For a glimpse of just how technical a discussion of “zero” can get, see NREL on definitions of net zero energy use by buildings: P. Torcellini, et al., “Zero Energy Buildings: A Critical Look at the Definition,” NREL/CP-550-39833, August 2006, accessed May 24, 2012, http://www.nrel.gov/docs/fy06osti/39833.pdf.

even greater margin of profit and pleasure? (To begin with, however, Greenway will stick to the goal of zero waste.)

Zero waste is both a vision and a collection of techniques. Below, we review the vision more closely, then touch upon some of the technologies that put it within reach.

The Vision

An ideal zero-waste industrial society would design and produce cars, houses, computers, and other products that optimize usage of resources during construction, life, and end of life. It would build things elegantly. It would "precycle" all its products, engineering them for easy breakdown when the time comes to reuse their ingredients. It would recycle all solid materials throughout the product lifecycle without degradation or "downcycling" to lower-quality products, reducing landfill and incinerator burdens to zero. It would produce zero pollution and thus suffer zero pollution-related disease. (Over 750 thousand people die every year, worldwide, from outdoor air pollution alone, and millions more from indoor air pollution.[3]) Its buildings would collectively produce their own heat, cooling, light, and power and would separate and treat their own graywater, sewage, and food leftovers. By using zero grid energy on-site, such buildings would incur zero emissions at distant power plants. Such a society would be *more* comfortable than ours, and its thrift would be technologically built-in and voluntary, not imposed on uncomfortable, unwilling citizens. And it could cost no more than, or less than, today's business-as-usual system.

Such a vision is so at odds with our current economy that it may seem a utopian pipe dream. But every single techni-

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[3] "Pollution: Costs of Inaction," *OECD Observer* 263, October 2007, accessed May 23, 2012, http://www.oecdobserver.org/news/fullstory.php/aid/2351/. Also, "Indoor Air Pollution and Health," World Health Organization, Fact Sheet No. 292, September 2011, accessed May 23, 2012, http://www.who.int/mediacentre/factsheets/fs292/en/.

cal building block of such a system has already been demonstrated. It is not technological inability that keeps us mired in our current puddle of cost, waste, discomfort, and pollution, but cultural inertia, irrational regulation, and simple lack of knowledge.

The economic and health costs of waste are heavy. Many of those costs have traditionally been externalized, that is, ignored by the waster because somebody else, downstream or downwind, pays the "cost" in discomfort or disease or rising sea levels or the like. Solid-waste disposal costs are not as easily externalized as those of other types of pollution, which is why cities, colleges, and other institutions must pay through the nose ($30 to $100 per ton) to have their solid waste hauled to landfills. Landfills occupy expensive real estate, can pollute groundwater, and are the USA's largest source of methane, a greenhouse gas twenty times more potent, molecule for molecule, than carbon dioxide. Incinerators are one alternative to landfilling; they can be integrated with recycling of noncombustibles such as metals and can generate heat and electricity. All existing incinerators pollute the air to some extent, however, especially since they have almost no control over the makeup of their incoming fuel (i.e., garbage). Today's trash-to-power facilities emit more CO_2 than a coal-fired power plant per unit of electricity produced.[4]

Perhaps a more explicit term than "zero waste," though clumsier, would be *zero pollution, zero hazardous waste, zero landfill.* In such a system, all emissions and unused hazardous and nonhazardous materials are captured during manufacturing or routine operations. These captured materials are then reused or processed and may be sold to other manufacturers (e.g., as in Rent-a-Solvent schemes). The final products them-

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[4] "Air Emissions," US Environmental Protection Agency, accessed March 12, 2012, http://www.epa.gov/cleanenergy/energy-and-you/affect/air-emissions.html.

selves are also recaptured and reused without being degraded to a lower-quality product. All manufacturing leftovers and final products are 100 percent environmentally benign. Such leftovers are directly reusable, ecologically neutral, or suitable for aerobic or anaerobic digestion by bacteria or other organisms, which would break it down into harmless (or, better yet, useful) materials.

At least, that is the goal. To attain it we at Greenway College will be counting on technological smarts, not on people's eagerness to be miserable. We respect those who are eager to radically simplify their lifestyle in order to achieve zero waste, and some studies even show that voluntary simplifiers may increase their happiness,[5] yet Greenway will not be predicated on anybody's willingness to give up basic comforts and conveniences. We envision a comfortable, spacious, and stimulating campus, generously appointed and lighted, where people work hard to design, test, document, and encourage environmentally benign and sustainable devices, from widgets to cities. This and other lofty environmental goals can, we believe, be achieved through progress in technology, without need for austerity.

Many of our professional graduates will, we hope, go on to work in industry and government, taking their expertise to ever-widening circles of society.

How Do We Do It?

Zero waste is achieved by meticulous attention to every aspect of consumption: buildings, manufactured objects,

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[5] Stephanie Rosenbloom, "But Will It Make You Happy?" *New York Times*, August 7, 2010, accessed May 23, 2012, http://www.nytimes.com/2010/08/08/business/08consume.html?pagewanted=all. See also Samuel Alexander and Simon Ussher, "The Voluntary Simplicity Movement: A Multi-National Survey Analysis in Theoretical Context," the Simplicity Institute, 2011, accessed May 23, 2012, http://simplicityinstitute.org/pub/The-Voluntary-Simplicity-Movement.pdf.

recycling, composting and wastewater, air pollution, hazardous waste, and, of course, energy in all its forms. Below, we glance at technologies for zero waste in each of these departments (energy generation and storage are covered in more detail in chapters 2 and 3). Finally, we outline of how these methods might be woven together at Greenway.

Buildings. Buildings and what goes on inside them—heating, cooling, cooking, computing, and the like—are major consumers of energy. Forty percent of all US primary energy use and 70 percent of all electricity use occurs within residential and commercial-class buildings. "Commercial"-class buildings include the nonresidential buildings one finds on campuses, such as libraries.[6] A large chunk of any university's budget thus goes for heating, cooling, and electricity consumed in buildings. Yet in no other area of energy consumption is there so much demonstrated room for improvement.[7]

The Passivhaus standard, invented in Germany, shows us how to build houses and other structures that need no large gas or oil burners, electric heaters, air conditioners, wood stoves, or other energy-eating technologies to remain fresh, well lighted, and at a comfortable temperature year-round. Even in the cool, cloudy climate of northern Europe (or the hot, sunny climate of southern Europe) these structures remain fresh, light, and warm. They achieve these goals largely through the use of passive solar heating, heat-exchanging air circulation, and insulation. The up-front cost of a

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[6] Paul Torcellini, Chad Lobato, and Tom Hootman, "Main Street Net-Zero Energy Buildings: The Zero Energy Method in Concept and Practice," NREL, May 2010, accessed December 1, 2011, http://www.nrel.gov/sustainable_nrel/pdfs/47870.pdf.

[7] M. Levine et al., "Residential and Commercial Buildings," in *Climate Change 2007: Mitigation*. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, ed. B. Metz, O. R. Davidson, P. R. Bosch, R. Dave, L. A. Meyer (Cambridge and New York: Cambridge University Press, 2007).

passive house's energy-saving features are largely recouped by minimizing expensive, unneeded heating and cooling systems. In Europe, tens of thousands of buildings already meet the Passivhaus standard; construction in the US lags in part because the high-efficiency doors and windows required are not widely available on the US market.[8]

In the US, several ways have been developed to rank buildings on their use of energy and other resources. The best known of these methods is probably the Leadership in Energy and Environmental Design (LEED) standard developed by the US Green Building Council, a nonprofit trade council. LEED ranks individual buildings on a number scale by awarding points for low-resource construction, water usage, energy efficiency, and other "green" features. At successively higher LEED point levels, a building can be deemed Certified, Silver, Gold, or Platinum. A LEED Platinum building approaches the net-zero ideal in energy and water usage, but Greenway College will strive to rethink and far exceed the LEED certification checklists.

The LEED certification levels are perhaps unfortunately named, since they may suggest that a Gold building is necessarily more expensive than a Silver, and a Platinum *very* expensive. Fortunately, this is not true: properly engineered efficiency is *less* expensive than inefficiency. The US National Renewable Energy Laboratory, putting its money where its mouth is, has erected six large, LEED-Platinum office buildings totaling over 300,000 square feet. Solar panels enable the facilities to use zero net grid electricity and zero on-site fuel for heating or cooling. NREL's per-square-foot construction costs were above average for commercial space, but the

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[8] Tom Zeller, Jr., "Can We Build in a Brighter Shade of Green?" *New York Times*, September 25, 2010, accessed December 1, 2011, http://www.nytimes.com/2010/09/26/business/energy-environment/26smart.html?sq=passivhaus&st=cse&adxnnl=1&scp=1&adxnnlx=1322755609-tH7jZG7KFppGTHS1CDDNnA.

buildings' unusual features will have a simple payback time of around five years,[9] after which the facility will have been earning *net profit* on those features. Ithaca College's Park Center for Business and Sustainable Enterprise, completed in 2008, and also LEED Platinum, incurred an up-front construction premium of only 5 percent and quickly recouped that investment from low operating expenses.[10] "Green," in building, is also the color of money.

A skeptic may ask: If net-zero buildings are so economical, why isn't everyone building them? There are several reasons. One is the ubiquity of split incentives: for example, if you're building a structure but will not be its future tenant, you will not be paying the energy bills, so why sweat the efficiency details? In general, however, the biggest obstacles are lack of knowledge and cultural inertia. Most builders and building buyers simply do not know that net-zero buildings are possible, or assume that they would be super costly and inconvenient. Our society's assumptions lag its actual know-how. In addition, since inefficient designs dominate the US mass market, efficient designs often are custom designs and therefore *do* cost more in part due to customization. As efficient designs and materials become the norm, their cost tends to decrease. A classic example is the refrigerator, which has increased in efficiency fourfold since the 1970s while it has shrunk in cost by two-thirds (in 2010 dollars), grown in capacity, and acquired more features.[11]

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[9] "Laboratories for the 21st Century: Case Studies: NREL Science and Technology Facility, Golden, CO," EPA/DOE, undated, accessed December 1, 2011, http://www.nrel.gov/docs/fy10osti/47662.pdf.

[10] Peter W. Bardaglio, "To LEED or Not to LEED," *Today's Campus*, 2011, accessed December 1, 2011, http://todayscampus.com/articles/load.aspx?art=1823.

[11] "BTP Drives Minimum Refrigerator Energy Use Standards to Save Consumers Money," DOE EERE program website, accessed June 19, 2012, http://www1.eere.energy.gov/buildings/saving_energy_refrigerator.html.

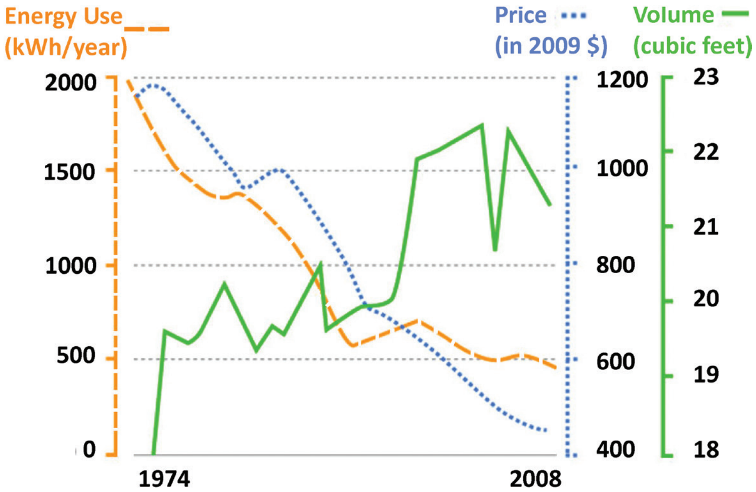

Fig. 4.1. Plot of the amazing success story of efficiency and the refrigerator. Long dashed line shows that average energy use for a new refrigerator in the USA has decreased fourfold since 1974; short dashed line shows that at the same time, average cost has decreased over two times; and solid line shows that both of these improvements in efficiency and cost occurred even while average refrigerator size grew substantially. (Source: US DOE EERE.)

In recent years, a number of colleges have seen how important sustainability is to incoming students and invested in green technology. The rapidly decreasing cost of solar energy especially has made this increasingly feasible. In 2018, American University became the first university in the United States to be certified as carbon neutral. The campus has six LEED-certified buildings, sources half of its energy from three solar arrays totaling 250,000 panels and half from renewable energy credits, and is renovating its heat and hot-water system.[12] Even this impressive facility still leaves room for improvement: it makes no claim to be zero *waste* (only zero net emissions, not solid or liquid waste) and is grid-con-

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[12] American University, "Carbon Neutrality Is Now Reality at American University," April 25, 2018, https://www.american.edu/media/news/20180425-carbon-neutrality.cfm.

nected. Yet it is important proof—one of many examples that could be cited—that the goals we are setting are not fantastic. Net-zero building technologies already exist: we need only apply them (and then spend the next decades figuring out how to make them even more elegant, effective, and profitable than they already are—chasing the refrigerator curves, as it were, of manyfold increased efficiency, lower costs, and improved features). Greenway will take advantage of lessons learned by early adopters like American and NREL, but will push the bar higher and yet higher, using newer technology, better designs, and smarter strategies.

When a site for Greenway has been selected and funds are in hand, we will hire an architectural firm with ample green-building experience to design a state-of-the-art green campus. Its structures will be traditional college buildings in outward appearance, but will *exceed* the standards of a 100 percent LEED Platinum campus (which does not yet exist anywhere). Leapfrogging LEED is our goal because LEED, with its point awards for Sustainable Site, Water Efficiency, Energy and Atmosphere, Materials and Resources, and Indoor Environmental Quality, encourages an *incremental* approach to sustainability. The LEED checklists are superb, but in building Greenway we have a chance to blow past them—indeed, to abandon checklists entirely for an all-at-once approach that will achieve better results for lower costs. Green aspects of Greenway's built-to-last buildings will include solar positioning and window sizing, super-insulation, computer-controlled air freshening and heat exchange, advanced windows, daylighting (which, besides saving money, improves student health and academic performance[13]), high-efficiency artifi-

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[13] "Daylighting in Schools: Improving Student Performance and Health at a Price Schools Can Afford," NREL/CP-550-28049, US National Renewable Energy Laboratory, August 2000, accessed March 15, 2012, http://www.nrel.gov/docs/fy00osti/28049.pdf.

cial lighting, open architecture for visualization of plumbing, mechanical, and electrical workings, and much more.

Greenway's concern for sustainability and zero waste will begin with construction itself. Contractors will be identified who are willing to enter into zero-waste agreements with Greenway, to include minimization and reuse of construction waste. For future study and reference, Greenway's construction will be thoroughly documented, preferably with the help of a film crew.

Manufactured Objects, Solid Waste, and Recycling

A college campus is in some ways a microcosm of the consumer side of industrial society. Therefore, in addressing the goal of zero waste at the level of the Greenway campus it behooves us to consider the waste experience of our society as a whole.

In the United States, we generate a huge amount of solid waste—400 million tons of industrial solid waste and 250 million tons of municipal solid waste. Only about 34 percent of US solid waste is recycled.[14]

Municipal solid waste, which is the sort that a typical college campus would be expected to produce, is a mix of every possible material—glass, plastics, organics, metals, paper, wood, concrete, chemicals, you name it. To reuse, optimally recycle, or compost its component parts, this mixed waste stream must be separated. Efficient sorting is, therefore, key to successful recycling of solid waste. The most economic options for efficient sorting are hand-sorting by individual consumers (as in some curbside recycling programs) and automated sorting, which is sometimes combined with hand-sorting at a centralized facility. A disadvantage of consumer sorting is

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[14] Municipal solid waste figures from "Municipal Solid Waste," US Environmental Protection Agency, accessed March 12, 2012, http://www.epa.gov/epawaste/nonhaz/municipal/index.htm.

that single errors can ruin a batch of product: just one chunk of the wrong plastic in a bin can render a whole load worthless. Bar-coding and built-in radio-frequency ID tags may someday enhance the purity of auto-sorted materials, as might manufacturer return of used products, since manufacturers have intimate knowledge of their products' constituents.

Properly done, washing and reuse (of bottles and dishes, for instance) always uses less energy than recycling or throwaway alternatives, and where direct reuse of objects is not possible, recycling of relatively pure, fusible materials like glass, steel, and aluminum is straightforward. Recycling of paper and plastics is also possible, though these typically result in lower-quality products than the original. Greenway will, of course, engage in these classic forms of reuse and recycling.

However, most manufactured objects are impossible to assign to a recycling bin. Computers and other electronic devices, for example, mingle glass, metals, and plastics in a nearly inextricable fabric. Various plastics are often mingled in single products in a manner that prevents each one from being truly recycled: mixed plastics are reused, if at all, as raw material of lower grade. This is not true "recycling" but, as William McDonough and Michael Braungart term it in their seminal *Cradle to Cradle* (2002), "downcycling." Downcycling merely postpones a material's trip to the landfill by one or two usage cycles. The goal of true *re*cycling should be to cycle materials back into materials of comparable or even higher value, indefinitely. This ideal is not always attainable: some materials, like glass and pure metals, are essentially immortal, but others, like paper fibers (which shorten with each trip through the paper-making process), can be reused only so many times for a single function. Yet, the lifecycle of paper may be adjusted so that no toxins are released and each fiber ends in the compost heap or biomass power plant after its life as paper.

A large part of the answer to the problem of impure, mixed, and inextricable materials lies in product design. The designer should look at the whole "cradle to cradle" lifecycle, taking into account all costs from raw-material extraction to reuse, recycling, or final disposal. Unfortunately, in most industries, once a plastic toy, a French fry container, a bottle of motor oil, or an automobile leave its place of assembly, the original manufacturer has practically zero responsibility for it. Accordingly, current standard industrial practice is to look only at the cost of manufacturing and to try to meet environmental regulations at the manufacturing site. There is no incentive—beyond PR and sheer goodness of heart—for a company to exceed these regulations or to consider the whole product lifecycle.

Nevertheless, in recent years the cradle-to-cradle (C2C) concept has been translated into technical standards and is being taken with increasing seriousness by a number of manufacturers, including Nike and Ford.[15] Cisco, Apple, and other companies have instituted end-of-life, product-take-back programs that begin to close the product lifecycle loop, albeit imperfectly. It is a small beginning, but a beginning.

The task at hand touches on the whole globalized system of resource extraction, product manufacture, and material disposal or reuse—a challenge that Greenway will exist, in part, to help address. Clearly, Greenway cannot singlehandedly reform the manufacturing habits of the planet, and so at least in the beginning will be obliged to participate to some extent in downcycling and the waste production embedded in the making of many essential complex items for an educational setting such as computers, maintenance equipment, and even light bulbs. However, Greenway is intended to be a living laboratory, not a museum piece: it will reflect the

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[15] Reena Jana, "New Clout for Cradle to Cradle Design," *Bloomberg Businessweek*, September 19, 2007, accessed December 2, 2011, http://www.businessweek.com/innovate/content/sep2007/id20070919_689774.htm.

state of the art, not the stasis of the art. We will therefore welcome engagement with thorny issues such as downcycling and e-waste, rather than shunning them.

Certain positive measures can be already be foreseen. For example, we will strongly favor suppliers of chemicals and objects that can engage in C2C-type takeback programs. In some cases we may be able to negotiate bulk-purchase agreements conditioned on takeback and recycling. We will not only continually monitor, analyze, and reinvent our own usage patterns, but will also encourage and empower profitable green engineering by developing new technologies, cataloging technologies and their costs, providing education and tools for good analysis, and presenting awards to companies that demonstrate new technologies. The keynotes will be tracking of materials, lifecycle analysis of products, and constructive engagement with manufacturers and suppliers.

As an institution, Greenway College will not participate in legislative lobbying or political activism (though our individual community members will, of course, do as they please). Rather, Greenway will work strictly within the parameters of technology and markets. We believe that good design, uncoerced social conscience, and market forces will join to make our demonstrations and quest a successful one.

Organic Wastes and Wastewater

Graywater (mildly contaminated water), blackwater (sewage), kitchen wastes, and other organic materials such lawn clippings and agricultural leftovers have one thing in common: bacteria love them. Our waste is their feast. By various methods, including compost heaps and anaerobic (no-oxygen) digester tanks, such wastes can be made harmless and useful at the same time: waste becomes a resource.

When bacterial digestion takes place in the absence of oxygen, as it typically does in liquids, the major gaseous product is methane (CH_4), a useful fuel. Biodigestion is widely used across Europe, and New York City already harvests half the methane released by its vast wastewater-treatment system and burns it to generate about $10 million of electricity per year.[16] Aerobic composting allows oxygen-breathing (aerobic) bacteria to do a similar job and produces carbon dioxide rather than methane. (Wetter composts, or large piles, can produce some methane.) In general, liquids containing organic waste are *anaerobically* digested, reducing waste to methane, while solid wastes are composted *aerobically*, producing generally carbon dioxide. In particular, aerobic composting produces temperatures on the order of 70º C (160º F), which kill pathogens (bacteria, viruses, fungi, parasites) and plant seeds from organic wastes (including human excrement and food wastes). Both kinds of composting transform unpleasant, troublesome wastes into reduced volumes of potentially useful solid residue.

The solid residue from a properly designed anaerobic digester or compost system has no offensive odor, contains fewer harmful bacteria than its inputs (or none), and, depending on source material and process, can be used as fertilizer, a soil amendment, or animal bedding. Recology, a company that composts 10,000 metric tons of material for San Francisco each year, sells most of its rich, black product at a premium to the California wine industry.[17] Your last glass of California merlot probably consisted, in part, of recycled restaurant scraps . . . proof that the zero-waste economy will not be without its pleasures.

In theory, 55 to 70 percent of the weight of a typical

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[16] Mireya Navarro, “City Is Looking at Sewage Treatment as a Source of Energy,” *New York Times*, February 8, 2011, accessed December 2, 2011, http://www.nytimes.com/2011/02/09/science/09sewage.html.

[17] Jim Carlton, “San Francisco Garbage Helps Make Vineyards Thrive,” *Wall Street Journal*, October 31, 2011, accessed December 2, 2011, http://online.wsj.com/article/SB10001424052970203633104576621633242608082.html.

municipal waste stream—which Greenway's will resemble—can be composted.[18] Not all of it may be ideal, however, as it may contain impurities. As with various other forms of recycling and zero-wasting, separation earlier in the stream and decreasing the mingling of disparate materials increases recovered-material purity and therefore value while decreasing downstream processing costs.

Greenway will employ a mix of well-tested technologies to recycle valuable organic materials. Humus from composting will be sold to gardeners or farmers or else used for on-campus farming and landscaping. An anaerobic biodigester will process blackwater (sewage) into useful methane and harmless compost, and can also be fed with cellulosic materials such as wood harvested sustainably on-site and paper. Methane can be either burned directly for heat and power (releasing CO_2 in the process) or "reformed" to produce CO_2 and hydrogen, where the latter can be used as an ultraclean fuel in fuel cells and engines. Greenway may, in fact, choose to put *all* its organic solids into biodigestion, to squeeze the maximum fuel and compost value out of every ounce; but such decisions will depend on engineering analysis during preconstruction campus design.

Wastewater processing is most effective when graywater is pre-separated from blackwater, because graywater is about 50 to 80 percent of residential wastewater, has a much lower nitrogen content, can be stabilized faster, and contains far fewer pathogens. Graywater treatment options include landscape irrigation, greenhouse infiltration beds, or constructed wetlands. These methods process the graywater in a shorter time than needed for effective blackwater treatment and can also be visually attractive.

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[18] Mitch Renkow and A. Robert Rubin, "Does Municipal Solid Waste Composting Make Economic Sense?" in *Waste Management and Planning*, ed. R. Kerry Turner, Ian Bateman, and Jane Powell (Cheltenham, UK: Edward Elgar Publishing Ltd., 2001), 15–38.

Greenway will find a high-grade use for every ounce of organic matter produced on campus, from potato peels to poop. Every gallon of water Greenway releases to its environment will be at least as clean as when it was pumped in.

Hazardous Waste

Waste is deemed "hazardous" if it is flammable, reactive, corrosive, toxic, or radioactive. Our ultimate goal is to produce zero hazardous waste not only on-site, but throughout the supply chains of all foods and manufactured products consumed on campus. A realistic first goal, however, will be zero on-site hazardous waste production coupled with *minimization* of hazardous-waste production by upstream suppliers.

Most hazardous "wastes" are actually valuable resources, and their disposal can be expensive. It is therefore often in the financial interest of an industry to recapture and consume all such materials. Even apart from the financial incentives for reducing hazardous waste, in many instances it is only a matter of proper engineering and design to manufacture products while producing zero hazardous waste. Greenway will push for cleaner production while helping manufacturers understand its technology.

Air Pollution

Most air pollution consists of the six "criteria" pollutants that the Clean Air Act requires the Environmental Protection Agency to regulate: sulfur dioxide (SO_2), nitrous oxides (NO_x), carbon monoxide (CO), ozone (O_3), lead, and particulates (soot, smoke). Air pollution drains between $71 billion and $277 billion from the US economy per year, over 95 percent of it in health costs.[19]

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[19] "Pollution: Costs of Inaction," *OECD Observer* 263, October 2007, accessed December 1, 2011, http://www.oecdobserver.org/news/fullstory.php/aid/2351/.

We will produce zero air pollution on Greenway College campus and will work at first to minimize—ultimately, to zero out—air pollution in the manufacture of the products we purchase. We will record emissions produced during manufacture of products used at Greenway and maintain an up-to-date, open-access record of these data on the college website. The list will be broken down into lifecycle emissions from purchased products and any on-site emissions. Indeed, web pages will be maintained for all waste products, energy consumption and production, and other inputs and outputs of the campus system. These dashboard-type accounting tools will make Greenway's successes and challenges transparent to the community, encouraging and informing efforts to improve.

Carbon dioxide, CO_2, falls into a special category. Until a few decades ago, CO_2 was not considered a pollutant at all, since it is a natural part of the Earth's atmosphere. However, even clean, fresh water must be considered a problem—call it a "pollutant" or whatever you like—if you are drowning in it. Drastic increases in human-caused CO_2 output since the mid-nineteenth century, mostly from fossil fuels, have increased CO_2 in the atmosphere by almost 40 percent over its preindustrial value, to a level not seen in fifteen million years.[20] In recent years the rate of increase of global emissions has accelerated, and there is no end in sight.[21] Some activities at Greenway will inevitably release some $CO_{2,}$ but others will utilize $CO_{2,}$ such as plant life, including an appropriately sized on-campus woodland, which can be sustain-

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[20] "Last Time Carbon Dioxide Levels Were This High: 15 Million Years Ago, Scientists Report," *ScienceDaily*, October 8, 2009, accessed December 2, 2011, http://www.sciencedaily.com/releases/2009/10/091008152242.htm.

[21] "CO_2 Increase in Atmosphere Accelerating," Associated Press, November 21, 2011, accessed March 15, 2012, http://www.cbc.ca/news/technology/story/2011/11/21/environment-wmo-greenhouse-gas.html.

ably managed for forest products, recreation, wilderness, and wildlife—allowing for on-site net zero CO_2 emissions.[22]

The largest US source of air pollution (all types included, not just CO_2) is energy generation—burning of coal for electricity and gasoline for transportation. However, Greenway's zero grid-electricity plan (see chapter 2) and energy storage plans (see chapter 3) will ensure the production of zero electricity-related and transportation-related emissions including zero net CO_2 emissions.

The Never-Ending Quest

Zero output of waste—gaseous, liquid, and solid, whether on campus or in the network of supply—will be a continuing challenge to attain. Indeed, it is a part of the zero-waste program to always be striving toward complete elimination of waste and moving toward maximal resource utilization. Our journey toward zero waste will be just beginning when Greenway opens its doors. The zero-waste mission will never be absolutely achieved because opportunities will multiply, rather than be used up, as technology progresses. A large part of Greenway's mission will be to apply, develop, and learn from zero-waste processes, technologies, and design principles through many decades to come.

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[22] Simultaneous management for all these values is feasible: see R.W. Malmsheimer et al., "Managing Forests Because Carbon Matters: Integrating Energy, Products, and Land Management Policy," *Journal of Forestry*, October–November 2011, accessed December 2, 2011, http://www.safnet.org/documents/JOFSupplement.pdf.