

Greening MIT:

Generating Indicators for Campus Environmental Management

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Abstract:

To reduce environmental impacts, organizations must first gain a sense of how their activities affect their surroundings. Operations that impact the environment include purchasing, production, waste disposal, and material processing. Environmental management systems help organizations consider the unique consequences of these activities and control the ecological impacts associated with them.

Colleges and universities have a special role to play in modeling environmental management's best practices. By implementing carefully crafted management systems that consider the use, reuse, and recycling of resources, universities such as MIT can practice what their environmental curricula teach. When practice and teaching are consonant, universities serve as a model that tomorrow's leaders can follow to affect further institutional change. This thesis considers the topic of campus environmental management, examining in particular the question of how MIT might audit the ecological impacts associated with its operations.

The document begins by surveying auditing tools and exploring environmental indicator design. Its penultimate discussion proposes a set of indicators that support the Environmental Program Office's current information management efforts. After considering the value and feasibility of implementing the recommended indicator suite as an environmental management tool, the document concludes with a discussion as to how future indicators might approximate campus sustainability. Appendices catalogue cross-institutional indicator information, indicator calculation procedures and student projects that will facilitate indicator calculations, and campus impact data sources that may be useful for informing the suggested projects.

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Terms Defined

The following terms are integral to this discussion.

Environmental Management:

Monitoring and controlling ecological impacts. Implicit in environmental management is the concept of stewardship, which emphasizes the conservation of vulnerable resource stocks. In a broader sense, stewardship incorporates the holistic treatment of organizational relationships with nature. Eagen (1992a) states that effective stewardship “requires a long term commitment to the tasks of acquiring data and monitoring change.”

At times, this document denotes environmental management using the acronym “EM.” To dispel any confusion, it is emphasized that “EM” signals the phrase “environmental management,” not “electro-magnetism.”

Environmental Indicator:

“A parameter or value that describes the state of a phenomenon, environment, or area, with a significance extending beyond that directly associated with a parameter value” (OECD, 2001a). Another definition posits that indicators signal changes in either anthropogenic environmental pressure or the state of the environment (Kuik and Verbruggen, 1991a). The purpose of indicators is to provide strategic EM information by simplifying the approximation of campus ecological impacts. This thesis uses the terms environmental indicators and ecological indicators interchangeably.

Ecological Efficiency:

Minimizing services’ consumption intensity through the prevention and recycling of wastes (Strong, 1997). To date, incremental measures intended to improve eco-efficiency remain the hallmark of environmental sustainability initiatives (Breyman, 1998).

Sustainable Development:

Several definitions of this term exist, most of which conceptualize sustainable development as a set of social, economic, and environmental goals (Kuik and Verbruggen, 1991b; Landres, 1992). This thesis adheres to the following meaning: “Development that meets the needs of the present without compromising the ability of future generations to meet their own needs” (Our Common Future, 1987). At times this document denotes sustainable development as “SD.”

Chapter 1: Campus Environmental Management

1.1: Institutional Ecological Impacts

Colleges and universities consume fuel, water, and other material resources and dispose of them as effluent, emissions, runoff, and solid waste. Successfully managing campus impacts depends on the measurement and reporting of strains associated with these ecological loads. The impetus to collect this information - “what is measured is managed” (OECD, 1999a) - is a fundamental motive of institutional auditing efforts.

As towers of cultural innovation, technological prowess, and social responsibility, colleges and universities have a unique obligation to be conscientious of their ecological impacts. Orr (1992) describes their role, noting that “institutions purporting to induct students into responsible adulthood should themselves act responsibly toward Earth and all its inhabitants.” Responding to the call, academic institutions have turned to the campus audit as their standard environmental information management tool. Audits construct impact comparisons that track institutional performance over time.

Environmental management (“EM”) then is the process of monitoring ecological impacts to inform operational reforms. Implicit in environmental management is the concept of stewardship, which emphasizes the conservation of vulnerable resource stocks and more generally inculcates the holistic treatment of organizational relationships with the natural world. Eagan (1992a) affirms that effective stewardship “requires a long term commitment to the tasks of acquiring data and monitoring change.”

To fully discuss environmental management, one must also engage the topic of sustainable development (“SD”). Several definitions of SD exist, most of which conceptualize sustainable development as a set of social, economic, and environmental goals (Kuik and Verbruggen, 1991b; Landres, 1992). This thesis adheres to the following meaning: “Development that meets the needs of the present without compromising the ability of future generations to meet their own needs” (Our Common Future, 1987).

EM approaches sustainable development or SD incrementally, encouraging iterative environmental impact reductions that improve organizations’ ecological efficiency.¹ Numerous works (Keniry, 1995; Orr, 1992a, 1992b) suggest that academia transcend conventional EM aims and make more holistic commitments to engender sustainable development. However, sustainability is a nebulous problem; many possible scenarios fall under the scope of sustainable development but few, if any sustainable systems exist (Bell and Morse, 1999). Therefore at this time sustainability is probably better conceived as a process rather than a goal and auditing campus sustainability may be ill-advised.² Accordingly, this thesis will limit its purview of sustainability topics,

¹ Sustainability is a frontier for ambitious environmental management programs.

² Bell and Morse (1999) criticize the entire premise of SD measurement, claiming that “the idea of measuring sustainability in absolute, traditional, reductionist terms, as with sustainability indicators, is non-viable. It cannot be done because sustainability itself is not a single thing.” Generally, the ill-defined nature of sustainability problems confounds the identification of methodical guidelines for SD reporting, and

seeking instead to examine the information management tasks associated with auditing MIT's environmental impacts and management practices.

The document continues as follows: Chapter 2 surveys topical literature regarding campus auditing and environmental indicator measurement. Chapters 3 and 4 explore indicator design methodologies evident from literary and practical perspectives. The former highlights common indicator design recommendations forwarded by academics and policy makers engaged in creating current indicator sets. The latter assays indicator tracking efforts on nine other campuses to survey how design methodologies work when their products are incorporated into campus EM efforts. Generally, both chapters seek to flesh out sample indicators and logistical considerations made in support of indicator tracking, and do so by making the following inquiries: Which indicators does academia recommend? What indicators do other campuses employ? How do these indicators process information? If quantitative, how are the indicators normalized? How are they organized, categorized, and presented? Resultant indicator findings are inventoried in appendix A.

Chapter 5 establishes a methodology with which to prepare EM indicators for MIT, summarizing indicator methodologies apparent from the previous two chapters and selecting from them design criteria that are appropriate for describing MIT's campus-specific impacts. The chapter also notes points on which its selections diverge from prior indicator practices, demonstrating how existing campus auditing techniques might be manipulated to improve indicators' value as campus EM measurement tools. Chapter 6 then assesses the unique ecological impacts associated with MIT campus operations, providing normative assessments and statistics concerning environmental legislation, responsible campus management departments, pressure loads, and management responses associated with different ecological impacts.

Chapter 7 advances a set of indicators tailored to inform environmental management at MIT. It also recommends an overall presentation style so that the indicator suite allows for time series tracking of EM performance. The chapter packages indicators in categories and augments individual measures with alternative indicator possibilities, arguments to defend their EM relevance, and descriptions of their parameters. Categories are accompanied by a catalogue of recent campus conservation projects and future project horizons for responding to the campus impacts they consider.³ Additionally, the chapter discusses evidence of how certain indicators might approximate campus sustainability.

measurement difficulties arise in estimating the economic and social aspects of sustainability that more limited environmental management efforts do not survey. In the absence of scientific tools to approximate campus sustainability, EM measures are presumed valuable for their incremental approach of ecologically sustainable development. For this reason, this thesis will focus on developing environmental indicators rather than sustainability indicators.

³ The discussion of these operational elements is derived from interviews with members of the Departments of Facilities and Procurement, the Environmental Programs Office, the Environmental Health and Safety Office, and the Parking and Transportation Office, and the data sources listed in Appendix C.

Chapter 8 restates the indicator suite and examines the value of the selected indicator set, reviewing important constraints on indicators' descriptive power, reliability, and utility for identifying specific campus EM opportunities. The chapter also notes linkages among proposed indicators to observe how the recommended indicator suite acts as a system and discusses the institute's current measurement capacity in order to evaluate the feasibility of collecting the recommended indicator information. Ideas for further refining the recommended indicators complete the chapter's valuation exercise.

Chapter 9 delivers closing remarks as to how MIT's environmental management practices might further engage issues of campus sustainability. Specifically, it surveys existing eco-efficiency projects that seem to make considerations for sustainability, assays courses of action that will improve campus sustainability, and suggests how future indicator sets might better approximate issues relevant to developing a sustainable university.⁴

1.2: Project Value

This thesis may be of value to the Department of Facilities, the Environmental Programs Office, and the Environmental Health and Safety Office (herein designated "EPO" and "EHS," respectively). It should be particularly helpful to the Environmental Programs Office (EPO), which is charged with mitigating campus ecological impacts and is sponsoring this endeavor as a project client, because the final product will help program managers establish campus-wide priorities for funding eco-efficiency improvements.⁵ Steve Lanou, Director of Campus Sustainability Initiatives at EPO, believes that this project will serve to "better identify and understand the complex relationships between our resource use, campus operations, community responsibilities, and our Institute's core education mission."

The act of publicizing the state of campus environmental affairs should also stimulate interest among the student body, which will be pleased to know that MIT has made considerable EM progress and wishes to pursue further environmental responsibility. The DUSP community and activism-oriented students in particular will also benefit from the list of further EPO consultant partnership opportunities tendered in appendix B. The broader university community engaged in auditing other campuses should find the discussion presented useful for reexamining their own efforts as well.

More generally, all of those interested in sustainable development should appreciate the accumulation of knowledge that might help large organizations like higher

⁴ This report makes no attempt to calculate the submitted indicators, as the time and energy required to determine these values go beyond the scope of an undergraduate thesis. However, it is essential that indicator values be tabulated to initiate the processes of campus measurement and performance evaluation. Therefore, in lieu of making specific calculations the document's final appendices examine further student work needed to facilitate indicator measurement and useful sources for gathering campus resource consumption and waste generation data.

⁵ Currently, campus indicator tracking is limited to officers applying indicators to monitor individual impacts.

education institutions become more sustainable. Affecting change in these vast operations makes appreciable strides towards environmental sustainability.

Chapter 2: The Auditing Process

2.1 Prominent Auditing Mechanisms

Scholars report on multiple environmental auditing mechanisms. Among them are embodied energy measurements, life cycle costs accounts, green house gas inventories, ecological footprint analyses, and environmental indicators. To consider these mechanisms' utility to managerial efforts, it is important to note what results they deliver and which aggregate decision-making levels they might best inform.⁶

Embodied energy analyses measure the energy consumed in the course of a production process (Federici. et al., 2003; Spangenberg, 2002). Manufacturers are typically interested in conducting embodied energy analyses to identify modifications to energy-intensive production phases.

A logical extension of embodied energy analysis is the practice of life cycle cost accounting. This auditing mechanism estimates an item's true `cost over its functional lifetime (development to disposal), including payments tendered for acquiring and displacing production inputs and outputs (Schulze and Frosch, 1999). Life cycle cost accounts are more comprehensive than embodied energy audits, which fail to incorporate devices for tracking non-energy consumption data like water use information. However, like their counterparts life cycle cost accounts cannot address the full range of campus EM decisions because their figures address item costs and not environmental impacts.⁷

More complex auditing tools such as green house gas inventories and ecological footprint analyses assimilate accounting strategies similar to embodied energy and life cycle cost assessments but process information differently to increase their measurement scope. Green house gas (GHG) inventories arose in response to the scientific community's warnings of climate change and are designed to enumerate the climactic impacts of consumption behavior.⁸ These inventories provide two useful snapshots of institutional environmental management dynamics. First, energy-related expenditures leading to greenhouse gas emissions are likely an institution's most significant environmental impacts (Groode, 2004). And second, comprehensive green house gas audits, like other successful EM investigations, must consider impact contributions from sources as diverse as power generation, transportation use, and waste incineration. Unfortunately however, GHG inventories cannot stand alone as complete campus audits since emissions statistics do not fully capture other operational consumption profiles such as water and material use.

⁶ Though not all of these instruments are appropriate for campus monitoring, discussing them helps to familiarize the subject of campus environmental information management.

⁷ Such cost analyses are useful, however, for informing more compartmentalized campus operating decisions like procurement choices and selections among alternative building design scenarios.

⁸ Tiffany Groode conducted a GHG inventory as part of her 2004 Mechanical Engineering Master's thesis, fulfilling the institute's obligation to perform such an audit under Cambridge's municipal Climate Protection Plan.

Ecological footprints assemble more complex findings than the other auditing tools discussed so far. Similar to environmental space measurements (Hille, 1997; Spangenberg, 2002a), footprint analyses quantify areas' capacity to provide for their inhabitants' resource consumption and waste discharge activities (Wackernagel and Rees 1996; Wackernagel and Yount, 1998). Examples of footprint measurements include productive ocean and land areas necessary to support processes like power generation and assimilate resulting carbon dioxide emissions. Therefore, the ecological footprint tool bundles a complex data set into an easily processible figure, aggregating diverse impact measurements into a one-dimensional acreage quantification. (Bossel, 1999).⁹

Several factors indicate that ecological footprint analyses can be precarious analytical instruments despite their apparent utility to campus EM. First among these are data quality concerns, as current calculation methodologies are anything but scientific. For instance, Hille (1997) criticizes footprinting's assemblage of a composite acreage index that groups different impacts using arbitrary factor weights. Van den Bergh and Verbruggen (1999) specify the critique, noting that footprint methodologies weigh environmental impacts from infrastructure land uses and agricultural land uses equally. Clearly, this aggregation methodology oversimplifies the diverse intensities of environmental impacts resulting from these two very different land use activities.¹⁰ Hille further notes that footprints employ complex material use quantifications to approximate waste disposal activity, the amortization methods among which may not be grounded in strong scientific underpinnings. Moreover, a recent footprint survey of national ecological impacts reports that the global footprint currently eclipses the total land mass available within the biosphere (Van den Berg and Verbruggen, 1999), which casts doubt as to whether the figure demonstrates a true exceedance of threshold yields or the inaccurate predictions of faulty measurement tools.

Utmost among footprints flaws, however, is the deliverance of largely inoperable EM information. One need only assume a manager's perspective to imagine the limited utility of a vast acreage impact figure to campus EM efforts. To a manager concerned with accumulating information that could illuminate potential eco-efficient facilities projects, index figures claiming that his or her university's ecological footprint is many times its campus size are trivial notations (Dalal-Clayton and Bass, 2002).¹¹ Furthermore, footprint figures may be particularly useless to urban campus managers whose grounds might seem disjointed from distinct ecosystem communities.¹² Ecological

⁹ Footprint analyses also report footprint contributions from impact categories. This extra reporting layer is key to environmental management planning since compiling compartmentalized impact data facilitates the identification of priority environmental action areas. Several municipal entities, including the city of Santa Monica, California and the County of Sarasota, Florida, now track their ecological footprints, wielding the tool for these very same purposes of impact prioritization. The University of Newcastle, Australia also tracks its impacts using the footprint tool.

¹⁰ Soil erosion, contaminant runoff, and atmospheric emissions, to name a few.

¹¹ Bartlemus notes that "the purpose of complex indicator indices may indeed be more to provoke by shocking sum totals than to provide statistical support for decision making" (Bartlemus, 1999).

¹² Distinct connections between urban campus operations and the state of surrounding ecosystems may seem diluted by the ancillary impacts presented by nearby populations. This limits the value of environmental state information to campus managers and receives further mention in the indicator design process undertaken below.

footprints may generally be more relevant to larger scale EM efforts, such as those conducting municipal audits, than to more isolated campus management exercises.¹³

Environmental indicators are the last auditing mechanism worthy of exploration. An environmental indicator can be defined as “a parameter or value that describes the state of a phenomenon, environment, or area, with a significance extending beyond that directly associated with a parameter value” (OECD, 2001). Another definition places environmental indicators as quantitative descriptions of changes in either anthropogenic environmental pressure or the state of the environment (Kuik and Verbruggen, 1991a). Indicators are perhaps the most informative and scientific instrument for campus auditing because they employ a range of topics, descriptive methods, aggregation techniques, and presentation styles (GRI, 2002; Hammond et al., 1995).

The following example more clearly illustrates indicators’ potential application to specific campus management scenarios. A facilities engineer, pondering how to reduce cogeneration system costs and resource use, might consider cogeneration practices such as those outlined in the boiler profile below. From his analysis he might identify the annual CCF of potable water injected to cool the boiler chamber and the CCF of associated waste water, or blow down, that the process expels. Knowing the combined costs of water provision, sewage disposal, and auxiliary expenses to be incurred during waste water recapture, the engineer could then estimate the potential dollar and water savings achievable from filtering and recycling blow down as boiler coolant. Provided that necessary appropriations were available, the project would most likely receive serious consideration if its savings repaid capital outlays within a four or five year investment horizon.

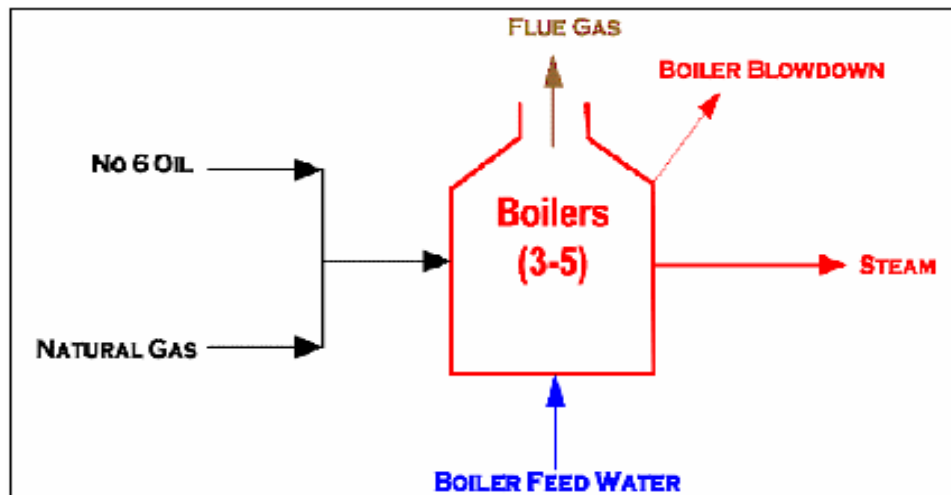


Figure 1: Cogeneration Plant Boiler Diagram (Groode, 2004)

But where do indicators fit into this process? The answer is simple: if comprehensive indicator measurements were available, the manager in question would likely have arrived at the selection of a boiler coolant recapture project because indicator

¹³ Municipal analytical efforts are better informed by ecological footprints as they encompass extensive boundaries that can assimilate important, otherwise transboundary biological areas (Van den Berg and Verbruggen, 1991c).

data gauging current managerial performance would have steered him toward that particular water efficiency opportunity.

Environmental indicators serve one of three purposes, (1) expressing anthropogenic pressures from consumption activities, (2) measuring environmental states like resource stocks and biodiversity, or (3) quantifying human responses to environmental stresses. These purposes are most commonly described by the United Nations Organization of Economic and Cooperative Development (herein referred to as “OECD”) pressure-state-response model (OECD, 1999a, 2001; Rennings and Wiggering, 1997; Therivel and Rosario Partidario, 1996). Other names have come to characterize their roles as well; for example, pressure indicators are frequently dubbed stresses, or loads (Dalal-Clayton and Bass, 2002; Rump, 1996), state indicators are sometimes referred to as synoptic indicators (World Bank, 1997), and response indicators are also known as performance measures (Spangenberg et al. 2002). The organizational model below documents the relationships between pressures, states, and responses, noting that each is a function of the other.

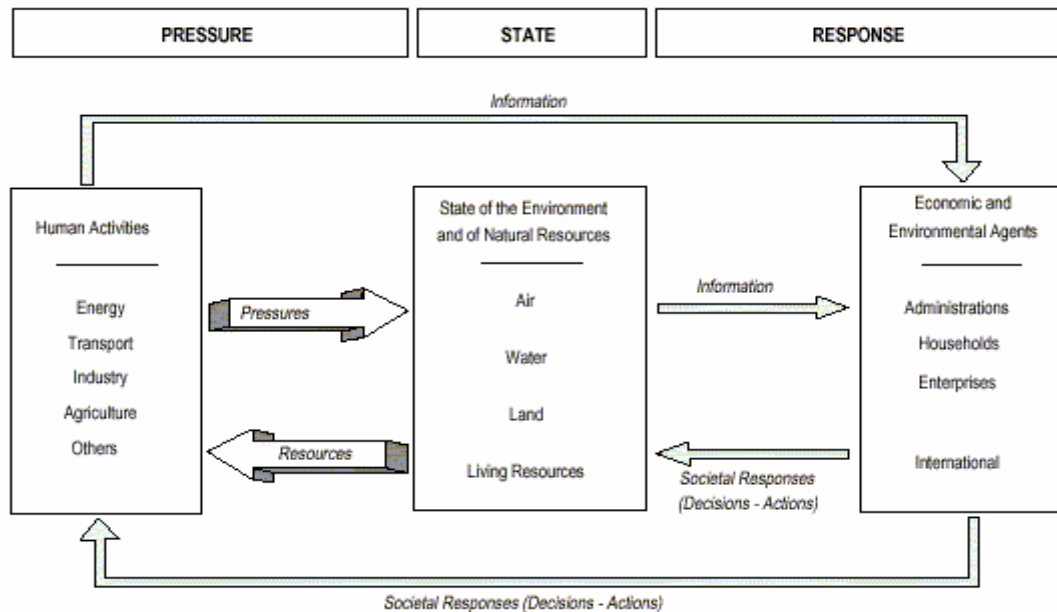


Figure 2: The Pressure State Response Model (OECD, 1994)

Though the PSR classification system is a simple first order ecological cause and effect model (Bossel, 1999; Hille, 1997; Hukkinen, 2003), the PSR construct remains an appropriate, functional guidepost for baseline environmental indicator projects because further groundwork must be laid before the Institute’s practices can make use of more sophisticated indicator frameworks.¹⁴ In the absence of a more practical classification

¹⁴ Many sophisticated sustainability models exist but some of the measurement infrastructure needed to make SD approximations is not currently in place at MIT. So, it seems logical to limit the application of sustainability indicator frameworks in this design exercise and lay further measurement groundwork before adopting those more sophisticated models.

scheme suitable to preliminary indicator tracking efforts such as that undertaken here, this thesis relies on the pressure state response model to guide indicator generation.

Indicators operate by way of different factual separation mechanisms, delivering either nominal, ordinal, or cardinal measures (Spangenberg et al. 2002). Nominal indicators usually affirm or deny some characterization, ordinal indicators signal placement within ranks, and cardinal indicators relay distances from preordained targets. Surveys as to whether an institution has certain programs in place relay nominal information, quantile impact reduction statistics provide ordinal data, and disparities between consumption patterns and maximum sustainable yields are cardinal measures.¹⁵ In relation to the table above, nominal indicators might document environmental state information, ordinal indicators might be applied as pressure measurements, and cardinal indicators can employed as gauges of managerial response.

Audits conducted from more limited EM perspectives tend to rely more heavily on quantitative indicators while their sustainability counterparts balance qualitative and quantitative reporting. Differences in goal orientation explain this phenomenon; while environmental management efforts are likely to center on conservation opportunities embedded in linear, once-through resource flows, sustainable development efforts consider possibilities for cyclical feedbacks across social, economic, and environmental systems (Curwell and Cooper, 1998). As a result, sustainability reporting systems that attempt to describe broader and more abstract concepts contain many non-quantifiable elements that rely on nominal descriptions.¹⁶ Because they are more quantifiable, environmental indicator sets generally provide more powerful management tools than sustainable development indicator suites.

Besides bearing in mind project goals and classification types, indicator design methodologies must also consider the task of data aggregation. A fundamental issue in indicator reporting is whether to assemble data as absolute or normalized figures (Global Reporting Initiative, 2002; Hamilton, 2004). This is an important consideration because figures that deliver, for example, absolute campus water consumption data help to track total gallon usage over time, but ignore variable underlying trends such as student populations and built space totals that might be driving fluctuations in consumption behavior (Green et al, 1992). Without being responsive to possible fluctuations in these and other underlying trends, indicators cannot distill policy performance approximations.

Another aggregation concern is whether to compound indicators into lists or indices. Oopscher frames this dilemma best, submitting that managers must decide whether indicators will be true aggregates or transformations of other, more specific indicators (Kuik and Verbruggen, 1991b). Indicator lists, sometimes called suites, separate indicators into impact categories that recognize the uniqueness of individual indicators' reporting subjects and measurement units (Dale and Beyeler, 2001; Nilsson and Bergstrom, 1995; World Bank Report, 1997). Indices apply reductive techniques,

¹⁵ Sustainable yields advance thresholds against which consumptive sustainability can be gauged.

¹⁶ These might for instance explore institutional capacity issues.

agglomerating diverse indicator measurements into more palatable, singular statistics (Bossel, 1999).

Both of these accrual methods can be misleading because of analytical flaws. More specifically, indicator lists frequently present indicators that are interdependent (Dalal-Clayton and Bass, 2002; Gustavson, 1999; Lopez-Riduara, 2002; OECD, 2001) and often feature categories with inconsistent numbers of component indicators, which may not consider different impact areas equally (Bossel, 1999). Lists can also be either too short and non-descriptive or too long and unwieldy (Gustavson, 1999; Hammond, 2004; Hille, 1997).¹⁷ In contrast, indices too often employ opaque operations, applying faulty factor weighting methods to deliver aggregate figures whose units bear little resemblance to their underlying metrics (Dalal-Clayton and Bass, 2002; Hammond, 2004; Hille, 1997; Rump, 1996).¹⁸

Presentation style is another distinguishing indicator characteristic, as indicators efforts frequently deliver data by transforming static figures into signals of programmatic efficacy. Common presentation styles include barometers, gauges, numerical ranking scales, and report cards (Aalfs et al., 1998; Hammond et al., 1995; OECD, 1999b; Shriberg, 2004), all of which analyze fluctuations in indicator value to deliver time series performance assessments (Uhl, 2004). Differences among these presentation styles arise principally from their methods of signaling directional changes. For instance, barometer indicators and some report cards characterize policy manifestation as improving, stagnant, declining, or more or less sustainable (Bell and Morse, 2003), while ranking scales like green grade point averages assign numerical values to signal change. Generally, the strongest presentation methods avoid the designation of arbitrary quantities, limiting their focus instead to the more nominal signaling of programmatic direction.¹⁹

2.2: Summary

Reexamining other environmental measurement tools helps to contextualize the indicator characteristics mentioned above. It should be evident from the discussion presented so far that embodied energy analysis and life cycle costing procedures approximate environmental pressures resulting from production, normalizing impacts by quantities of manufactured products. Green house gas inventories are indices that assemble, using global warming potential conversion coefficients (Cambridge City Climate Plan, 2002), pollutant emission loads into tons of carbon equivalents. Ecological

¹⁷ Bell and Morse (2003) characterize the choice of indicator numbers as a necessarily arbitrary science.

¹⁸ Even sophisticated aggregation weighting methods like multi-criteria analysis can fail to approximate environmental factor loadings scientifically (Lee, 2004). Furthermore, indices can fail to report important data because of their basic emphasis on aggregation. Gallopin notes that “the development of highly aggregated indicators is confronted with the dilemma that, although a high level of aggregation is necessary in order to intensify the awareness of problems, the existence of desegregated values is essential in order to draw conclusions for possible course of action” (Moldan et al., 1997)

¹⁹ Utilizing directional performance indicators also meshes well with the premise of contemplating sustainability as a process, not an end goal.

footprints transcend these more constrained environmental management concerns, indexing a single acreage figure that internalizes both ecological strain and carrying capacities. Regardless of their scope and purpose, all of these tools derive their long-term management value from their capability to track impact reduction progress over time.²⁰

Environmental indicators are the most suitable campus auditing tools, leveraging many other mechanisms' functional characteristics while avoiding many of the analytical shortfalls that they incur. However, it is worthwhile to note indicator shortfalls to be cognizant of potential indicator design mishaps. Critiques center on indicators' data parsing approach and subsequently, their relevance, claiming that statistics relating whole building energy use are less useful for identifying efficiency opportunities than detailed figures like appliance power demand factors comprising building energy use profiles (Creighton, 1998).²¹ Bearing such criticism in mind, the indicator design process can be tailored to resolve many of shortcomings that often hinder indicator functionality.

²⁰ None of these are appropriate campus management tools because they best approximate systems with boundary conditions that are either more narrow or broad than campus operations.

²¹ These comments address the fundamental matter of information specificity, which herein shall be referred to as information resolution. Admittedly, information of greater resolution will be more useful in helping managers to prioritize among efficiency upgrade opportunities, but information addressing higher aggregate levels remains of value to informing directors leading thorough campus auditing efforts. There is clear potential for a sophisticated indicator suite to reflect the current success of and new directions for campus environmental management.

Chapter 3: Indicators Employed by Other Colleges and Universities

This chapter surveys indicator efforts at nine higher learning institutions, contextualizing by way of case methods how commonplace methodologies are applied in practice. It build an understanding of how design affects indicator function, illuminating indicator possibilities that will ultimately inform the selection of auditing tools for MIT.

The audits considered consist of indicator efforts from Michigan State University, Oberlin College, Pennsylvania State University, Tulane University, and the Universities of California at Los Angeles, Florida, Michigan, North Carolina at Chapel Hill, Pennsylvania, and Vermont.²² These reports employ a range of qualitative and quantitative instruments and feature commitments to either environmental or sustainability measurement. All labor by similar approach however, cataloging institutional goals, documenting the effects of current policies, and considering possibilities for future management initiatives.

3.1 Sample Audits

The Michigan State University Campus Sustainability Report

In keeping with its sustainability orientation, the Michigan State report assembles a suite of economic, environmental, and social indicators. The numerical devices among these illustrate a number of pressure metrics typically employed in ecological auditing: energy consumption,²³ emissions (tons), hazardous waste disposal (tons), sewage load (gallons), impervious storm water generation areas (square feet), waste generation (cubic feet to landfill) and water consumption (gallons, irrigation gallons). The study also reports on transportation activities like commuter vehicle use (vehicle mode shares) and average commute distance (mileage).

The bulk of indicators submitted are pressure indicators, but the report also forwards some response indicators. These signal material recycling (tons), composting (cubic feet), and surplus exchange sale performance (\$). Including such information strengthens the environmental sustainability component of the measurement effort, since these reflections on waste reduction, reuse, and recycling progress consider fundamental sustainable development strategies.²⁴

Oberlin and the Biosphere: A Campus Environmental Audit

Oberlin's study assesses campus environmental management progress and opportunities. The report makes several campus eco-efficiency measurements, exploring in particular the application of normalization by built space. It also evaluates individual campus buildings' energy consumption profiles and building-specific efficiency

²² These initiatives were selected for their innovative indicator preferences and availability in report form.

²³ Measured in British Thermal Units (BTU). Herein, units appear in parentheses after their parameters.

²⁴ These response variables apply a systems perspective to EM, gauging institutional success in closing resource flow loops to achieve cyclical, rather than linear consumption behavior.

investment payback horizons. This compartmentalized information is more valuable to managerial efforts than campus-wide consumption figures, because managers empowered by such data can more easily distinguish opportunities for eco-efficiency reconfigurations within the campus building portfolio.

The audit also ponders barriers to further campus eco-efficiency improvements. Among the barriers cited are procedural difficulties in interpreting campus consumption data²⁵ and perverse incentive structures that do not hold individual campus departments fiscally responsible for their consumption behavior.

The Penn State Indicators Report: Steps Toward A Sustainable University

The Penn State Green Destiny Council study covers much the same topics as the Michigan State University report in evaluating university sustainability. In addition, it addresses important environmental indicator topics related to land use and the built environment. These describe subjects like impervious surface cover (% campus area that is impenetrable to runoff and precipitation) and green building practices (# buildings exhibiting green design principles).

The report's primary environmental indicator set also demonstrates appreciable measurement complexity, deploying some noteworthy normalization methods. It compares pressures like total campus energy and water consumption against per capita baselines and considers a per capita waste recycling percentage as well.²⁶ Other ratio methods employed lend the audit even finer resolution in management performance reporting, exploring specific driving force and procedural response indicators like % paper consumption reduction, % dining hall waste recycled, % campus vegetative cover devoted to native vs. exotic fauna,²⁷ and % of green space converted to parking spaces. These response ratios, coupled with support data measuring stressor composition (e.g. a pesticide use by hazardous category profile) help to elucidate problematic stresses and facilitate the identification of actions that can relieve them.

The Penn State effort bears one last notable distinction: its graphical assessment of management performance in specific issue sectors. For each indicator delivered, the report provides a barometer mechanism labeled by thumbs up or down designations to signal management progress or digression. Providing this additional directional indicator solidifies the value of individual indicators as baselines for approximating environmental change.

Greening the Campus: Institutional Environmental Change at Tulane University

²⁵ For instance, the report discusses underlying trends in building occupancy and water meter monitoring schedules that affect the time series interpretation of building water consumption figures.

²⁶ Normalized recycling measures communicate progress more effectively than absolute figures, as the latter measurements are only meaningful when compared against desired reduction targets in the first place.

²⁷ Xeriscape philosophies suggest that native fauna typically require less irrigation than exotic species.

Greening Tulane is a principally qualitative audit of campus EM actions. The document first describes ecological impacts from building practices, energy generation, food service, hazardous, medical, and solid waste management, procurement, and water distribution operations and then goes on to assay institutional programs and sectoral eco-efficiency opportunities. Heavily policy oriented, the audit makes few attempts to deliver information quantitatively, employing nominal indicators almost exclusively to gauge institutional response. Little if any pressure data is given.

Most intriguing about the Tulane Report is its allocation of a campus environmental grade point average (GPA) determined by individual progress scores across the aforementioned management sectors. Needless to say, the presence of a numerical ranking characterizing a set of qualitative findings is alarming and should raise concerns about the validity of a green GPA or any similar quantification system. And indeed, investigating the survey manipulation methods used to accrue individuals' approximations of institutional performance confirms that assigning a green GPA thusly is arbitrary and unscientific. Tulane's endorsement of the report card format points to the need to exercise caution not only in indicator selection, but also in indicator presentation.

In Our Own Backyard: Environmental Issues at UCLA, Proposals for Change, and the Institution's Potential as a Model

Perhaps the first campus indicator auditing exercise attempted, *In Our Own Backyard* is nevertheless a sophisticated endeavor. Far ahead of its time, the document delivers indicators measuring certain notions of sustainable development that later auditing efforts fail to consider altogether, such as percentages of total municipal water and energy loads represented by campus demand and the portion of campus built space illuminated by day-lighting projects. The former measures should be seen as synoptic pressure indicators that assimilate carrying capacity concerns and the latter an innovative response indicator delineating a refined-scale management opportunity.

The University of Florida Sustainability Indicators Report: The Greening UF Program

The University of Florida Sustainability report assembles various numerical indicator sets, the environmental indicators among which exhibit many free-standing, non-indexed metrics. It tenders important indicator design considerations, achieving aggregation simplicity in waste generation reporting (total kilograms hazardous and non-hazardous waste per capita) and an alternative land use quantification (acreage designated as conservation area). The study uses a Sustainability Trend, similar to the Tulane report card, to quantify campus managerial opinions of positive, neutral, or negative trend movement into values between -3 and 3.²⁸ Though the index shows some promise as a presentation method that recognizes trend directions, its method for quantifying opinion survey findings into numerical rankings again begs the consideration that assigns values arbitrarily.

²⁸ "3" designating strongly improved performance and "-3" documenting deteriorating performance.

Greening the Maize and Blue: The University of Michigan Environmental Task Force Advisory Report

Greening the Maize and Blue presents a simple suite of eight primary environmental indicators that is augmented by a set of auxiliary indicators that address some unique campus consumption issues. These include new response measures concerning the built environment (building utilization in terms of square foot floor space per capita, % of campus buildings that are LEED Certified,²⁹ and % of parking spaces provided in multiple deck parking garages³⁰) and campus transportation reliance (fleet fuel economy and college-related air miles traveled). In addition, the report explores yet unmentioned pressure indicators that achieve resolution improvements in measuring transportation energy use figures (BTU consumption by mode share) and land use (% campus area covered by green space).³¹

The University of North Carolina at Chapel Hill Campus Sustainability Report

The Chapel Hill report delivers principally nominal descriptions of university efforts across EM sectors. The audit does however deliver some useful quantitative response measures, suggesting that indicators document annual gallon savings from water retrofits and total annual dollar savings generated by materials recycling efforts. Additional metric submissions evaluate impervious surface ratio determinants like total acreage of storm water storage and infiltration projects and building management topics like % of buildings outfitted with HVAC control devices.³² These fine grained indicators point to specific management opportunities to redouble campus eco-efficiency.

The University of Pennsylvania Campus Environmental Audit

The UPenn Report engages conventional ecological stressors like campus energy consumption, hazardous waste generation, procurement, sewage and solid waste disposal, transportation, and water consumption. It forwards thorough discussions pertaining to each of these impact areas, delineating responsible campus management offices, efforts undertaken to address related sources of environmental strain, future suggestions for improved sector management, and regulations and operational procedures that managers must consider to affect those improvements. The document is reflective of the fact that no matter how streamlined campus EM information systems might become, measurement efforts must remain compartmentalized to deliver data that helps identify conservation opportunities within priority impact areas.

²⁹ LEED is the U.S. Green Building Council's Leadership in Energy and Environmental Design building accreditation system.

³⁰ This indicator reflects sprawl reduction efforts to curb impervious parking space cover.

³¹ It is worthwhile to mention that these indicators recognize potential cross-cutting reductions across multiple impact areas. For instance, transportation energy use implies linkages between transportation activity and overall campus energy consumption. Percentage green space speaks to the amount of surface area coverage that can absorb storm water runoff, preventing polluted effluent from entering storm drains.

³² HVAC is an acronym for heating, ventilation, and air conditioning systems.

The audit's numerical measurements include typical pressure quantities. For instance, fuel use and an end use composition profile characterize energy consumption, tons disposed and a composition profile appraise solid waste disposal, and commute distances, transportation use by vehicle mode, and a parking space inventory summarize transportation ramifications. In contrast, some specific policy areas such as hazardous waste management and procurement are almost entirely described qualitatively, in order to relay important managerial constraints and actions that quantitative indicators simply cannot capture.

Tracking UVM: An Environmental Report Card For The University of Vermont

The Vermont Report Card describes an extremely important campus environmental data set, namely, campus energy and water use and solid and liquid waste generation by building type. Accruing such information allows managers to determine the distinct environmental impact profiles of academic, laboratory, office, and residential space, facilitating the identification of categorical eco-efficiency projects across the campus building repertoire. The report also discusses innovative response indicators like % energy use supplied from renewable sources, % stormwater peakflow reductions achieved and % biodiesel composition of campus vehicle fuel and in recognition of UVM's character as a major radiological research campus, the report also specifies that tons of radioactive waste generated should be quantified.

The presentation method employed by the UVM report card conveys environmental management progress in a manner similar to the Penn State indicator gauge signal mechanism. And, like the Penn State presentation style, the UVM report card exhibits two particularly advantageous tracking characteristics. First, the report card avoids the allocation of a GPA or any other abstract quantitative scoring method. Second, its presentation method uses clear symbols to track directions of progress, employing “+,” “~,” and “-“ symbols to indicate improvement, insignificant change, or environmental degradation resulting from EM initiatives.

3.2 Summary of Existing Audits

Several noteworthy facets characterize the indicator efforts reviewed. All address a range of environmental impact sectors like energy use, emissions, procurement, transportation, waste generation, and water consumption, whereas only a certain few explore more specific impact areas such as dining hall and hazardous waste management. In general, the strongest measurement efforts deliver both trend and institutional performance information, recognize that campus character is central to determining appropriate indicators for the institution under consideration, and establish a sense of how an institution is closing resource flow loops.

Data normalization and presentation methods determine the strength of indicator efforts. Those indicator efforts delivering ratios that compare consumption data to campus populations and built space provide mechanisms to control for time series changes in baseline data. In addition, those efforts that achieve the greatest degree of data

compartmentalization into, for example, consumption data for individual buildings or building types, furnish high resolution data framed to facilitate the identification of specific, micro-scale management opportunities. Future efforts to improve current audits should explore further possibilities for identifying such micro-scale opportunities. Last, the efforts delivering the most useful EM information rely on indicator presentation methods that signal directions of current programs' success, improving managers' awareness of policy efficacy. The specific quantifications employed by each indicator effort are assembled in Appendix A.

Chapter 4: Common Indicator Design Guidelines

4.1 Review Methodology

This chapter discusses how indicators for MIT might be selected given indicator creation guidelines found in topical literature. Important points considered in this chapter include indicators' scope and reliability, analytical complexity, suitability for campus-specific measurement, and presentation style.

4.2 Design Directives

The most fundamental design directive is indicator function: indicators should gauge management progress or help managers identify EM priorities (Dalal-Clayton, 2002; Hammond et al, 1995; McIntyre et al. 1998; Moldan et al., 1997). To do so, indicators must be relevant and reliable. Relevant indicator sets monitor as many institution-specific environmental impacts (Kuik and Verbruggen, 1991b; Liverman et al, 1998). Furthermore, to be relevant indicators must exhibit either retrospective or predictive ability. While retrospective indicators measure past impacts in isolation, predictive indicators assemble more ambitious figures that relate current trends to sustainable behavior (Hezri and Nordin Hasan, 2004; Kuik and Verbruggen, 1991c; Rump, 1996). Annual recycling rates assemble retrospective data while maximum sustainable yield figures predict the material and energy use reductions necessary to align consumption with sustainable thresholds.

Reliable indicators are derived by transparent calculations (OECD, 2000), make measures using common scientific units (Dalal-Clayton and Bass, 2002),³³ and are responsive to changes in underlying trends (Hamilton, 2004; Rump, 1996). They also gather information under reasonable time and budget constraints (Jackson et al, 2000).

Describing manageable impacts and scenarios implicit in current institutional behavior therefore begs the consideration of campus operations, built assets, and current EM organizational structures (Van den Berg, 1996). The institute's location within a major metropolitan statistical area should also dictate indicator design; as a consequence of MIT's urban location, state indicators' application should be limited since they may be of little informative value (See discussion on pages 8 and 9)

The impetus to report scientific information tailored to managerial user needs further dictates that indicators be sufficiently normalized to assay many different levels of analytical complexity (Bell and Morse, 2003; Rump, 1996). Since EM stakeholders as diverse campus planners and compliance officials, facilities engineers, institute executives, procurement officers and sustainability program directors engage different

³³ If indicators are to be useful for time series comparisons, their calculation methods and measurement units must remain stable or must be transparent so that any changes in calculation methodology can be easily distinguished.

ecological impacts, only an indicator suite offering a wide range of measurement data could appropriately inform these actors' various on-task decisions.³⁴

The diverse analytical complexity demands needed to inform campus EM signal that list presentation is the most suitable method for organizing indicator recommendations. Lists can accommodate a broad range of subjects and retain the explanatory power of very different measures as individual considerations. To avoid stylistic flaws associated with list presentation such as lack of subject coherency and interdependency among indicator values, efforts must be made to ensure that pressure and response measures align and that overlaps between indicator reporting topics are well understood.

One last imperative relative to presenting indicator suites as lists is that indicators should be limited in quantity but retain their descriptive ability (Bossel, 1999). This directive responds to suggestions that lengthy indicator suites can overwhelm managers and throw important impact information awash in an unfathomable number of measurements (Gustavson, 1999). Though there is no accepted standard governing the length of indicator lists, devising a grounded rationale can bring some rationale into this otherwise arbitrary process of indicator of list determination (Bell and Morse, 2003). Accordingly, the final design process must present a succinct, comprehensive indicator set that balances the number of indicators reporting on different impact topics.

³⁴ For example, a program director might want to know overall campus utility consumption statistics apportioned by building type, whereas a hazardous waste regulatory officer might require more particular statistics reporting quantities of solvents generated per laboratory experiment. A transportation officer, in contrast, might desire information describing what portion of private vehicle commutes are made as carpool trips.

Chapter 5: Selected Indicator Design Methodologies:

5.1: Literature Summary

Prevalent literature submits that indicators provide useful, analytically sound information to managers employing them. This thesis will therefore approach the indicator design process mindful of indicators' relevance to and reliability for informing a range of EM decisions applicable to MIT operations. As a consequence, its indicator recommendations will feature statements delineating indicators' purpose and analytical methods. Furthermore, suggested indicators will leverage sufficient normalization to control for possible influences from fluctuations in underlying trends.

5.2: Lessons from Measurement Efforts Elsewhere

Efforts from other higher learning institutions further demonstrate the mechanics of indicator design, carrying additional implications for indicator topics, normalization techniques, and presentation methods. The more focused organizational audits among these efforts rely on indicators to direct the strategic planning of future facilities capital outlays and meet managers' demands for data that facilitates the identification of action priorities.³⁵ To do so pressure indicators need to feature sophisticated normalization techniques detailing driving forces of ecological strain and response indicators must either reflect distances to eco-efficiency targets or assay programmatic success at reaping domain-specific micro scale management opportunities. All indicators should employ a presentation method signaling programmatic success or failure.

5.3 Selected Guidelines

The indicator guidelines adopted for this project govern options regarding indicators' aggregation methods, analytical complexity, congruency, and presentation.

Aggregation: Though it will share some of their attributes, this thesis will distinguish itself from prior indicator efforts on several points, the first of which is its general avoidance of index aggregation. Although it is acknowledged that the topical literature and other campus indicator efforts trumpet indices' utility for simplifying environmental state quantifications, it must not be forgotten that indices too often succumb to shortfalls in analytical validity. Indexing impact information can also hinder the identification of sector-specific management priorities when figures are simplified such that constituent contributions to the transformed product become unrecognizable. Moreover, it is clear that environmental state indices, such as measures of ambient air quality and Charles River pollution, may be of little use to the institute's campus managers because campus impacts are only a few among the many localized urban stresses impacting those states in question.

Analytical Complexity (Data Parsing) and Normalization: The thesis also differs from prior indicator efforts on points of information specificity and organization. All pressure

³⁵ These can include maintenance or retrofitting.

indicators will be normalized to deliver composite information describing impact driving forces, so that few, if any, describe absolute figures. To illustrate, indicators addressing several layers of complexity are preferred to singular tallies so that sophisticated measures like energy consumed per vehicle mode receive greater mention than more simple, absolute indicators like average commuter trip distances.³⁶

It is also important to note that the intended indicator audience factors in the determination of indicator complexity. This thesis is intended to inform program heads such as Steve Lanou, Director of Sustainability Initiatives at the EPO, or Peter Cooper, Director of Utilities for the Department of Facilities and will therefore assume a global management purview within that perspective. As such, indicators will assess the range of institute-specific energy, water, and nonfuel materials consumption profiles, describing specific impact contributions from, for instance, end-use energy demand sources and potentially substantial eco-efficiency opportunities related to them.

Assuming this broad focus will in all likelihood limit indicators utility to many other Department of Facilities, EPO, and EHS officers charged with the management of individual impact areas and the generation of specific project ideas. Their information demands might be better served by even more focused normalization methods than those employed here, such as those that document hazardous waste generated per laboratory experiment or gallons of laboratory reject water that are recyclable. To further illustrate this point, consider that a program manager might desire impact per building type data that is useful for strategic planning and priority identification, whereas a facilities project engineer might be more interested to learn about impacts per individual building to identify particular structures in which cost-effective eco-efficiency projects might be undertaken.

Congruency: To align measurements of ecological strain and institutional performance, response indicator subjects will address the specific areas of pressure composition reviewed. This should minimize the overlap between indicator topics and assimilate cross-cutting response indicators, such as impervious surface cover removal, that share less obvious connections with stresses like storm water runoff. The indicator suite will also balance the number of indicators devoted to pressure and response information and the number of measures comprising each indicator category selected. Congruency can also be interjected by presenting indicators along with time series barometer measurements, which recognizes indicator values' linked movement in similar or distinct directions

³⁶ The indicator suggestions will attempt to achieve such complexity in data parsing for the express purpose of informing action prioritization.

Chapter 6: Campus Resource Consumption Statistics

Regardless of their source, all environmental pressures share common distinctions, being either material input- or output-related stresses. The environmental impacts associated with static consumption sources like built space stem mainly from resource- and material-intense equipment and processes. Vehicular impacts, in contrast, arise specifically from the intakes and emissions of fuel combustion. This chapter addresses MIT's unique energy, material, and water consumption profiles and the byproducts generated by them, considering data that reflect the subtleties implicit in managing a leading research institution.³⁷ Its assessments of campus impact foci are supported by information from client interviews with campus management staff and campus impact publications (See appendix C).³⁸

Meeting the energy, housing, resource, and workspace demands of the institute's 18,000+ student and employee population requires the provision, maintenance, and servicing of several types of campus space.³⁹ Among these are academic buildings, apartment complexes, dormitories, engineering laboratories, medical facilities, office and studio space, power generation stations, and service buildings like athletic facilities and dining halls. The 2005 fiscal year apportionment of space among the institute's 162 buildings is as follows: ninety academic buildings encapsulate 6,257,955 square feet, twenty-six residential properties comprise 2,684,274 square feet, and forty-six service buildings represent another 2,372,586 square feet. The shares of the 11,314,782 square feet of total campus built space represented by these building types are 55%, 23%, and 22% respectively. Built assets are detailed in the campus property map below.



Figure 3: MIT campus (Cambridge, MA) [<http://web.mit.edu> – Accessed 5/5/05].

³⁷ The Environmental Health and Safety Policy states that MIT “is committed to being at the forefront of large academic research institutions in minimizing, as feasible, the adverse environmental, health, and safety impacts of our facilities, activities, and operations (which is one way we define sustainability).”

³⁸ Most data are static, providing consumption from individual fiscal years. However, time series data are listed where possible in recognition that impacts are variable and subject to changes in underlying trends.

³⁹ This 2004 Town Gown Report figure includes undergraduate students (4,109), graduate (5,963) and non-degree (158) students, and Cambridge-based staff (6,823) and faculty (952). See Appendix C.

6.1: Campus Energy Consumption Behavior

Utility generation sources are a natural starting point for discussing campus energy use. The bulk of institute energy demands are met by the onsite Central Utility Plant (CUP) production facility, located on Vassar Street, and a small portion of campus electricity (20%) is purchased from NSTAR, a regional provider.⁴⁰ These services utilize a mix of power generation inputs including fossil fuels and more renewable options like wind power.⁴¹ The Department of Facilities is responsible for making all design, maintenance, and procurement decisions involved in overseeing CUP energy production and maintaining outside vendor contracts.

The CUP is a cogeneration plant, which captures waste heat from oil and natural gas combustion exhaust to produce steam and then uses that steam along with generated electricity to refrigerate coolant water. By leveraging the thermal byproducts of combustion for use in further downstream generation, the current cogeneration configuration improved CUP efficiency by 18% and reduced emissions by 45% in its first year of operation (Groode, 2004).⁴² The utility products produced during cogeneration power much of MIT's electric, heating, and cooling demand and are conventionally referred to as chilled water, electricity, and steam. Specific cogeneration system components, which include boilers, chillers, cooling towers, a heat recovery steam generator, and oil, gas, and steam turbines, are documented in the energy flow diagram below.

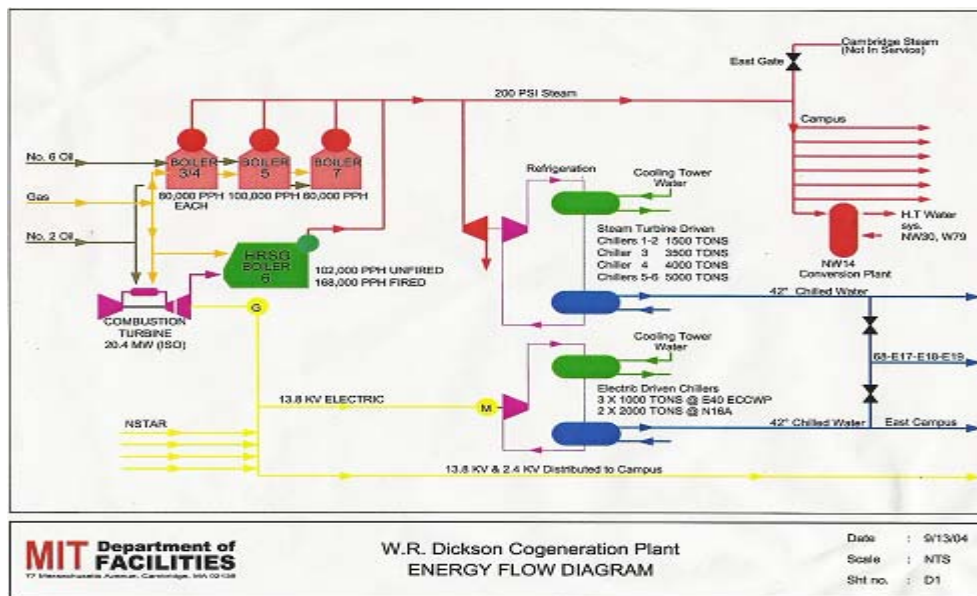


Figure 4: Central Utility Production plant diagram (Courtesy of Department of Facilities)

⁴⁰ Under Renewable Energy Standard regulations, NSTAR 04st supply a portion of its customer demand from renewable sources. In 2000, 5.9% of MIT's electricity was supplied by renewables (Groode, 2004).

⁴¹ For more detailed statistics on energy input source composition, see Groode (2004).

⁴² Upon installation in 1995, cogeneration technology produced immediate efficiency gains. The Environmental Protection Agency (EPA) defines the efficiency of a utility plant as “the sum of the net electrical and net useful thermal output divided by the fuel consumed by the plant” (Groode, 2004).

Apportioning utility demand by building type is an intuitive method for surveying impacts and forces that contribute to campus energy consumption. As indicated by the 2003 utility consumption tables and charts below, academic and service building use comprise a majority of campus electricity and steam demand. These buildings consume that energy to power appliances, lighting, refrigeration, temperature control, and ventilation systems. Also evident is that laboratory space, the least significant building type in terms of built square feet, is clearly the most energy intensive; labs consume the greatest absolute portions of chilled water, electricity, and steam among all built space types. This is logical since the institute's modern research facilities utilize specialized, high voltage machinery and often conduct experiments only under precise atmospheric conditions.⁴³

Table 1: Energy End-Use Demand by Building Type (Courtesy of Stone Webster Management Consultants Report, 2003).

Building Type	Gross Area	Chilled Water	Electricity	Steam
Yr 2003 Figures	Sq Ft	Annual Ton-Hr	Annual kWh	Annual Lbs (000)
Academic	2,662,698	14,125,627	52,711,488	386,249,124
Residential	1,578,815	581,217	4,765,997	71,703,665
Service	4,904,336	9,710,658	48,959,844	409,645,410
Wet Lab	1,309,863	26,568,985	73,713,285	497,650,001
Total:	10,455,713	50,986,488	180,150,614	1,365,248,201

Table 2: End-Use Demand by Square Foot Building Type (Courtesy of Stone Webster Management Consultants Report, 2003)

Building Type	Chilled Water	Electric	Steam
	Tons-Hours	KWH	Lbs (000)
Academic	3.96	17.67	0.095
Resident	2.70	10.80	0.070
Service	3.30	16.43	0.104
Wet Lab	11.92	42.42	0.203

⁴³ Examples of machinery that is particularly consumptive of chilled water, electricity, or steam are lasers, a nuclear research reactor, reverse osmosis water filtration systems, and steam sterilizers. The non-energy resource demands of this equipment are also significant and receives further mention below.

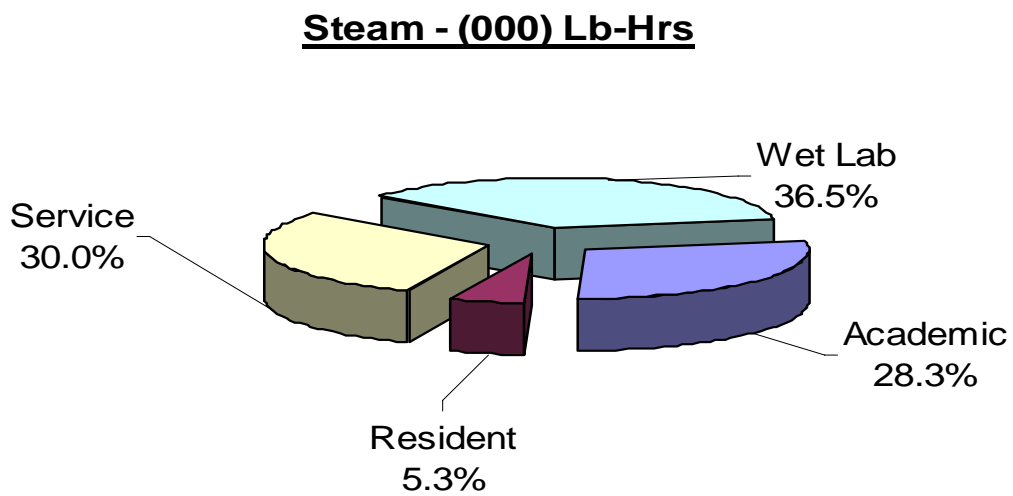
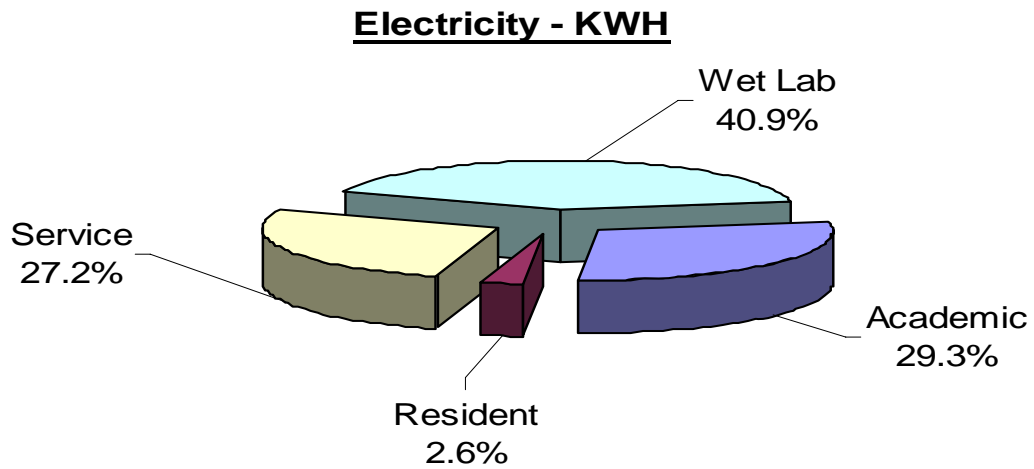
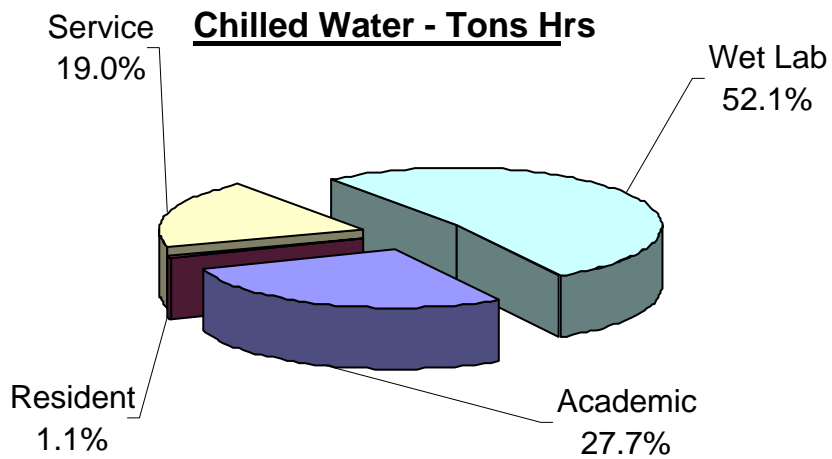


Figure 5: Chilled Water, Electricity, and Steam Demand Apportioned by Building Type
(Courtesy of Stone Webster Management Consultants Report, 2003)

Mobility needs are another major energy impact driving force, as departmental and commuter vehicle use are incurred in procuring goods, administering campus services, and providing transportation for the institute's 6000+ commuter population. The Office of Parking and Transportation supervises a large portion of the campus fleet and is responsible for implementing transportation demand management programs as required by federal Clean Air Act guidelines. The university fleet is comprised of department vehicles, commuter shuttles and vans, and zip cars that utilize a fuel or energy source mix including conventional unleaded gasoline, compressed natural gas,⁴⁴ diesel fuel, and electricity.⁴⁵ Cambridge city regulations also govern campus mobility, limiting acceptable numbers of campus-related private automobile commutes by prohibiting the institute from offering parking spaces for more than 26% of the campus population. In accordance with those rules the institute currently provides 4814 spaces and the Parking and Transportation Office issued less than 4000 parking permits in 2004.

The 2004 Parking and Transportation survey, completed by ~50% of MIT's student and employee population, contains substantial information regarding campus transportation demand, use, and motivation. It reports that campus commuters travel by several vehicular modes, including bicycle, private automobiles, public transit (bus and subway), and shared car or vanpools. This thesis will not make a significant effort to make complicated commuter mode share tabulations since the Transportation Survey documents them with greater precision and detail, but it is evident that the ridership frequency shares of the aforementioned modes are roughly 40% for multi-modal trips, 25% for single occupancy vehicles, and 10% for bicycle travel.⁴⁶ Commuter's average one way trip distance to campus was reported at 8.8 miles in 2002 (Groode, 2004).

Besides consuming fuel, these utility generation and transportation activities also generate atmospheric emissions. Pollutant discharges include GHG emissions, ozone, particulate matter, volatile organic compounds (VOCs), and acid-rain causing compounds like carbon monoxide and dioxide, methane, and nitrogen and sulfur oxides. MIT's emission behavior is regulated by the federal Clean Air Act and the Cambridge Climate Protection Plan, which, in keeping with the Kyoto Accord, calls for a 20% reduction in 1990 GHG levels by 2010. Reduction targets set for specific impact areas affecting this more general goal include a 12.5% reduction in electricity use, a 10% reduction in natural gas and fuel oil use, a 40% decrease in electricity generation emissions, a 40% increase in average fleet fuel economy, and a 10% reduction in vehicle miles traveled as compared to 1990 baseline levels. The Climate Protection Plan also stipulates that the institute must also work to purchase 20% of its electricity from renewable sources.

⁴⁴ Used to power Massachusetts Bay Transit Authority (MBTA) transit buses.

⁴⁵ Campus fleet vehicles travel over 200,000 miles per year, serving about 500,000 riders annually. A complete audit would also concern itself with fuel consumption, miles traveled, and emissions generated by campus purveyors, but tallying those figures is beyond the scope of this undergraduate thesis.

⁴⁶ These figures represent rough shares of ridership frequency. More useful information for determining vehicle mode share would report on mode share determined by total commuter miles traveled by mode.

While the principle byproducts of utility generation are carbon dioxide and sulfur oxide, transportation emissions mostly release carbon monoxide, ozone, and nitrogen and sulfur oxides. Since MIT incinerates the bulk of its solid waste, there is also an emissions contribution from the burning of these materials. Groode (2004) however, estimates that waste emissions are insignificant components of the institute’s GHG footprint when compared to contributions generated by utility and transportation activities. Emissions from waste incineration represent less than 1% of the 209,000+ tons of total carbon dioxide equivalents released in 2004.⁴⁷ Correspondingly, waste emission contributions are barely visible in the GHG emission source composition diagram provided below. A subsequent figure documents emissions contributions, in metric ton CO2 equivalents, from various commuter modes.⁴⁸

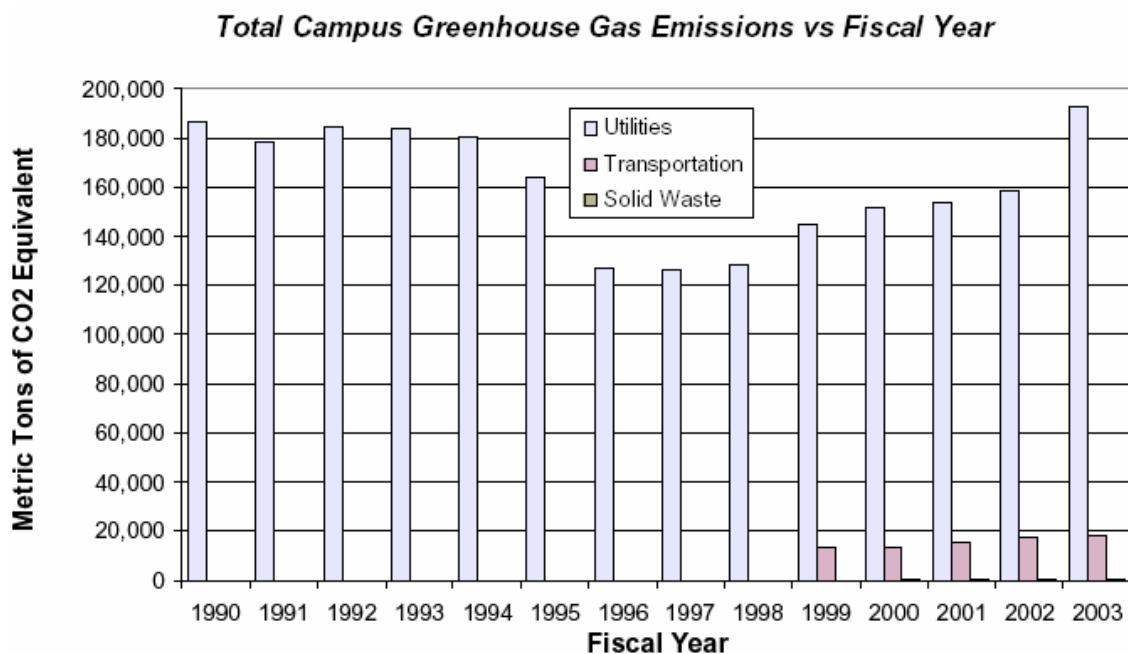


Figure 6: Annual GHG Emissions by Source Activity (Groode, 2004)

⁴⁷ The apportionment of campus GHG emissions by source is roughly 90% from utility generation, 9.5% from transportation, and .5% from waste incineration (Groode, 2004). Emissions from transportation sources are imputed since institute Transportation surveys only reach about half of the possible sample population.

⁴⁸ The most polluting form of commuter conveyance is the private automobile mode. This is unsurprising when considering that the EPA estimates that vehicle GHG emissions attributable to automobile use are at least 88% higher than emissions due to subway use and are 93% higher than that of bus use (Groode,2004).

Maximum Transportation Emissions vs Fiscal Year

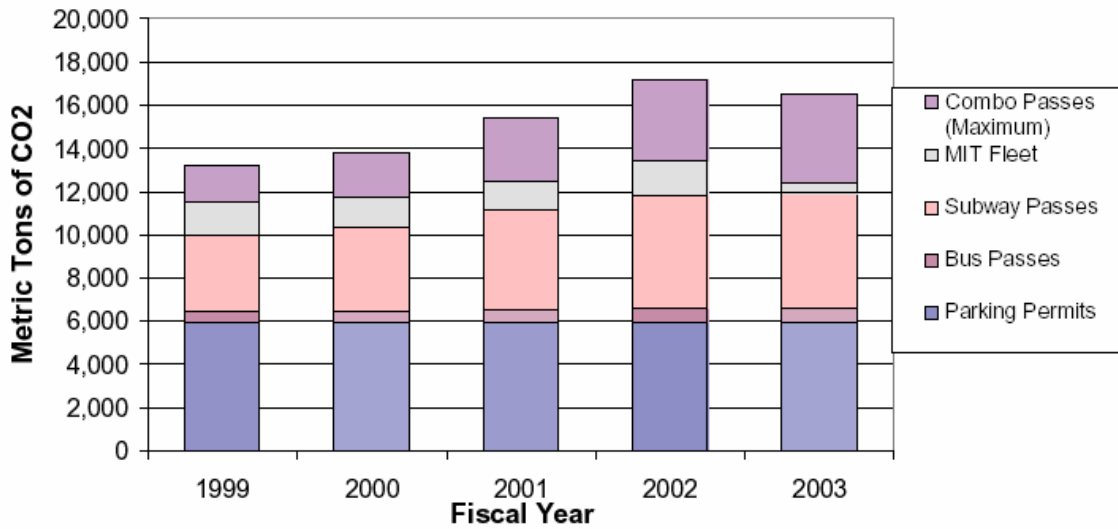


Figure 7: GHG Emissions by Transportation Mode (Groode, 2004)

6.2: Water Consumption Activities

Water filtration, distribution, and wastewater handling practices are monitored by the Massachusetts Department of Environmental Protection, which administers the stipulations of the federal Clean Water Act. MIT purchases its water from the Cambridge municipal water supply, which draws from Fresh Pond near the northwest city limits. Campus effluent is disposed of down storm, sewer, and combined storm-sewer drains and processed at the Deer Island treatment plant in Boston Harbor. In compliance with local regulations all buildings fronting city streets must be metered for water use and to comply with EPA storm water directives these buildings must dispose of accumulated rainwater directly into storm drains and mitigate the amounts disposed to avoid combined sewage overflow. New buildings construction plans must also document storm water mitigation strategies employed in building design. Furthermore, under Massachusetts Water Resource Authority regulations MIT makes every effort not to dump clean water into sanitary sewer drains. The campus sewage load is calculated by subtracting permitted sewage mitigation project gallons from total water use and municipal sewage fees are assessed based on the calculated total.

A Department of Facilities Report states that 102 MIT buildings consumed 477,191 CCF of water and disposed of 380,315 CCF of sewage in 2003.⁴⁹ Total water and sewage costs amounted to \$4,235,501 in 2004. There are no known estimates of campus storm water runoff and figures apportioning campus water use by building type are also unavailable. However, it is clear that the institute’s potable water use is driven by certain

⁴⁹ CCF is an abbreviation that stands for 100 cubic feet, a billing unit commonly used by water providers. MIT’s water costs \$3.30 per CCF. Combined water and sewage disposal costs were \$10/CCF in FY 2003.

significant factors, including dining hall use, irrigation needs, utility and laboratory equipment coolant demands, and all facilities' restroom loads.⁵⁰

6.3: Non-Fuel Material Consumption Profile

Annual institute capital outlays for purchasing amount to nearly \$350 million. The Procurement Department coordinates institute purchasing with the campus accounting office, department administrators, dining hall managers, office personnel, and laboratory managers. Informal procurement policies encourage purchasing agents to consider waste stream source reduction possibilities and select recycled content products to the extent possible. To date, EHS and Procurement managers have made significant efforts to educate purchasing agents and tame virgin material consumption behavior in the building material, office, and laboratory chemical supply sectors.

MIT incinerates its solid waste at a Coventa waste-to-energy plant in Haverhill, Massachusetts. Among the benefits characterizing waste-to-energy conversion are the aversion of waste volumes sent to landfills and the reduction of green house gas emissions associated with more conventional forms of waste disposal.⁵¹ Under a recent EPA consent decree, the institute established a Pollution Prevention Program aimed at reducing, recycling, and reusing waste. Materials recycled in accordance with the plan include aluminum, cardboard, glass, electronics, fluorescent lamp components, paper, plastics, and wood pallets. Furthermore, excess cooking oils are recycled and food scraps and yard trimmings are composted and the institute also has an effective building demolition materials recycling plan; 96% of discarded materials from a media lab renovation initiated in 2001 were recycled.

Between 2000 and 2003, MIT generated non-hazardous material waste loads that ranged between 5,700 and 8,900 tons annually. In 2004, the institute disposed of 7,046 tons, or about 780 annual pounds per capita using Town Gown Report population figures.⁵² Of the 7, 046 total tons, 1870 tons were recycled, establishing a 26% recycling rate. The institute's current recycling target, reached in an agreement that satisfies the Cambridge Climate Protection Plan, is to achieve a 40% recycling rate by 2005 and a 60% long term recycling rate. Informal waste audits have estimated that an 80% conventional material recycling rate is feasible. Figures documenting recyclable components of the waste stream follow below.

⁵⁰ Dining halls can use substantial amounts of water and deposit sewage high in bio-organic content if not properly administered. Utility generation and laboratory equipment also present a significant coolant water demand to control their operations.

⁵¹ Groode (2004) compares GHG emissions associated with different waste disposal methods, determining CO2 equivalent emissions from landfilled waste eclipse those resulting from waste incineration.

⁵² These tallies do not account for construction demolition waste.

Table 3: Waste Stream Composition (Courtesy of EHS, 2004)

Waste Type	Cumulative Total (tons)	% of Waste Stream
Basic Recyclables	748.6	11
Composted Organics	762.6	11
Other Recyclables	359.5	5
Total Recyclables	1870.7	26.5
Trash	5175.7	73
Total Discards	7046.4	100

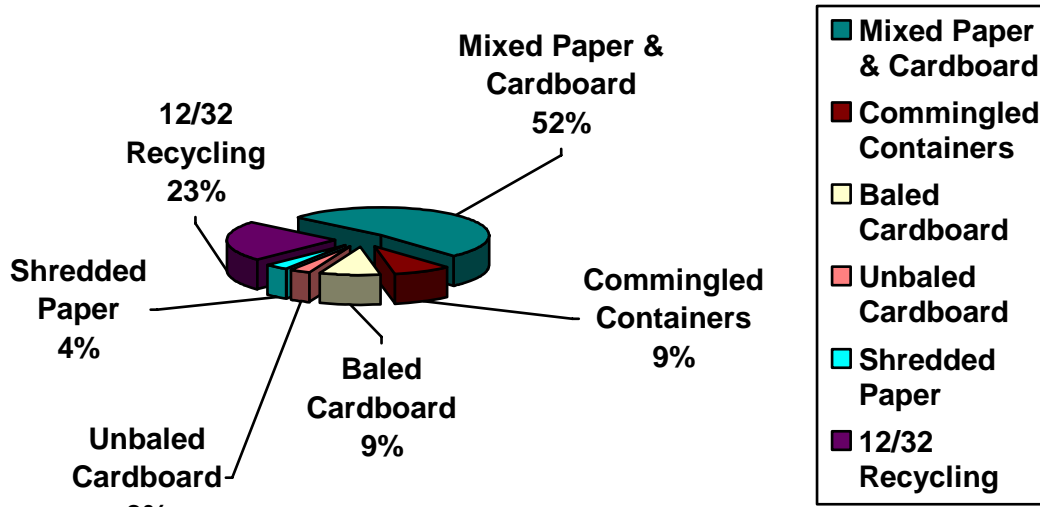


Figure 8: Basic Recyclables Composition (Courtesy of EHS, 2004).

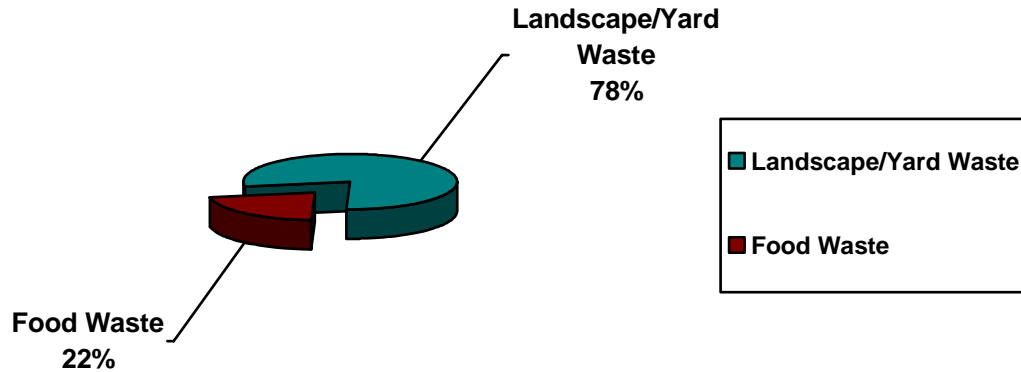


Figure 9: Composted Waste Sources (Courtesy of EHS, 2004)

The institute also generates a number of hazardous solid wastes in the course of conducting its various laboratory activities. Potentially harmful substances used on site include biohazard waste, chemical solvents, herbicides, medical waste, mixed fuel oils, pesticides, and radioactive materials. A large part of the Environmental Health and Safety Office's administrative duty is devoted to complying with hazardous waste handling regulations like the federal Comprehensive Resource, Conservation, and Liability Act (CERCLA, also known as the "Superfund") and the Resource Conservation and Recovery Act (RCRA), which aim to induce the cleanup, tracking, and safe and responsible handling of hazardous substances.⁵³ The federal Insecticide, Fungicide, and Rodenticide Act (FIFRA) also applies to hazardous waste management, specifically governing pesticide use, and in compliance with that regulation landscaping practices are designed to minimize the application of pesticides and herbicides on public spaces. Pesticide application personnel and other hazardous waste handlers on campus must be certified by the Massachusetts Departments of Environmental Protection and Public Health. Radioactive materials are regulated specifically by the Nuclear Regulatory Commission and both biohazard and radioactive wastes are monitored by the Department of Public Health.

⁵³ Hazardous waste statistics are compiled in a biannual report to the EPA, but figures were not available before the thesis submission date.

Chapter 7: Recommended Indicators

Indicators are organized in categories that recognize significant campus impact focal areas including energy consumption, water consumption, and non-fuel material consumption.⁵⁴ Each category internalizes both resource supply and disposal pressures associated with consumption behavior and incorporate cross-cutting impacts such as building and transportation activities. Response indicators measure institutional performance in addressing campus-related ecological strains.

Individual indicators meant to audit MIT are listed along with considerations as to their measurement parameters, indicator type,⁵⁵ potential measurement alternatives, relevance to environmental management, value among available alternatives, and where appropriate, their approximation of campus sustainability. The indicator characteristics described are very much akin to those surveyed in the OECD Core Indicator Set methodology sheets (OECD, 2001). For the purposes of time series tracking and restricting measurements such that the accumulated data represents a manageable information load, indicator amounts should be tallied as annual totals, not smaller monthly increments.

7.1 Energy Consumption Indicators and Managerial Scenarios

The energy section addresses major contributions to campus energy consumption and associated emissions. It examines campus utility sources, uses, and related emissions apportioned by built space and vehicular modes. Since gauging energy efficiency involves accounting of energy use across various impact sectors that are measured with different parameters, all figures will report processes' efficiency in terms of equivalent BTU consumption.

Energy Generation Consumption Per Type Built Space

Indicator Type: Pressure

Parameters: BTU/Square Foot Academic, Residential, Service, and Wet Lab Space.⁵⁶

Alternative Indicator(s): Consumption Per Capita, Consumption Per Built Square Feet

EM Relevance and Justification for Selection: This measure portrays energy use by space type, facilitating the identification of conservation priorities among spaces exhibiting variable energy consumption intensities. Measuring consumption per square foot of those spaces addresses another level of information complexity beyond BTU consumed per building type, delivering figures that are comparable across spaces with different floor areas.

Power Generation Fuel Inputs

Indicator Type: Pressure

Parameters: BTU Generated/Fuel Type⁵⁷

Alternative Indicator(s): Amount Fuel Used by Fuel Type

⁵⁴ Fuel use is internalized in the energy consumption category.

⁵⁵ Indicators deployed are either pressure or response indicators.

⁵⁶ Wet lab space is research area outfitted with hazard controls such fume hoods and chemical sinks.

⁵⁷ Fuel totals should include inputs used to power NSTAR's energy contract with MIT.

EM Relevance and Justification for Selection: This indicator demonstrates the apportionment of energy generated from each input source. It has the power to signal shifts toward the expenditure of more or less renewable fuels.

Energy Product Source Demand by Building Type

Indicator Type: Pressure

Parameters: BTU Expended/Total Chilled Water, Electricity, and Steam Delivered/SF Building Type.⁵⁸

Alternative Indicator(s): Ton-hrs, kWh, and lbs. per SF building type.

EM Relevance and Justification for Selection: Measuring building energy demand from sources like chilled water, electricity, and steam generation demonstrates how intensively each building type consumes these specific energy use inputs.

Total Campus Fleet and Commuter Fuel Consumption

Indicator Type: Pressure

Parameters: BTU Expended/Mode.

Alternative Indicator(s): BTU Expended/Fuel Type

EM Relevance and Justification for Selection: This indicator is relevant to campus-related vehicle fuel economy and is unique among alternative indicators for its approximation of campus transportation energy use by mode.

Approximation of Sustainability: The measure might be used to approximate improvements in campus-related vehicle fuel economy, signaled by a shift to greater proportional energy use by less and not more consumptive travel modes.

Total Campus Green House Gas Equivalent Emissions by Source

Indicator Type: Pressure

Parameters: Tons CO₂ Equivalent Emissions/Source Activity. Pollutant types should be separated into three groups: carbon dioxide, methane, and sulfur and nitrogen oxides, all of which can be converted into tons CO₂ equivalents using global warming potential coefficients.⁵⁹

Alternative Indicator(s): Total Equivalent Tons CO₂ Emissions

EM Relevance and Justification for Selection: This indicator is important for approximating campus impact contributions from stressors that are linked to climate change. Normalization by source activity is important for documenting which stressors are responsible for causing GHG emissions. Furthermore, delivering information that recognizes different green house gases factors can also approximate secondary climate impacts like the acid rain stress induced by nitrogen and sulfur oxide emissions.

% Power Generation Energy Procured from Renewable Sources

Indicator Type: Response

Parameters: Share of Campus Utility BTU Consumption from Renewable Sources

Alternative Indicator(s): None

⁵⁸ Groode offers campus conversion factors for BTU expended in creating one ton-hr of chilled water, one kilowatt hour of electricity, and one pound of steam.

⁵⁹ Combustion figures used to determine GHG emissions should internalize campus waste incineration and transportation emissions (see Groode, 2004).

EM Relevance and Justification for Selection: This measure indicates utility power source composition from renewable inputs that do not combust fossil fuels and avoid associated resource use and pollutant emissions.

Approximation of Sustainability: Approximating renewable energy use is a direct measure for how well the institute is capitalizing on environmental sustainability opportunities by leveraging power sources with full renewable potential.

% Campus Buildings with Modern HVAC Controls

Indicator Type: Response

Parameters: % Campus Buildings Retrofitted with HVAC Schedule Control Devices

Alternative Indicator(s): None

EM Relevance and Justification for Selection: Modern controls regulate the operating schedules of HVAC units, which maintain indoor climates and require a significant portion of building electricity demand to power their operation. This indicator assesses progress towards achieving system efficiencies possible from reducing energy waste associated with HVAC units that currently do but need not operate continuously.

% Campus Built Space Served by Day-Lighting by Building Type

Indicator Type: Response

Parameters: Daylighting Coverage (SF)/SF Service Space/Building Type

Alternative Indicator(s): kWh Equivalent Captured by Day-lighting Projects, kWh Avoided by Building Type

EM Relevance and Justification for Selection: Electricity demand for lighting is a major source of building energy demand (Creighton, 1998; Groode, 2004). Measuring day-lit space on campus provides a proxy for how well the institute is leveraging this more subtle form of renewable power that is not reflected in the broader renewable energy indicator above. The rough measure of space apportionment of day-lighting projects is selected rather than the kWh equivalent electricity demand avoided because of the difficulty implicit in measuring displaced power demand, which depends on highly variable daily light loads and tabulations of light capture from many small-scale reconfigurations of light fixture placement. Normalizing by building type is important for identifying building categories that are currently underserved by day-lighting, that might particularly benefit from the installation of day-lighting retrofits like reflecting lamps and skylights⁶⁰

Approximation of Sustainability: Cataloging day-lit space approximates the institute's approach of this obvious renewable energy opportunity that can offset MIT's significant electricity demand for lighting.

% Annual Commute Distance Made by Single-Occupancy Vehicles

Indicator Type: Response

Parameters: Miles Traveled by Single Occupancy Vehicle/Total Commuter VMT

Alternative Indicator(s): Single Occupancy Vehicle Mode Share

EM Relevance and Justification for Selection: This indicator represents not only the proportional travel but also the absolute distance traveled by single-occupancy vehicles.

⁶⁰ Daylighting is often claimed to enhance worker productivity and student learning (Creighton, 1998), so dormitories, laboratories, and buildings housing libraries might particularly benefit from added daylighting.

It is preferred to measures of transit ridership, for instance, because it indicates the deferral of commutes made by the fuel-intensive automobile mode more directly. Approximation of Sustainability: Energy expenditure and emissions from automotive travel are significant stresses on ambient air quality and fossil fuel resource stocks. This indicator can reflect shifts from single occupancy vehicle travel to more sustainable commuter modes that use road space and fuel more efficiently, and therefore also signals traffic and emissions reduction progress.

Fleet Vehicle Fuel Economy

Indicator Type: Response

Parameters: BTU Consumed/VMT

Alternative Indicator(s): VMT/Gallon

EM Relevance and Justification for Selection: Campus fleet fuel mileage is an important measure of consumption efficiency and emissions reduction efforts. Absolute BTU consumption figures are preferable to those utilizing gallon measurements because campus vehicles currently use a range of fuels with different energy contents. This indicator has the power to reflect fuel economy improvements while controlling for increases or decreases in campus VMT.

Approximation of Sustainability: Improved fleet fuel economy could signal the purchase of more efficient vehicles or the use of cleaner, more efficiently combustible fuels like biodiesel.

The institute has undertaken several major in-situ energy conservation initiatives during the last two decades. Perhaps the most significant efficiency improvement accompanied the construction of the cogeneration plant, which immediately improved power production output and reduced GHG emissions after its completion in 1995. Other major energy conservation actions deployed building efficiency upgrades like envelope tightening, HVAC schedule control systems, and extensive lighting retrofits, which were conducted as part of the EPA's Green Lights Program. Amended institute building codes now dictate that all new campus buildings must meet minimum LEED silver design criteria.

Recently, MIT put several solar panel arrays into service with the help of grant funding from the Massachusetts Renewable Energy Trust,⁶¹ and as previously mentioned a nominal amount of the institute's electricity comes from renewable sources within NSTAR's energy distribution portfolio. Future capital projects must invest in more renewable energy inputs, upgrades to improve lighting, heating, and cooling system efficiencies, and further decentralized power generation. Specific potential projects include the installation of room occupancy sensors for lighting fixtures and the utilization of renewable sources like solar-generated electricity and solar-heated water to supply point source energy demands like Athena cluster electricity and restroom hot water loads.

⁶¹ The solar arrays are situated atop the Student Center, Hayden Library, and Building N52. Their combined generation supplies a 20 kWh load and currently the panels atop the Student Center feed portions of Athena Computer Cluster energy demand.

MIT has also addressed mobility impacts through its Transportation Demand Management (TDM) program, which is primarily aimed at reducing single-occupancy vehicle travel. The program limits parking permit distribution, offers day and nighttime shuttles and emergency rides home for off-campus residents, subsidizes public transit passes, provides scheduling information for accessible transit routes, and promotes carpooling by connecting commuters with Massrides, a vanpooling transit company. Recently, the program won acclaim when the federal government recognized MIT as one of the nation's top workplaces for commuting employees. In deferring automobile travel and boosting transit ridership, the TDM program has shifted commuter travel patterns towards modes that use infrastructure more efficiently and subsequently reduce traffic, related idling, and associated pollution. The institute is also exploring the use of more renewable vehicle fuels, with the hope of improving average fleet fuel economy to 40 miles per gallon.

7.2 Water Consumption and Institutional Response

The water consumption section addresses pressure impacts by assessing MIT's water demand as a portion of Cambridge's total municipal distribution load, comparing indoor and outdoor water use, and considering water demands and sewage loads normalized by built space. Response indicators center on points of potential water reuse, on-site sewer and storm water filtration, and campus space configurations affecting runoff and irrigation demands.

Water Consumption Per Type Built Space

Indicator Type: Pressure

Parameters: Potable Gallons Consumed/SF Built Space/Building Type

Alternative Indicator(s): Gallons/Capita, Gallons/Total Built SF

EM Relevance and Justification for Selection: This measure will help streamline the comparison of water-intensive building types by delivering per square foot consumption statistics and will describe in more detail conservation progress that broader indicators like gallons per square foot would approximate anyhow.

Sewage Load Per Type Built Space

Indicator Type: Pressure

Parameters: Gallons Disposed/SF Built Space/Building Type

Alternative Indicator(s): Gallons/Total Built SF

EM Relevance and Justification for Selection: This quantification will help rank building types as sewage generators and might direct managers to building types where projects to install grey water reclamation or on-campus natural filtration systems could be particularly affective for reducing municipal sewage disposal.

Share of Water Used for Irrigation

Indicator Type: Pressure

Parameters: Irrigation Demand/Total Campus Water Purchased

Alternative Indicator(s): % Water Used Indoors vs. Outdoors

EM Relevance and Justification for Selection: This measure will indicate the apportionment of institute water use devoted to irrigation, which should signal improvements in displacing irrigation demands for municipal potable water. Measuring irrigation share is preferred to calculating indoor and outdoor shares because indicators should directly signal direction movement in addition to reflecting stress composition.

% Municipal Load Represented by Campus Water Demand

Indicator Type: Pressure

Parameters: MIT Water Purchases/Total Cambridge Water Delivered

Alternative Indicator(s): None

EM Relevance and Justification for Selection: This is a synoptic indicator that contextualizes MIT's potable water demand as a stress on Cambridge's total municipal load. Wielding this measure might help MIT to gauge progress towards stabilizing or diminishing its share of the municipal load. Although this indicator might reflect increases in other users' demand rather than progress in reducing institute water use, it is nevertheless important to be cognitive of this ecological strain and further measurement improvements can be made to solidify the value of this synoptic information to facilities managers. An example of such a refinement would be to measure progress against a benchmark that fluctuates according to growth in others' annual water use.⁶²

Approximation of Sustainability: This indicator might serve as a springboard for future efforts to decide a maximum sustainable water yield allowance for the institute.

% Campus Impervious Surface Coverage

Indicator Type: Pressure

Parameters: Square Feet Impervious Surface/Total Square Feet Campus Area

Alternative Indicator(s): Square Feet Impervious Surface Coverage

EM Relevance and Justification for Selection: This indicator is relevant for approximating the portion of campus surface coverage that contributes to contaminated storm water runoff and combined sewage overflows. It could reflect response progress from initiatives like green roofing projects or surface pavement retrofits that would reduce impermeable surface cover.

% Grey water Reused

Indicator Type: Response

Parameters: Gallons Grey water Recycled Onceover/Total Grey water Generated

Alternative Indicator(s): None

EM Relevance and Justification for Selection: Reusing grey water is perhaps the most feasible and effective method of reducing potable water demands from consumption sources that currently use but do not need potable quality water.

Approximation of Sustainability: Grey water recycling is a practice in direct keeping with the waste reuse and source reduction principles implicit in applied sustainability.

% Potential Rainwater Harvested

⁶² The institute's sewage load as part of the Boston Metropolitan Statistical Area's municipal load is not considered because the institute's contributions to the amount of sewage processed at Deer Island is statistically insignificant when compared to total metropolitan area disposals.

Indicator Type: Response

Parameters: Rain Water Harvested/Total Potential Rainwater Harvestable

Alternative Indicator(s): None

EM Relevance and Justification for Selection: Rainwater is another potential supply for feeding processes that use potable water but do not require potable quality water.

Approximation of Sustainability: This indicator will reflect the institute's progress towards leveraging this yet untapped sustainability opportunity.

% Campus Irrigation Demand Comprised by Native Species Needs

Indicator Type: Response

Parameters: Water Demand from Native Plantings/Total Irrigation Demand

Alternative Indicator(s): Share of Native vs. Exotic Species

EM Relevance and Justification for Selection: Native species typically consume less water than exotic, imported species, so it is important to gauge planting types to appreciate possible reductions to exotic species cover and subsequent irrigation water demands.

% Campus Parking Spaces Housed in Multi-tiered Garages

Indicator Type: Response

Parameters: Spaces in High Rise or Underground Garages/Total Parking Spaces

Alternative Indicator(s): None

EM Relevance and Justification for Selection: Storm water falling on parking surfaces is particularly contaminated with volatile organic compounds (VOCs) because it absorbs fuel and oils from leaking vehicles. Approximating the institute's progress towards its plans of eliminating surface parking spaces serves as a proxy measure for gauging reductions in contaminated runoff that is funneled through storm water transport into local water bodies.

% Campus Space Covered by Natural Water Filtration/Capture Projects

Indicator Type: Response

Parameters: SF Campus Area Served by Natural Water Filtration/Campus SF

Alternative Indicator(s): % Campus Covered by Storm Water Infiltration Projects

EM Relevance and Justification for Selection: This measure will indicate MIT's progress towards runoff reduction and keeping water filtration practices in-house, which reduces loads sent to storm drains and the Deer Island sewage treatment plant. Measuring natural water filtration space provides a more comprehensive measure than storm water infiltration space because the former figure describes on-campus grey water filtration as well as storm water purification processes, thereby recognizing greater ecological-interconnectedness than more limited storm water project approximations.

Approximation of Sustainability: This is a holistic measure that appraises MIT's function as a contained ecological unit and assesses progress towards affecting more sustainable effluent disposal and reuse practices.

The institute's water conservation initiatives are extensive and range from point source appliance retrofits to the more systematic reuse of water that would otherwise be disposed of as storm water or sewage effluent. Retrofitting dormitories and academic

buildings with low-flow faucets and shower heads and low-flush toilets in conjunction with reusing coolant water for CUP chilled water production reduced campus water use by 70% since 1990. Other contributing factors to these substantial savings were the installation of irrigation system rain sensors and steam sterilizer controls,⁶³ the elimination of many water-cooled pumps, the reuse of reverse osmosis reject water, and the replacement of hydrophilic seals that required water to maintain suction.

Potent strategies for affecting more sustainable water consumption behavior include leveraging more efficiency upgrades, engaging further reuse efforts, and tapping new, renewable water supply streams that reduce municipal supply demands. Two such potential supply streams are grey water and rainwater. The Stata Center's storm water management system highlights the source reductions possible from campus design that harnesses these more sustainable supply streams, working to capture and filter rainwater for use in toilet flushing. Moreover, utilizing such alternative water supplies represents a cross-functional integration of strategies to mitigate storm runoff and offset institute potable water demands.

Future water conservation projects should continue to exploit possibilities for grey water reuse from sinks, showers, boiler blow down, and laboratory water rejected by reverse osmosis purification equipment. They should also explore significant rainwater harvesting potential and pursue in-situ water filtration more extensively, perhaps with the long-term goals of capturing as much rainwater as is economically feasible and conducting all campus-related sewage treatment on-site.

7.3 Non-fuel Materials Consumption and Waste Reduction and Reuse Performance

The material consumption section surveys the composition of conventional, biohazard, and hazardous waste. Response indicators seek to establish performance measures for the recycling of substantial waste stream components like dining hall, lab solvent, and paper and packaging waste reuse. Indicators meant to gauge the extent of green product procurement are also provided.

Conventional Waste Composition

Indicator Type: Pressure

Parameters: Tons Conventional Waste Collected/Waste Type. These measures should assay waste regularly collected by MIT's contracted haulers and more variable waste sources like building demolition materials disposed of by construction contractors. Dining hall waste is considered separately in another indicator.

Alternative Indicator(s): None

⁶³ Steam sterilizers, sometimes called autoclaves, are machines that clean laboratory equipment. Coolant water is mixed with the superheated condensate by-product of steam sterilization to regulate condensate temperature before it is disposed of down storm drains. Installing control mechanisms to govern system valves helps to ensure that coolant water is only mixed in precise increments when it is needed, not continuously.

EM Relevance and Justification for Selection: It is important to track conventional waste composition to identify possible waste disposal reductions from handling potentially recyclable refuse sources differently.

Dining Hall Waste Composition

Indicator Type: Pressure

Parameters: Amount Dining Hall Waste by Type

Alternative Indicator(s): None

EM Relevance and Justification for Selection: Dining hall waste is easily recyclable and tracking the composition of this waste stream is a method for identifying potential recycling opportunities.

Non-Medical Biohazard Waste Composition

Indicator Type: Pressure

Parameters: Amount Biohazard Waste by Source Type

Alternative Indicator(s): None

EM Relevance and Justification for Selection: A better understanding of MIT's biohazard waste profiles might facilitate the identification of recycling opportunities that remain untapped. Animal bedding discarded from research laboratories represent one such opportunity.

Non-Radioactive Hazardous Solid Waste Composition

Indicator Type: Pressure

Parameters: Tons Hazardous Waste Generated/Waste Type. This should exclude biohazard and medical waste.

Alternative Indicator(s): None

EM Relevance and Justification for Selection: Laboratory research and teaching activities generate hazardous waste that represents a clear ecological strain when it is sent to landfills or incinerated.

Non-Radioactive Hazardous Liquid Waste Composition

Indicator Type: Pressure

Parameters: Liters Hazardous Waste Generated/Waste Type

Alternative Indicator(s): None

EM Relevance and Justification for Selection: Liquid hazardous waste is either incinerated or disposed of down drains, and it is although certainly regulated by the Clean Water Act and RCRA, it remains an activity presenting ecological strains.⁶⁴

% Environmentally Preferable Laboratory Solvents Procured

Indicator Type: Response

Parameters: Environmentally Preferable Solvent Orders/Total Solvent Purchasing Weight

Alternative Indicator(s): None

⁶⁴ The Clean Water Act and RCRA make strict stipulations for permissible chemical amounts and concentrations dumped down drains.

EM Relevance and Justification for Selection: This indicator will measure the institute's efforts to offset hazardous solvent use by purchasing environmentally preferable or perhaps even biodegradable solvents.

% Paper and Packaging Waste Recycled

Indicator Type: Response

Parameters: Total Weight Paper and Packaging Waste Recycled or Reused/Total Paper and Packaging Material Accumulated

Alternative Indicator(s): None

EM Relevance and Justification for Selection: Garbage composition studies conducted at other universities demonstrate that paper and packaging waste can represent more than half of a campus' waste stream. Furthermore, paper and plastic products are either particularly harmful, in the case of paper dyes, or often non-biodegradable as with plastic packaging waste. Since these and other materials like cardboard are easily sanitized and reusable there is no reason that they should not be recycled.

Approximation of Sustainability: Recycling paper and packaging waste is a potential method for reducing the campus waste stream and campus virgin material consumption substantially. In addition, affecting source reduction through bulk ordering and recycled content materials purchasing could be effective ways to generate cost savings.

% Food Waste Reused

Indicator Type: Response

Parameters: Amount Food Preparation Scraps, Waste Oils, and Plate Tailings Composted or Recycled/Total Food Waste Generated

Alternative Indicator(s): None

EM Relevance and Justification for Selection: This indicator measures reductions in wasteful food-discarding practices. It is also a crosscutting quantification that implies possible reductions across other distinct impact areas since food waste represents materials that can be recycled for fertilizer, food kitchen donation, or in the case of oil, soap production. Furthermore, recycling food waste can offset the dumping of food scraps down drains, which ultimately reduces the effluent processing load placed on the municipal sewage plant that must eventually filter out those biosolids.

Approximation of Sustainability: As the human population and subsequent nutrition demands grow, achieving greater efficiency in the use of harvested biomass is essential. Reusing food waste is an incremental step towards improving such efficiency.

% Lab Solvents Reused

Indicator Type: Response

Parameters: Liters Solvent Reused/Total Liters Purchased

Alternative Indicator(s): Liters Lab Solvents Exchanged Between Laboratories

EM Relevance and Justification for Selection: The institute's laboratory activities require a significant amount of solvents to facilitate experimentation. Some solvents are used to clean lab equipment and cannot be reused because they come into contact with hazardous

substances, but many can be redistilled after their primary use.⁶⁵ Redistilling substances can reduce purchasing needs, affecting both source reduction and waste stream deferral. Approximation of Sustainability: The reuse of lab solvents is a source and waste stream reduction technique that, complementing current efforts to encourage excess chemical exchange among laboratory groups, will encourage the more sustainable utilization of hazardous substances.

% Non-Solvent Green Products Procured

Indicator Type: Response

Parameters: Weight Products Meeting a Recycled Content Benchmark/Total Purchases. All institute purchases made inside and outside of the Procurement Office's purview should be considered.

Alternative Indicator(s): Number of Green Products/Total Number of Products Purchased

EM Relevance and Justification for Selection: This indicator is a proxy representing the environmental-consciousness of campus purchasing decisions. By purchasing recycled content products, the institute can encourage the formation of a stronger market for reused materials. Although the amount of recycled content products that might be purchased will necessarily be limited by pricing constraints, there are many recycled content items available for sale and a commensurate amount of opportunities to improve recycled content purchasing.⁶⁶ Further research must be conducted before selecting a recycled content benchmark that is achievable within reason and current economic realities. As a last note, calculating total green purchasing weight is preferred to tallying the number of green products procured because of a desire to know the green content of the total product mass purchased.

Approximation of Sustainability: This indicator will track yet another significant environmental impact sector, relating how well the institute utilizes its purchasing budget to discourage virgin material harvesting and encourage waste stream deferral.⁶⁷

A 2004 Environmental Goals Task Force working paper assembled by several campus managers offers steering advice for purchasing decisions, stating that procurement should contribute to reducing the volume and toxicity of the institute's waste stream. Other informal internal documents encourage responsible agents to explore the procurement of green cleaning solutions, office supplies, and maintenance supplies like low-VOC paints. Already, all paper purchased for Athena cluster, office, and copy center use is recycled content paper and the institute has an agreement with Office Depot to work towards streamlining green office product purchasing.

Other direct strategies for waste stream mitigation are source reduction and waste recycling techniques. The institute currently recycles or composts a large portion of its

⁶⁵ Many researchers might be reluctant to redistill solvents for fear of compromising chemical purity, equipment cleanliness, and subsequently, research results. However, experiments in teaching labs can be redesigned to both redistill substances instead of breaking them down and test the chemical purity of newly distilled solvents, which may overcome related contamination concerns.

⁶⁶ Sources include green product clearinghouses like greenpages.com and buyers clubs such as the Sarasota Green Connection.

⁶⁷ A complete set of sustainability indicators would by necessity consider this and other investment decisions.

food waste and commingled containers. For instance, it recycles excess cooking oil for use in soap manufacture and transfers lawn trimmings to landscapers who mulch the yard waste to produce fertilizer. It also recycles cardboard packaging and building demolition materials. Over 96% of construction debris from a 2001 Media Lab renovation was recycled.

MIT's source reduction efforts have taken on a special role in the hazardous waste management sector. The Office of Environmental Health and Safety currently administers an industrial hygiene program to educate hazardous waste generators and handlers, ensuring that lab employees and service providers are aware of safe chemical and solid hazardous waste use and disposal procedures. Furthermore, the Procurement Department and OEHS have teamed up to centralize chemical purchasing and maintain an excess chemical storeroom to facilitate inter-laboratory material exchange, thereby avoiding unnecessary bulk purchases of similar products made by different labs in isolation. These departments also held a campus symposium on hazardous waste reduction techniques and have explored the micro-scaling of laboratory experiments, with the effect of reducing the institute's chemical intake to a limited extent. Future source reduction efforts should mine further alternative green product purchasing opportunities with a specific mind to purchase more environmentally preferable and perhaps even biodegradable laboratory solvents. They should also explore more general materials exchange between different campus operations and further micro-scaling of experiments where possible.

7.4 Indicator Presentation

Indicators should be tracked by a barometer measurement device. For simplicity, the gauge should employ +, ~, and – signs to denote time series movements that indicate improved, stagnant, or declining impact or management performance. Since no baselines for comparison will be available in the first year of tabulation, the barometer can initially assess whether the institute's behavior is negligent, cognizant, or aggressively pursuant of eco-efficiency opportunities.

Chapter 8: Value of Selected Indicators

Campus environmental management is a dynamic science, which relies on the screening of educational, residential, and other institutional activities for opportunities to reduce the ecological impacts associated with them. Innovations in campus EM are driven by information that facilitates the recasting of operating decisions that are ecologically inefficient. Indicators support managers' awareness of facilities and operations, measuring ecological impacts and institutional responses to them. Useful indicators are relevant, reliable, or consistent and methodically sound, and simplify the processing of various campus-related impacts either by helping managers to scrutinize among mitigation priorities or recognize realizable operational efficiencies.

To reiterate, this thesis aimed to help environmental managers process the enormous amount of campus impact information needed to facilitate informed decisions concerning programmatic focus. Its subsequent indicator recommendations are specifically designed for use by programmatic directors and those controlling budget expenditures, who might leverage the measures to steer future department initiatives and allocations. Indicator submissions are briefly summarized below.

Figure 10: Recommended Indicator Suite

Energy Consumption Indicators and Managerial Scenarios

1. Energy Generation Consumption Per Type Built Space
2. Power Generation Fuel Inputs
3. Energy Product Source Demand by Building Type
4. Total Campus Fleet and Commuter Fuel Consumption
5. Total Campus Green House Gas Equivalent Emissions by Source
6. % Power Generation Energy Procured from Renewable Sources
7. % Campus Buildings with Modern HVAC Controls
8. % Campus Built Space Served by Day-Lighting by Building Type
9. % Annual Commute Distance Made by Single-Occupancy Vehicles
10. Fleet Vehicle Fuel Economy

Water Consumption and Institutional Response

11. Water Consumption Per Type Built Space
12. Sewage Load Per Type Built Space
13. Share of Water Used for Irrigation
14. % Municipal Load Represented by Campus Water Demand
15. % Campus Impervious Surface Coverage
16. % Grey Water Reused
17. % Potential Rainwater Harvested
18. % Campus Irrigation Demand Comprised by Native Species Needs

- 19. % Campus Parking Spaces Housed in Multi-tiered Garages
- 20. % Campus Space Covered by Natural Water Filtration/Capture Projects

Non-fuel Materials Consumption and Waste Reduction and Reuse Performance

- 21. Conventional Waste Composition
- 22. Dining Hall Waste Composition
- 23. Non-Medical Biohazard Waste Composition
- 24. Non-Radioactive Hazardous Solid Waste Composition
- 25. Non-Radioactive Hazardous Liquid Waste Composition
- 26. % Environmentally Preferable Lab Solvents Procured
- 27. % Paper and Packaging Waste Recycled
- 28. % Food Waste Reused
- 29. % Lab Waste Reused
- 30. % Non-Solvent Green Products Procured

The recommended indicators survey several significant campus ecological impacts, like fuel uptake and emissions from power generation and transportation, water demand and storm water and sewage disposal, and material waste generation. Most indicators strive to demonstrate several layers of analytical complexity, normalizing stress composition by pollutant or building type, with the goal of informing the prioritization of actions to relieve the most pressing impacts they describe. All indicators listed make retrospective considerations and are thus augmented with mechanisms to track consumption patterns and related managerial response trends over time.

From a system perspective, the indicators function as a coherent list. They provide for the congruent consideration of pressure and response components, linking stress composition approximations with measures of managerial responses to address their sources. This linkage carries significant ramifications for understanding the movements of potential indicator values. In general, as most response indicator values increase, most pressure indicators documenting resource inputs and waste disposal will decline. There is however one exception to this rule, as is the case with indicator 9, % Commute Distance Traveled by Single-Occupancy Vehicles, under which declining single-occupancy vehicles use should be understood to indicate impact reductions (See discussion on page 37).

One overt yet so far unmentioned design ramification is indicator measurability: the recommended indicators were tailored to be quantifiable given current institute data collection capabilities and planned measurement improvements. As discussed, the institute meters nearly all campus buildings for water and energy use, collects data concerning fleet vehicle utilization and commuter travel, and has established calculation methodologies that estimate campus emissions and sewage generation and apportion these strains among various contributing sources. MIT also continually tracks its hazardous and conventional waste streams and keeps inventories documenting on-

campus parking spaces and tree species. These data sources and other elements necessary for making indicator calculations, such as proxy coefficients for energy associated with vehicle fuel combustion, are outlined in Appendices B and C.

Certain barriers stand in the way of indicator measurement and validity however, as some information and campus impact inventories relevant to calculating the proposed indicator suite do not yet exist. For instance, the institute does not currently track impervious surface coverage and has conducted no grey water inventory that might furnish managers with ideas as to how to best leverage grey water recycling and reuse possibilities. Nor has there been a scientific effort to determine what percentage of institute purchases procure green products.⁶⁸ Furthermore, data sets like the Transportation Survey and building impact reports are incomplete and only survey fractions of the impacts associated with campus buildings or commuter travel.⁶⁹ These shortcomings in data collection necessitate rough approximations of campus-wide impacts, which, because they utilize imputation to estimate total impacts from a limited sample set almost certainly overshoot or underscore actual impact values. However, information quality and hence indicator utility are soon likely to improve as managerial departments make outlays for the enhanced monitoring capabilities currently outlined in short term capital plans.

Indicators' utility to managers using them is also necessarily limited by scenarios affecting the underlying trends that indicators describe. Some of these scenarios arise from stochastic factors like weather or traffic reports that affect consumption behavior like traveler mode choice, while other underlying situations are anchored by economic and logistical realities. For instance, that environmentally preferable products are often more expensive than their conventional counterparts can hinder green procurement and since the cogeneration plant can only be fueled by certain inputs, the institute's ability to procure power from more renewable sources may be limited for the time being. In addition, fleet vehicle fuel economy adjustments can only be affected in so far as newer, more efficient vehicles are purchased and prove themselves to be capable of serving the departmental and student mobility needs as economically as today's fleet vehicles and heavy diesel shuttles do.

The presence of such potential modeling limitations demands that complete indicator analyses recognize these underlying economic scenarios and operational realities in their approximation of achievable system efficiencies. Therefore, comprehensive evaluations of the indicator suite would be best accomplished by augmenting the indicators with background reports explaining results from individual measures.⁷⁰ Assembling thorough driving force quantifications with error approximations would help managers generate more realistic benchmarks, or reduction targets, for offsetting consumption factor loadings. The graph from Groode (2004) that is

⁶⁸ Student projects designed to respond to these information gaps are documented in appendix B.

⁶⁹ Proof of this point is demonstrated by Groode (2004), which details information limitations extensively.

⁷⁰ Such a task is beyond the scope of this thesis but would be an excellent source of student UROP projects.

provided below demonstrates the interrelationships among indicator measurement and benchmarking, examining GHG emission levels as compared to reduction goals.⁷¹

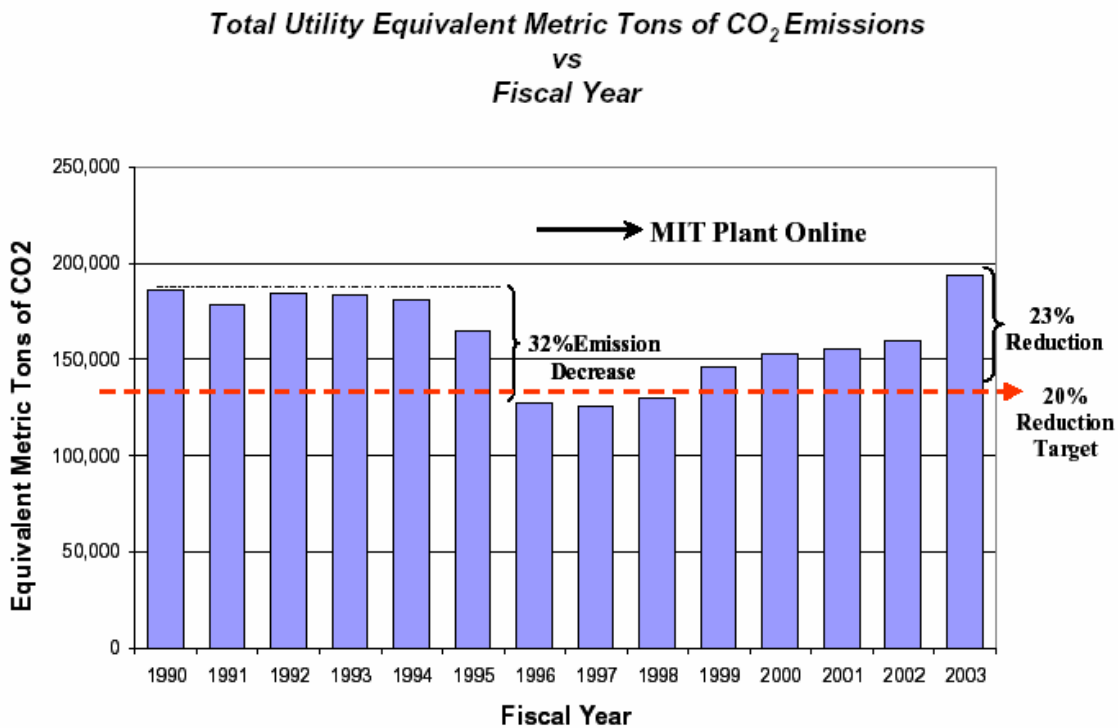


Figure 11: Utility CO₂ Emissions Set Against a Reduction Target (Groode, 2004)

Several other logistical considerations concern the measurement of the proposed indicator suite. First, in recognition that determining an appropriate indicator suite should be an open process, students and managers are encouraged to critique and revise the proposed indicators; constructive criticism from sources outside the institute like operations consultants, other universities, and perhaps even the Environmental Protection Agency might also be valuable, as would their services in helping to measure and database indicator information. Affecting an observatory relationship with another institution like the University of Cambridge in England might further eliminate potential bias in campus impacts audits, focus organizational scrutiny, generate new environmental management ideas, and produce a system of indicators that could perhaps be standardized for use as a model campus ecological auditing tool.⁷² Last, future measurement efforts can contribute indicator sets that are tailored to managers operating under program

⁷¹ This thesis barely broaches the topic of benchmarks with its recycled product content indicator. It makes no attempt to recommend benchmarks for the indicators, which would be premature if decided before measurements could be assembled. Benchmarking decisions should be left to managers who are most familiar with current operations and program budgets.

⁷² The application of such a standardized indicator set also necessitates the reporting of more global campus impact figures with more simple normalizations such as impacts per capita and total built space. Cross-institutional impact comparisons must not neglect potential growth in absolute consumption trends that normalized indicators can hide.

directors' supervision, who require more sector-specific impact and performance approximations.

The final indicator set omits some important impact areas discussed earlier in Chapter 5. Notable pressure omissions include automotive oil disposal from vehicle servicing, heating losses, ozone depleting refrigerator coolant use, and pesticide application, and response indicators omitted include buildings designed with ecological principles, coolant water reuse, demolition materials recycling, and downspout connections to modern storm drains. Broader impact areas deserving further consideration as compared to that devoted by the current indicator set are dining hall management, medical and radioactive waste, and campus procurement. All of these topics were excluded or given short shrift for one of three reasons, foremost among which was the need to limit the list so as to produce a coherent, manageable indicator suite. Other topics are omitted either because the institute has already ceased or does not plan to maintain related impact activities or because the impacts in question deserve further study in more focused student projects.⁷³

Future indicators should take additional steps to assay ecological strains and gauge the Institute's leveraging of specific asset management opportunities. For instance, new energy indicator topics might relate appliance energy efficiency, waste heat recapture performance and the portion of energy generated by decentralized, renewable power sources and a new water consumption indicator might track the amount of wastewater treated on campus. Other potential material consumption indicators can address topics like biodegradable solvent purchasing. The new indicators can also more generally survey cost savings associated with retrofit projects and might employ more sophisticated normalization techniques to measure energy, water, or material use per academic department or per laboratory experiment. All future indicators should point to specific utility conservation, facilities maintenance, process redesign, or end pipe solutions that managers can use to improve campus eco-efficiency.

⁷³ Building design criteria, coolant water reuse, and demolition materials recycling are not included in the final indicator set because almost all campus coolant water is already recycled and because MIT's recent evolving campus program has come to a close, indicating that the institute is entering a period of buildings stasis in which demolition materials, which are also already recycled, will be generated minimally.

Chapter 9: Campus Sustainability

9.1 Future Directions for Campus Sustainability

Currently, there is no scientific method with which to gauge whether MIT's consumption behavior is sustainable. Given performance limitations characterizing the institute's aging built asset stock, it might be impossible to achieve operational sustainability, even if pertinent sustainable thresholds become known. However, there are many available methods for making campus operations more sustainable and these strategies hinge on leveraging opportunities for improved operational eco-efficiency. Capitalizing on these opportunities will mean reducing consumption behavior and recycling and reusing waste to achieve more cyclic resource flows. This chapter describes sustainability projects currently deployed on campus, examines future projects that might contribute to making greater environmental sustainability progress, and explores the potential for developing an indicator set that approximates how well the MIT campus functions as a sustainable ecological unit.

9.2: Sustainability Projects on Campus

MIT has enacted several campus retrofit projects that transcend traditional conservation aims and achieve cyclic resource flow. These projects, notable among which are the Stata Center's biofiltration infrastructure and the cogeneration plant's heat recovery steam generator and algae reactor, all wring out possible ecological efficiency gains from specific operations. As mentioned previously, the Stata Center filtration setup captures rainwater for use in toilet flushing and the cogeneration plant's heat recovery steam generator (diagrammed below) utilizes waste heat from boiler combustion to drive steam production. The algae reactor is perhaps the most sustainable innovation on campus, removing substantial amounts of CO₂ from flue gas emissions and generating decomposed biomass, or dead algae, that can be distilled into biodiesel fuel at the end of algae colonies' functional lifetimes. Other sustainable projects include the installation and testing of a hydrogen fuel cell for renewable energy research at the on-site Nuvera test location.

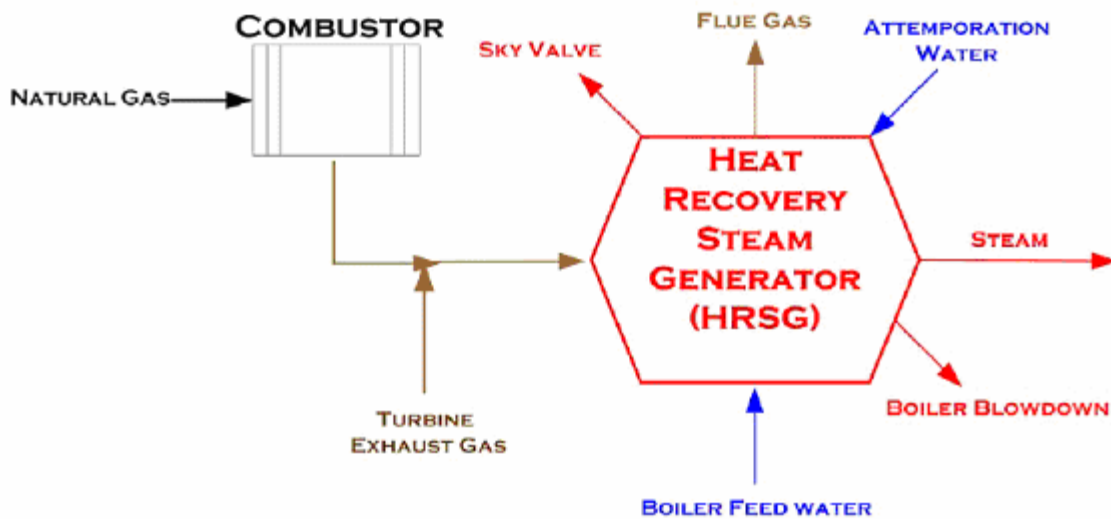


Figure 12: Heat Recovery Steam Generator Schematic

9.3: Sustainable Project Horizons

Future sustainability projects will rely on technological and behavioral solutions to remedy problems of overconsumption, advancing fixes that will recognize linear material flow regimes and consider process redesign opportunities to exploit greater cyclic resource use potential. Oberlin and The Biosphere confirms the value of such solution patterns to improving eco-efficiency, noting that:

“solutions to environmental problems will tend to arise from: a) better information about real costs (life cycle costs) and what are now discussed as externalities which are costs that someone else pays; b) better design and an effort to close waste loops; c) improvements in efficiency; d) attention to quantity and quality of inputs; and (e) a concentration on sufficiency” (Green et al, 1992).

Making strides similar to those described above will facilitate the transition of MIT’s campus into a more self-sustaining ecological unit, in which system components achieve reduced energy, water, and material source demand by feeding off of each other’s consumption byproducts.

Such a transition might be affected by greater decentralized power generation, materials recycling, and on-site effluent treatment via living machines that employ constructed wetlands’ filtration capabilities.⁷⁴ Implementing these and other like projects would shift campus operations away from wasteful behaviors and towards more ecologically-efficient practices, signaling a commitment to perfecting the institute’s use of environmental capital. Hence,

⁷⁴ Biomimicry techniques such as water filtration via constructed wetlands generally incorporate sustainable considerations.

current environmental management efforts should aim to transform the campus into more of an organic machine⁷⁵ and should remain confident that eco-efficiency improvements represent definitive steps on the uncharted path towards sustainability.

In order to affect practical change, sustainable solutions need to surmount existing cost barriers and incentive structures that prevent their current application. Current cost barriers arise from the initial price of retrofitting initiatives and additional eco-efficiency outlays will require considerable financial support since most potential “low-hanging fruit” projects with rapid payback periods have already been exhausted. As a result, future retrofit investments such as heating system modernizations must accept longer repayment horizons that exceed current five year capital recovery expectations. Furthermore, management efforts will have to address perverse research reimbursement incentive structures that do not currently reward or penalize academic departments for reductive or intensive resource consumption behavior. Refashioning these perverse incentive structures might induce behavior that for instance, transcends baseline legal compliance and supports specific sustainability improvements like converting individual campus buildings from net energy and water consumers into net resource exporters.

9.4: Potential for Producing a Campus Sustainability Indicator Set

David Orr summarizes the goal of SD auditing, noting that campus sustainability audits intend to “stimulate thinking about the evolution of institutions of higher education toward a twenty-first century agenda that must take account of the finiteness of earth, the logic of systems and their interrelatedness, and an emerging ethic about our role as citizens of the biotic community and our responsibilities to future generations” (Eagen and Orr, 1992a). As MIT’s indicator auditing becomes more sophisticated, environmental management goals should adapt to proscribe the development of a sustainability indicator set.

The sustainability indicator set should first distinguish itself from prior environmental indicator efforts by incorporating threshold values into indicator measurement. Essentially, sustainability indicators should feature more predictive ability, doing more to demonstrate current distances separating observed consumption behavior and maximum sustainable loads. Investigating these threshold values scientifically will require considerable study and will likely necessitate the employment of environmental state indices that incorporate ecosystem carrying capacities.

A sustainability indicator suite must also study a broader range of less tangible driving sources like sustainability research, institutional investment, and procurement activities. Sample indicators relating to these impact activities might survey

⁷⁵ Experimenting with biomimicry methods that further structure the campus as an organic machine is the most direct method of realizing the institute’s environmental management goal of becoming a model for sustainable research operations.

sustainability research grants, portions of the institute's endowment portfolio invested in socially responsible businesses, and miles traveled by food products comprising dining hall meals. Theoretically, declining tallies of total food delivery mileage would signal that the institute is using its resources to support local agrarian markets.

One obvious question concerning the deployment of sustainability initiatives surrounds the issue of funding. Since EPO and facilities budgets are spent mainly on day-to-day campus management, leaving few reserves for efficiency upgrade projects, how might allocations to enact sustainable initiatives be made? One viable solution to this funding dilemma would be the establishment of a sustainability revolving loan fund, which would make below market rate loans to fund future capital improvement projects and would subsequently be repaid through the sequestration of portions of saving streams resulting from decreased resource use.⁷⁶ Such a loan fund might also be used to fund projects that improve campus measurement capabilities and information management for indicator tracking. Another monetary policy maneuver that might generate additional potential for funding sustainability projects is the deferral of portfolio investment gains to fund further sustainability investments. Similar maneuvering could be incorporated into more overt sustainability investment strategies if a portion of the endowment portfolio were earmarked for investment in socially responsible business indices like the Chicago Climate Exchange and then redrawn after appreciation to provide additional seed capital for sustainability projects.

Finally, the institute should mine opportunities to expand current Martin Sustainability Fellowship funding to facilitate more topical research. One particularly focused application of this new research money might be the creation of a center for waste material reprocessing and reuse research within the Laboratory for Energy and the Environment. Perhaps some research funds could also be earmarked to accumulate sustainability research findings, campus impact publications and other student efforts like this thesis into a campus environmental library. If no physical space is available for additional library use, then such an environmental library could still be put to useful digital application as an augmentation to the institute's current environmental virtual campus database.

⁷⁶ As with all functional revolving loan practices, this fund would grow itself until attaining appreciable lending capacity by reclaiming savings payments set higher than the actual borrowing cost of funds. Universities like Harvard and several schools within the California State University system are already putting revolving loan practices to work to fund efficiency upgrades.

Appendix B: Indicator Calculation Procedures and Recommended Student Projects

Indicators should be calculated using the following methodologies. Some student projects to improve monitoring capabilities are necessary if these quantifications are to be made successfully.

1. Energy Generation Consumption Per Type Built Space

This calculation should examine the total BTU equivalent energy of fuel inputs consumed to power the MIT campus, apportioned by building type. Since no apportionment of fuel inputs by building type exists, this statistic should use the apportionment of end use demand sources by building type as a proxy for fuel input apportionment. This information can be found in the Stone Webster Management Report of 2003.

The calculation should proceed as follows:

Utility generation consumption per type built space = (BTU equivalent per combustion of 1 unit fuel input)x(fuel expended in utility generation)x (apportionment of end use demand by SF building type)

2. Power Generation Fuel Inputs

This indicator is simply a fuel input profile and does not involve any significant calculation beyond the transformation of fuel use statistics by BTU equivalent coefficients, which are available from the Environmental Protection Agency. However, student research is needed to compile this data. Cogeneration plant fuel use is tracked by the Department of Facilities and inputs comprising NSTAR's electricity contribution can be determined by forwarding inquiries to the power provider. For an example of how such a source composition profile might be compiled see Groode (2004).

3. Energy Product Source Demand by Building Type

This information is available in Stone Webster Management Consulting reports, which document chilled water, electricity, and steam demand per type built space.

4. Total Campus Fleet and Commuter Fuel Consumption

The Office of Parking and Transportation accounts campus vehicle fleet mileage and fuel use and its annual transportation survey tracks commuter mode shares. Student projects undertaken to calculate this indicator must wield methods of imputation to determine campus-wide energy consumption however, since the Transportation Survey only reaches ~50% of MIT's student and employee population. Until data quality improves, then, this calculation should be undertaken as follows:

Campus Transportation Energy Consumption = ((Fleet fuel use)x(BTU from combustion of 1 gallon by fuel type)+(commuter miles traveled by mode)/(average fuel economy per mode)x(BTU from combustion of 1 unit

by fuel type)). All necessary combustion coefficients are available from the EPA (see Groode, 2004).

5. Total Campus Green House Gas Equivalent Emissions by Source

The methodology necessary to make this calculation is extensive and students intending to perform the necessary quantifications should see Groode (2004), which concerns itself entirely with this subject.

6. % Power Generation Energy Procured from Renewable Sources

This calculation is very similar to the calculation for indicator two, except that the share of renewable energy is the focus of tabulation here.
 $\text{Renewable Contribution} = (\text{BTU from Renewable Sources}) / (\text{Total Utility BTU}) \times 100.$

7. % Campus Buildings with Modern HVAC Controls

To tabulate this indicator, a student project is needed to survey recent Department of Facilities capital projects to retrofit building HVAC controls. Once this is complete, the indicator calculation is simple:
 $\% \text{ Buildings of Interest} = (\# \text{ of building with HVAC control devices}) / (\text{total campus buildings}) \times 100$

8. % Campus Built Space Served by Daylighting by Building Type

Another student project is needed to survey campus building plans and inventory day-lit space. Building service space should be tabulated as the indicator denominator so that the measure does not consider structural building space that could not be functionally served by daylighting anyway.
 $\% \text{ Space Day-lit} = (\text{SF day-lit space per SF building type}) / (\text{total serviceable SF per building type}) \times 100$

9. % Annual Commute Distance Made by Single-Occupancy Vehicles

This indicator can be imputed and tabulated using Transportation mode share figures and Groode (2004) statistics.

$\% \text{ Commuter Miles by Single Occupancy Vehicle} = (\text{Average commuter trip distance}) \times (\text{Single occupancy vehicle mode share}) / ((\text{Average commuter trip distance}) \times (\text{total mode share frequencies}))$

10. Fleet Vehicle Fuel Economy

These statistics can be procured from Larry Brutti at the Office of Parking and Transportation.

11. Water Consumption Per Type Built Space

Individual building water consumption statistics can be procured

from Peter Cooper at the Department of Facilities. The student tabulating this indicator must apportion the available statistics by square foot building type.

12. Sewage Load Per Type Built Space

The individual building sewage information necessary for measuring this indicator is also inventoried by the Department of Facilities and a student project to apportion sewage disposal by building type is once again necessary.

13. Share of Water Used for Irrigation

Irrigation water use is monitored by the Building and Grounds division of the Department of Facilities and the information necessary to make this tabulation can be procured from Norman Magnuson.

Irrigation Share = (CCF water used for irrigation)/(total CCF purchased)

14. % Municipal Load Represented by Campus Water Demand

Campus water consumption statistics are available from the Department of Facilities and municipal supply information is available through the city of Cambridge and the Massachusetts Water Resource Authority.

Campus Share = (Total CCF purchased)/(Total CCF supplied by Cambridge)

15. % Campus Impervious Surface Coverage

Very little information necessary to calculate this indicator is available. A campus green space inventory does exist but an extensive student project is necessary to inventory impervious space.

Impervious Surface Cover = (SF of impervious surface)/(Total Campus SF)x100

16. % Grey Water Reused

Another extensive student project is necessary to document potential sources of reusable greywater (including toilet, sink, and shower water) and CCF sequestered by current greywater reuse projects.

Share of Grey Water Reused = (CCF Grey water recycled)/(Total CCF potentially recyclable grey water).

17. % Potential Rainwater Harvested

An inventory similar to that necessary for tabulating grey water reuse is a requisite for calculating this particular indicator. Student projects should obtain estimates of current rain water capture by storm water projects from the Department of Facilities. A simple proxy for the total

amount of harvestable rainwater could be constructed by measuring the total square foot coverage of building roof space and ground level storm water capture projects and multiplying that space by an estimate of total rain water capturable per unit area given average annual rainfall in the Greater Boston Metropolitan Statistical Area. These estimates are available from the EPA and the National Weather Service.

Share of Rain Water Capture = $(\text{Rain water collected}) / ((\text{Total roof and storm project space}) \times (\text{Average annual rainfall}) \times (\text{Rain collectible per unit area storm water capture projects})) \times 100$.

18. % Campus Irrigation Demand Comprised by Native Species Needs

A campus tree inventory already exists but to facilitate the tracking of this indicator a student project to assay all on-site plant species and determine the composition of plants native to New England is needed. A sophisticated methodology should inventory the total annual water requirements for each type of plant species on campus and would apportion the native species composition by determining the percentage of irrigation demands devoted to feeding native species. Such information is available from horticulture texts.

% Native Species Composition = $(\text{Campus native species composition}) \times (\text{Water demand by plant type}) / (\text{total irrigation demand}) \times 100$.

19. % Campus Parking Spaces Housed in Multi-tiered Garages

To calculate this indicator a student should inventory campus parking spaces, information about which is available from the Office of Parking and Transportation, and determine what percentage are housed in multi-tiered garages.

% Multi-Story Parking = $(\text{Spaces housed in garages}) / (\text{Total space}) \times 100$.

20. % Campus Space Covered by Natural Water Filtration/Capture Projects

The calculation of this indicator should be similar to the procedure for calculating the rain harvesting indicator.

Natural Water Filtration/Capture Space Share = $(\text{SF of natural filtration/capture projects}) / (\text{Total campus space}) \times 100$.

21. Conventional Waste Composition

Measuring this indicator should be a relatively simple data collection exercise since the Department of Facilities and the Office of Environmental Health and Safety already measure the composition of the campus waste stream. Students should see Justin Adams at OEHS to obtain such data.

22. Dining Hall Waste Composition

Dining hall waste is also measured by the above offices and

measuring this indicator should be a simple data aggregation exercise.

23. Non-Medical Biohazard Waste Composition

Students should contact Susan Leite at EHS to initiate the process of inventorying this waste stream.

24. Non-Radioactive Hazardous Solid Waste Composition

The Environmental Health and Safety Office tracks solid waste stream composition in accordance with federal regulations. Students seeking hazardous waste data should contact Susan Leite.

25. Non-Radioactive Hazardous Liquid Waste Composition

Measuring this indicator will be yet another simple aggregation of data that is already in existence and available through OEHS.

26. % Environmentally Preferable Laboratory Solvents Procured

The information necessary to make this tabulation is available through the institute's accounting office and Procurement Department.
Environmentally Preferable Solvent Share = $(\text{Environmentally Preferable Solvent liters purchased}) / (\text{Total solvent liters purchased}) \times 100$.

27. % Paper and Packaging Waste Recycled

All recycling information is tracked by the Office of Environmental Health and Safety and interested students should contact Justin Adams for recycling figures.

Paper and Packaging Recycling Share = $(\text{Total quantity paper and packaging recycled}) / (\text{Total paper and packaging quantities purchased}) \times 100$.

28. % Food Waste Reused

Interested students should again contact Justin Adams to procure data that is already collected.

Food Waste Reuse = $(\text{Total volume food waste recycled}) / (\text{Total food waste generated}) \times 100$.

29. % Lab Solvents Reused

MIT does not currently redistill spent lab solvents and a student project surveying potential points of reuse would be instrumental to initiating a laboratory waste reprocessing operation and collecting this indicator information.

30. % Non-Solvent Green Products Procured

No comprehensive measure of green product procurement on

campus is known. Perhaps the most useful student project among these suggestions would be one surveying current purchasing practices, potential environmentally preferable alternatives, and more important yet, the distance traveled by current dining hall menu ingredients. Such a student project would help MIT green its procurement practices and leverage its expenditures to support local, sustainable economies. Upon completion, the weight of environmentally preferable products should be considered against the entire weight of all purchases made.

Appendix C: Campus Consumption Information Sources

Massachusetts Institute of Technology 2004 Transportation Survey.

The Transportation Survey documents commuter mode share statistics and travelers' preferences and awareness of available transit ridership inducements. Other students seeking additional transportation statistics should consult with Larry Brutti.

Massachusetts Institute of Technology Procurement Policy: Informal Memo to Staff (https://web.mit.edu/controller/procurement/pdf/mitonly/Purchasing_Policy.pdf)

This memo details guidelines encouraging procurement agents to explore green purchasing. Students wishing to learn more about Green Purchasing should contact the Procurement Department.

Massachusetts Institute of Technology 2004 Annual Town Gown Report.

The Town Gown Report demonstrates MIT's future relationship with the city of Cambridge, highlighting its future building, occupancy, parking space provision plans. The document also surveys municipal fees and other capital outlay projections. Further questions about planned capital outlays should be directed at Deborah Poodry and Peter Cooper.

Massachusetts Institute of Technology Environmental Health and Safety Policy

The Environmental Health and Safety Policy provides a directive for all MIT operations and lays out the core mission of the Environmental Program Office and the Office of Environmental Health and Safety. This document is available via the MIT environmental programs website or through EPO officers such as Steve Lanou.

MIT 2004 Environmental Goals Task Force Draft Implementation Plan.

This document is an oft-updated working paper that appraises the status and future horizons of environmental management projects at MIT. Questions regarding the document should be directed to Steve Lanou, who can connect interested students with particular program managers.

Groode, Tiffany. “*A Methodology for Assessing MIT’s Energy Use and Greenhouse Gas Emissions.*” MIT Master of Science in Mechanical Engineering Thesis, 2004.

Groode’s thesis is a thorough source of campus energy consumption information. It familiarizes the process of environmental auditing and impact calculation by way of GHG emission tracking tools.

Stone Webster Management Consultants Report, 2003.

The Department of Facilities hires management consultants to track annual campus energy consumption. This report details chilled water, electricity, and steam demand by building and building type.

“Sustainability Assessment Questionnaire for Colleges and Universities.” University Leaders for a Sustainable Future Publication, 2001.

This questionnaire is a good starting point for students considering the initiation of a campus sustainability audit. If not available online, interested students can call ULSF and request a copy.

“Sustainability Reporting Guidelines.” Global Reporting Initiative Report, Boston: 2002

This GRI report explores data quality dilemmas relevant to sustainability indicator tracking.

“The Benefits and Economics of Treating and Reusing Cooling Tower Bleed-Off” Department of Facilities Report by Raul Varella, 2003.

This report documents a typical method by which facilities engineers devise and evaluate potential projects. Raul Varella should be the leading contact for those students interested in campus water conservation initiatives.

No author listed. “*Research Examples.*” National Wildlife Foundation Publication, 2002. (<http://www.nwf.org/campusEcology/HTML/>)

This NWF web publication documents possible student research projects that will facilitate campus auditing.

Western Michigan University’s Campus Sustainability Assessment Project (<http://csap.envs.wmich.edu/>)

This webpage is a good resource for informing campus auditors as it contains an annotated bibliography of campus auditing literature and a database of best practices in campus management.

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