Report of the Environmental Research Council:

Prospectus for an Initiative on Global Environment at MIT

Global Challenges—Global Opportunities

MIT Environmental Research Council:

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Massachusetts Institute of Technology

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Executive Summary

Humans now exert a dominating influence on the global environment. Both intentionally and inadvertently, we are precipitating changes at rates and spatial scales unprecedented in human history. While our understanding of these changes is improving, we remain ill-equipped to respond to them, either through mitigation or adaptation.

The Environmental Research Council (ERC) has therefore identified a mission to which the community at MIT must address itself: developing science-based local, regional and global management strategies to maintain and restore resilience in both human and natural systems. To this end, we must build our understanding of how the global biosphere works, how human activities impact natural systems, and how social, economic and political forces drive those impacts. This enhanced understanding must also inform how we prepare our students for an environmentally sustainable future.

The ERC therefore proposes marshaling the Institute's core strengths and research momentum in earth and environmental science, environmental engineering, biology and genomics, computation and modeling, economics and business, environmental planning and design, and technological innovation into a cooperative enterprise dedicated to the rational management of humanity's role on Earth—an initiative on global environment at MIT.

Given MIT's tradition of innovative scholarship, signature commitment to collaborative work spanning disciplinary boundaries, and record of delivering scientific insights to the policy-making process, the Institute is uniquely positioned to undertake this vital effort. To best focus these capabilities for immediate impact, we further propose six inaugural areas of research emphasis that will build on existing strengths at MIT to address a comprehensive slate of global environmental challenges:

1. Future of the Oceans
2. Ecosystem Resilience
3. Changing Climate
4. Rethinking Water
5. Sustainable Cities
6. Synthetics in the Environment

With these challenges come unprecedented opportunities to harness the latest tools and insights of science in advancing our understanding of the Earth system, and how we can best build a sustainable future. These new capabilities promise to transform environmental science and management in much the same way that the science and practice of medicine have been revolutionized over the past half century through the advent of molecular biology and advanced imaging technologies.

While ambitious, the enterprise outlined in this report is both appropriate and imperative for MIT to pursue. We therefore advocate immediate action to create a strategic implementation plan for launching this initiative on global environment over the coming year as the nexus for coordinated environmental research and associated education at the Institute.

Prospectus for an Initiative on Global Environment at MIT

Global Challenges—Global Opportunities

1. MIT and the Environmental Challenge: Call to Action

Throughout its history, MIT has been committed to generating practical solutions to the grand challenges facing society. During World War II, MIT scientists and engineers worked across disciplinary boundaries to create many of the technical breakthroughs vital to the Allied victory. Today, the challenges of human health, energy and the environment demand that we rethink and refocus our proven collaborative, interdisciplinary research enterprise accordingly. With Institute-wide initiatives already well under way in both energy and health sciences, the Environmental Research Council (ERC) believes that the time is ripe for MIT to formalize its commitment to an initiative on global environment.

The primary function of this environmental initiative at MIT will be to foster new knowledge, technology and skills that enable sustainable interaction with our vital environmental systems. Of particular importance is our response to issues that manifest themselves at a global scale. For example, understanding, forecasting and responding to climate change represents one of the greatest challenges for interdisciplinary science and engineering in the 21st Century.

Successfully addressing such global challenges demands an integrated approach recognizing all physical, chemical, biological and human processes as interrelated parts of a single Earth system. The approaches we take to managing our environment and solving environmental problems must now move beyond simple trial-and-error. We must exploit our ever-expanding scientific and technological capabilities to revolutionize our understanding of, and relationship with our global environment—much as the advent of molecular biology and advanced imaging technologies have transformed the science and practice of medicine over the past 50 years.

1.1 Challenge and Opportunity

Over the past several decades, we have come to realize that our collective actions as humans are changing the physical and biogeochemical systems that support all life on Earth. In fact, human activities have become a major force in altering Earth system processes. For example:

- Greenhouse gas emissions, primarily from burning fossil fuels, are altering Earth's climate and weather patterns. The potential consequences of polar ice melting and resulting sea-level rise alone are cause for action.
- Overfishing, pollution, habitat destruction and the effects of climate change have degraded vital functions of the world's oceans, the largest of Earth's ecosystems.
- Escalating rates of deforestation to meet food, biofuel, and other social and economic demands threaten permanent losses in both biodiversity, and soil and water resources.
- Current water-use practices are inherently unsustainable. Scarcity and degradation of this resource—arguably more vital than oil but routinely squandered—make fresh water one of humanity's most pressing resource limitations.

- Half of the world's nearly 7 billion people now live in urban settings, most in coastal areas. The accelerating pace of urbanization threatens air and water quality, posing human and environmental health issues of unprecedented scale and intensity.
- Synthetic chemical compounds and genetically modified organisms released into the environment are spreading and accumulating at astonishing rates with generally unknown ecological and human health consequences.

While these challenges are enormous and pressing, so are the opportunities to confront them. Indeed, our scientific, technological and social capacities to examine, understand and modulate our impacts on the environment are accelerating apace. These include:

- Rapid advances in the life sciences and genomics;
- Exponential improvements in large-scale computational modeling capabilities;
- Unprecedented advances in sensitive yet affordable sensor technologies;
- The emergence of an integrated systems approach to understanding both Earth processes and human societies; and
- Dramatic innovations in "green chemistry", environmentally benign-by-design technologies and ecological planning at a variety of scales, ranging from urban to regional landscape infrastructure (water, energy, and open space).

Taken together, these advancements promise to revolutionize our understanding of how Earth's ecosystems function interactively to comprise our global environment.

The ERC also clearly recognizes that scientific knowledge alone cannot suffice to steer us in sustainable directions—knowledge must be put into action. The adoption of new technologies, designs and practices does not follow automatically from research. In addition to improving our understanding of the physical and biogeochemical processes of Earth's ecosystem, we must also comprehend and manage the economic, social and political dynamics that govern how we interact with our environment. These dynamics both contribute to the challenges we now face and are central to the successful implementation of the new technologies, practices and governance systems needed to address them.

1.2 Why MIT? Why Now?

World-class programs in all of the key disciplines—meteorology and oceanography, earth and environmental science, engineering and technology, life sciences and genomics, computation and modeling, economics and policy analysis—coupled with a history of tackling society's most pressing issues, make MIT the ideal institution to lead in developing knowledge-based management strategies to maintain and restore the resilience of both human and natural systems. Indeed, given the wealth of resources and relevant research activity at MIT, the absence of a formal environmental initiative here is misleading, particularly in light of the programs already launched at many of our peer institutions. The time to correct this omission has come.

To that end, this report offers a roadmap for marshaling the Institute's core strengths and cutting-edge research into a cooperative enterprise dedicated to the rational management of humanity's role on Earth. In keeping with existing momentum—from the birth of the MIT Earth System Initiative (ESI) in 2002, to the commitment to issues of energy and the environment in President Hockfield's 2005 inaugural address, to the launch of the MIT Energy Initiative

(MITEI) in 2006, to the report of the Committee to Assess Environmental Activities in 2007, to the formation of the Faculty Environmental Network for Sustainability (FENS) in 2008—we formally propose an Institute-wide initiative designed to focus the inherent interdisciplinary creativity of MIT on a broad agenda of impact-oriented environmental research. The combined leverage of this environmental initiative at MIT will greatly exceed that of its component parts, and the ERC proposes its creation with great enthusiasm and optimism for the future.

2. Outline for Engagement: Building Strength on Strength

Over the past two decades, the focus of MIT's core research strengths relevant to issues of the environment has evolved in concert with growing faculty commitment to the perspectives of global change and Earth system science. In particular, the Earth system notion of a unified biosphere comprised of intimately interrelated physical, chemical, biological and human systems informs our concept for an initiative on global environment, and provides the governing approach for its practical research agenda. Although individual research efforts must necessarily focus on problem-driven subsets of the larger system, these can never be regarded as isolated or separable from the whole.

2.1 Research Agenda

The ERC proposes six inaugural areas of global research emphasis upon which to build an environmental initiative. Each area represents the confluence of existing research expertise at MIT with a pressing environmental issue. The first three areas—Future of the Oceans, Ecosystem Resilience and Changing Climate—are intimately linked in addressing three pillars of the global biosphere. Yet each area also presents its own scientific research challenges, tools and methods. The fourth and fifth areas—Rethinking Water and Environmentally Sustainable Cities—address the exploding challenges of managing freshwater resources and the habitability of urban environments. While global in their impact, these two areas are also closely related to environmental issues affecting human welfare at regional and even local scales. The final area of research emphasis—Synthetics in the Environment—addresses the proliferation of chemicals and organisms that have been altered or entirely created by humans. This represents an as yet little recognized, but alarming issue already impacting the environment at ever-increasing scales.

Together, these six research areas span the realms of Earth system science and global environmental challenge, while also providing a very practical and integrated research agenda. Naturally, the specific research agendas outlined below will evolve, expand and interweave over time in concert with new discoveries, priorities, cross-disciplinary synthesis, and collaborative faculty interests—but the path starts here.

2.1.1 Future of the Oceans

Earth's oceans represent its final frontier. Very little is known about them relative to our world on land. However, the impacts of climate change on the oceans are very real and pose significant physical, ecological, social and economic challenges for humanity. For example, ocean surface waters are warming, sea level is projected to rise over the coming century to threaten coastal communities, the oceans are becoming increasingly acidic, and marine habitats are under threat. Human activities are compromising the health of the oceans and their ability to sustain our lives, with implications for fishing, shipping, tourism, off-shore mining, oil and gas exploration, and ocean governance.

The challenge is to understand and model critical aspects of our oceans today such as sea-level rise, declining marine habitats and fisheries, reduced seasonal sea-ice coverage, ocean acidification and pollution. We propose the following slate of initial research thrusts to launch this effort:

- Use observations and models to develop future scenarios for the oceans and their ecosystems;
- Develop ocean models that integrate marine physics, chemistry and biology;
- Develop autonomous physical, chemical and biological measurement platforms and adaptive sampling strategies;
- Advance large-scale data-fusion techniques that draw together ocean observations with models;
- Reduce uncertainty in projections of polar ice persistence, sea-level change and ocean acidification;
- Explore the capacity of oceans to provide both energy and storage for anthropogenic greenhouse gases;
- Characterize the dynamics of fisheries, the effects of pollution on fish populations, and the policies and political dynamics that result in overfishing; and
- Analyze the regional planning and real-estate practices that lead to overdevelopment in coastal regions.

2.1.2 Ecosystem Resilience

Humans have transformed terrestrial and aquatic ecosystems at the global scale. We have altered global biogeochemical cycles of compounds that affect living systems as well as the climate. A sizeable fraction of Earth's primary productivity—photosynthesis—has been co-opted by humans, fundamentally changing the structure of Earth's ecosystems and the diversity of life that depends on them. Over half of all accessible fresh water is appropriated by humans. These actions all have consequences for ecosystems that raise questions about their future viability.

We must better manage these vital ecosystems by building our knowledge of how they function from microbial to global scales, understanding the sources of their resilience and fragility, and creating economic systems that properly value the goods and services they provide. We propose the following slate of initial research thrusts to launch this effort:

- Develop advanced physical, chemical and biological sensor systems;
- Understand how genes, assembled into organisms, ensure basic functions of ecological communities;
- Quantitatively characterize physiological and evolutionary adaptability of organisms and ecological communities to environmental change;
- Understand the relationship between biodiversity and resilience in ecosystems;
- Develop and evaluate innovative approaches to biodiversity conservation, such as ecosystem-based management and rational valuation schemes for ecological services.

2.1.3 Changing Climate

Human activity is now precipitating changes in the global climate at rates approaching those of natural perturbations and shifts throughout human history. The eventual response of the climate system to our actions remains uncertain, mostly because we are only now beginning to comprehend the intricate feedback mechanisms that can either buffer or destabilize the system.

We must significantly add to our basic scientific understanding of how the climate system functions, while bolstering our ability to forecast its response to varying scenarios of human impact and natural forcing. We propose the following slate of initial research thrusts to launch this effort:

- Quantify the impact of land-use change on the global carbon budget;
- Advance our knowledge and modeling of atmospheric chemistry and aerosols;
- Forge greater understanding of the linkages between global energy, biogeochemical and water cycles; and
- Analyze the vulnerability of major urban, agricultural, coastal and other areas to climate change, and facilitate planning for enhanced resilience and adaptation.

2.1.4 Rethinking Water

Fresh water is becoming an increasingly scarce resource worldwide, one too often squandered in inefficient, inequitable and unsustainable ways. We must fundamentally rethink how water is used to enhance human welfare and environmental health. New approaches to integrating water system design, planning, policy and governance must be developed to enable evaluation of trade-offs between water and related resources such as energy. These management innovations will depend upon deeper scientific understanding of the scaling and synthesis of solutions that address water challenges in creative, practical and sustainable ways. We propose the following slate of initial research thrusts to launch this effort:

- Develop cost-effective desalinization, treatment and other technologies to augment fresh water supplies;
- Improve life-cycle analysis for water and energy use in manufacturing and recycling;
- Synthesize hydrological, ecological and social analyses of water use across scales;
- Quantify the performance of water-conserving environmental design technologies at different spatial and temporal scales;
- Develop policy mechanisms that foster the diffusion and adaptation of innovations across different geographic, historical and cultural contexts; and
- Evaluate the effectiveness of aquatic conservation and restoration initiatives.

2.1.5 Environmentally Sustainable Cities

Urban living is the most likely future for most of the world's rapidly growing population. Yet our approach to urban design and management fails to ensure that we will be able to deliver clean water, remove waste, maintain air quality, and provide energy over time. We must develop new approaches to urban planning, design and policymaking that promote urbanization that is environmentally sustainable, socially equitable and economically viable. To embark on this path will require a concerted interdisciplinary effort. We propose the following slate of initial research thrusts to launch this effort:

- Create integrated models of urban transportation and utility networks, as well as of air, land and water systems;
- Develop urban environmental monitoring systems using pervasive sensing and real-time modeling; and
- Develop models of urban environmental sustainability that also addresses critical social needs such as racial, ethnic and religious integration;

2.1.6 Synthetics in the Environment

The production, use and disposal of synthetic manufactured materials and pharmaceuticals release new chemical compounds into the environment. These materials are often unusually resistant to natural degradation. Instead they tend to disperse and accumulate at astonishing rates with unknown ecological and human health consequences. Genetically-modified organisms are raising similar concerns. This trial-and-error approach to introducing new chemicals, processes and organisms into the environment defies common sense. Developing the capability to predict the environmental impacts and exposure consequences of new chemicals, materials and life forms during their design phase and before release is vital. We propose the following slate of initial research thrusts to launch this effort:

- Advance environmentally benign product design and manufacturing;
- Develop the capability to predict the impacts of synthetic agents and organisms on human health; and
- Analyze the effectiveness, and economic and social costs of regulations that aim to mitigate risks to human health and the environment posed by synthetics and genetically-modified organisms.

2.2 Momentum at MIT

MIT boasts long-standing and current excellence in oceanic, atmospheric and terrestrial sciences, including global hydrology and climate research. The Institute's well-established expertise in modeling and computation are also being fully engaged in the geosciences. In addition, MIT has developed significant research programs and infrastructure in the life sciences, particularly in environmental microbiology and genomics, geobiology and environmental health sciences. Finally, the Institute offers substantial strength in science and technology policy, urban planning, landscape and architectural design, and business and economics. Each of these areas of excellence and expertise will provide immediate momentum to the environmental initiative, and will contribute resources essential to realizing its proposed research agenda.

Many issues of energy production and use are intimately interrelated with issues of global environmental health, necessitating a coordinated approach to sustainable management that will require close collaboration between MITEI and the new environmental initiative.

The structure of the environmental initiative must also provide an open framework in which to forge mutually advantageous relationships with other key programs already established at MIT, such as the Center for Global Change Science (CGCS) and its Climate Modeling Initiative, the Joint Program on the Science and Policy of Global Change, the Center for Environmental

Health Sciences, the Sloan School Sustainability Lab, the Center for Clean Water and Clean Energy, the Alliance for Global Sustainability, FENS and ESI. The Joint Program on the Science and Policy of Global Change represents a particularly powerful example of the integration of the natural and social sciences. Similarly MIT and the Woods Hole Oceanographic Institution (WHOI), with whom MIT faculty closely collaborate through the MIT-WHOI Joint Program in Oceanography/Applied Ocean Science and Engineering, offer a broad program of education and research focused on Earth's oceans—their circulation, ecosystems, biogeochemistry, role in climate, and the co-evolution of life and climate.

Insofar as vibrant research is the life blood of experiential education for undergraduates and graduate students alike, the ERC specifically acknowledges the inherent educational component of the proposed environmental research initiative. We also recognize the imperative for close coordination between the new initiative and classroom teaching at MIT, particularly with regard to the new Minor in Energy Studies established by MITEI, and the proposed minor in environment and sustainability now being developed by FENS.

The ultimate success and productivity of the environmental initiative will depend on its ability to mesh with and harness the traditional grassroots initiatives of MIT—the collaborative energy of the faculty manifest in the many cross-disciplinary labs, centers and programs already in existence. The value-added by the environmental initiative will lie in its ability to foster new collaborative connections, attract the funding to sustain them, and deliver the resulting insights and technologies where and when they are most needed.

3. MIT Creates: The Way Forward

Through this initiative on global environment, MIT can assume a lead role in both creating the knowledge and in training the new generations of scientists, engineers, planners, designers and policy makers needed to enable sustainable relationships between humanity and our natural systems. The ultimate success of the endeavor will be fueled by the talented individuals attracted to it—from within MIT and around the world. While ambitious, the enterprise outlined in this report is both appropriate and imperative for MIT to pursue. We therefore advocate immediate action on a strategic implementation plan to launch this initiative on global environment over the coming year as the new nexus for coordinated environmental research at the Institute.

Specifics next steps should include:

- Soliciting white papers that span the full range of environmental research challenges and opportunities at MIT in order to inform the implementation process;
- Engaging MIT's offices of Resource Development and Institutional Initiatives to begin developing potential funding sources for the environmental initiative as a whole, and for specific research hubs as they develop;
- Establishing collaborative relations with key MIT groups including: MITEI, CGCS, the Joint Program on the Science and Policy of Global Change, the MIT-WHOI Joint Program in Oceanography/Applied Ocean Science and Engineering, the Sloan School Sustainability Lab, the Center for Environmental Health Sciences, the Center for Clean Water and Clean Energy, the Alliance for Global Sustainability, FENS and ESI; and
- Building an independent external board to advise the ERC on implementing, launching and managing the new initiative on global environment at MIT.

4. Appendix A: Provost's Charge to the Environmental Research Council

This charge follows up on the "Zuber Committee" report, "Creating a Sustainable Earth: An MIT Research, Teaching and Public Service Initiative for Understanding, Restoring and Managing the Environment" (http://web.mit.edu/provost/letters/letter05052008.html) and represents the MIT administration's response to the recommendations of the report.

The MIT Environmental Council is hereby established to support an Institute-wide Environmental Initiative. The members are:

Sallie W. Chisholm	Department of Civil and Environmental Engineering
Dara Entekhabi (Chair)	Department of Civil and Environmental Engineering
Michael Greenstone	Department of Economics
Judy Layzer	Department of Urban Studies and Planning
John C. Marshall	Department of Earth, Atmospheric and Planetary Sciences
Dianne K. Newman	Department of Biology
Daniel G. Nocera	Department of Chemistry
Martin F. Polz	Department of Civil and Environmental Engineering
Ronald G. Prinn	Department of Earth, Atmospheric and Planetary Sciences
Daniel H. Rothman	Department of Earth, Atmospheric and Planetary Sciences
John D. Sterman	Sloan School of Management
Phillip J. Thompson	Department of Urban Studies and Planning
James Wescoat	Department of Architecture

The central recommendation of the Zuber report is that MIT should launch a research initiative focused on the development of new insights into Earth's natural systems that are required to support science, technology, design, policy, and management of interventions that advance environmental sustainability. Advances in these areas represent potential major contributions that MIT can make based on needs in the field and its core strengths, and will influence research and education on a wide range of environmental topics.

The MIT Environmental Council is charged with development of a research prospectus by February 15, 2009. The prospectus will be broadly shared with the campus environmental community so as to insure the engagement of the faculty necessary to make the research prospectus compelling to potential donors, sponsors and other stakeholders. Potential donors expect to see a mobilization that will produce high impact research on an important topic. The charge and the composition of the Council are aimed at framing and advancing the focused research program recommended by the Zuber Committee, and at providing a foundation for the needed resource development. The MIT administration and the resource development office will assist the Council leadership in seeking such support.

MIT has robust research programs in a number of related areas – for example, water, climate change, and energy – with a separate identity, leadership, and momentum. The Environmental Council is charged with consulting and engaging faculty in these areas so that the necessary synergies can be achieved, duplication avoided, and additional environmental goals framed and advanced.

We recognize that additional opportunities will arise to advance new initiatives on the environment and sustainability, drawing upon knowledge from several fields. The Environmental

Council is charged with pursuing such opportunities to the extent that they complement the Earth systems research.

In addition to the establishment of the MIT Environmental Council, the Zuber Committee recommended support of a bottom-up faculty effort. A proposal has emerged for a Faculty Environmental Network, which will serve as an open forum for faculty to share their interests and goals for environmental research and education. We will support this network and look to it as a forum for ideas and information exchange within the broader environmental community.

As many of you know, the MIT Energy Initiative (MITEI) has established a task force to develop energy-related education at MIT (see MITEI's Education Task Force, http://web.mit.edu/mitei/education/taskforce.html). The Task Force is active and has broad engagement with faculty as well as with the leadership of key academic units. They expect to complete a major effort involving new subjects and degree programs this fall, all of which will have strong environmental components. Discussions with the Zuber Committee and MITEI leadership have suggested that this Task Force can be charged more broadly so as to serve effectively both the Environmental and the Energy Councils. The Environmental Council is charged with working with MITEI's leadership and with MITEI's Education Task Force to define and advance the energy and environmental education goals of MIT.

The Council is also asked to take a global perspective on the environment. All of the groups are charged with finding appropriate ways to engage the several student groups that have emerged – both to harness their passion for the topics and to engage them directly in discussions about educational programs.

The MIT Environmental Council is further charged with consulting with the MIT Energy Council on ways to exploit synergies between environmental and energy research. To facilitate this consultation, the chairs (or their representatives) of the Environmental and Energy Councils will serve ex officio on each other's Council.

The administration expects the MIT Environmental Council to have a life of five years and may be renewed. At the end of each year, the Council will submit a report and the administration will review the charge and the membership of the Council.

5. Appendix B: Report of the Committee to Assess Environmental Activities at MIT

Creating a Sustainable Earth:
An MIT Research, Teaching, and Public Service Initiative for Understanding, Restoring and Managing the Environment

A Report by the Committee to Assess Environmental Activities at MIT

Edward A. Boyle, Rafael L. Bras, Sallie (Penny) Chisholm, Elfatih Eltahir,
Dara Entekhabi, William H. Green, Patrick Jaillet, David H. Marks,
Daniel G. Nocera, Kenneth A. Oye, Paola M. Rizzoli, Jeffrey I. Steinfeld,
John Sterman, Lawrence E. Susskind, Jefferson W. Tester,
Lawrence J. Vale, Maria T. Zuber (Chair)

September 21, 2007

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EXECUTIVE SUMMARY

The Committee to Assess Environmental Activities at MIT was chartered to recommend a way forward in coordinating and expanding the scope of environmental activities at the Institute. Currently, there is an impressive array of outstanding research and educational endeavors that span all schools, but lack of coordination results in low visibility and the perception of sub-critical mass, and at an institutional level MIT is not viewed as being among the leaders in this field. MIT's commitment to the environment, and the related area of sustainability, must emphasize the integration of its research, practice, and teaching strengths across the Institute. The Committee recommends a shared vision to unite environmental studies: *Creating a Sustainable Earth: An MIT Research, Teaching, and Public Service Initiative for Understanding, Restoring and Managing the Environment.* This initiative will involve the breadth of MIT in understanding the environment and using this increased knowledge to design a sustainable future. Positioning this initiative for success will require a new organizational structure that must be at once "top down", ensuring buy-in from the senior Administration, and "bottom up", enabling faculty members to claim ownership. Environmental activities should be integrated to the extent possible with the Energy Initiative, to maximize intellectual synergies. By organizing optimally and expanding appropriately, MIT will greatly enhance its ability to provide a breadth of balanced scientific, technical, economic and policy analyses on issues relating the environment and sustainability and their relationship to energy.

I. INTRODUCTION

The Earth faces many challenges of both natural and human-induced origin: global warming, air and water pollution, the loss of key species, severe storms and a decline in readily-accessible natural resources to name just a few. The energy and resource requirements of the developed world today are placing significant environmental stress on the Earth at all scales. Furthermore, population growth, rapid urbanization, and increased industrialization in developing countries are accompanied by dire poverty and expanding energy needs. Both are having an increasingly adverse impact on the environment. Development is not proceeding in a sustainable fashion. These problems are complex, with scientific, technical, economic, social and political causes and impacts that must be addressed simultaneously. Integrative, out-of-the-box thinking is required. There is growing acceptance that we are entering a new chapter in the history of the Earth. We have interfered with natural Earth processes, and in doing so have become responsible for the well being of future generations. The time window for drafting a plan is short, and our current knowledge is inadequate.

Improved understanding of the natural processes that have shaped and sustain the environment, and charting a path towards sustainable development, is a grand challenge for this century, one that MIT can and should address as a highly-visible leader. An impressive amount of environmentally relevant research and education is underway on campus, and individual programs are regarded as elite. However, MIT as an institution is not currently viewed as leading the way in understanding the environment, nor in utilizing current knowledge to improve the lives of future societies. With the growing realization of the importance of the environment by governments, business, academia and the general public, the time has come for MIT to re-organize and elevate the priority it attaches to the various activities underway on the campus that fall under the banner of environmental science, engineering and policy, as well as sustainability.

Fortunately, the work that needs to be done to strengthen MIT's environmental portfolio dovetails naturally with the Institute's ongoing Energy Initiative, as well as with the range of cross-disciplinary, problem-solving efforts currently underway in all five schools. This is clearly a situation in which the whole can be greater than the sum of its parts if necessary actions are taken.

The Committee to Assess Environmental Activities at MIT was chartered to recommend a way forward in coordinating and expanding the scope of environmental activities in research and education at the Institute (see Appendices 1 & 2). This report summarizes the results of the Committee's efforts, and represents a consensus of the Committee.

II. THE VISION: CREATING A SUSTAINABLE EARTH

MIT needs to send a strong message that study of the environment and sustainability is an institutional priority and that these two branches of intellectual endeavor are synergistic forces. The Committee proposes to accomplish this imperative by establishing a bold, unifying vision: *Creating a Sustainable Earth: An MIT Research, Teaching, and Public*

Service Initiative for Understanding, Restoring and Managing the Environment. This endeavor builds upon MIT's *Virtual Earth* – a research, teaching and public service effort in its nascent stages (Appendix 3). The goal of *Virtual Earth,* developed under the auspices of the Earth System Initiative, is to characterize the diverse parts of the Earth system and their interactions in a form that will enhance understanding of processes and assimilation of data at multiple scales and of all Earth systems, spanning the solid, liquid and gaseous elements. The beginning stages of this project are already underway, with the Moore Foundation funded "Darwin Project", in which radically new approaches to modeling ocean ecosystems that incorporate genomic data are being developed. The Committee proposes that MIT greatly expand upon this idea by studying how to integrate the increased knowledge of how the full Earth system functions into technical, social, organizational and management concerns. This *Sustainable Earth Initiative* will study the link, not now well understood, between understanding current states and establishing innovative, economically- and socially-balanced, ways to change activities to preserve or at least mitigate damage to the environment.

The essence of this initiative is to involve the breadth of MIT in understanding the environment and using this increased knowledge to build platforms at many levels of detail to design a sustainable future. Furthermore, it will ultimately integrate human-made systems allowing for the formulation, testing, design and assessment of potentially helpful technologies, programs, and policies, both for innovative research and teaching purposes and in support of applied efforts undertaken in partnership with governments, business and civil society. This endeavor will require integrating data and analysis from disciplines across the Institute. Rooted in scientific principle and informed by *in situ* data collection, remote observation and modeling, the *Sustainable Earth Initiative* will provide an engineering and policy testing ground that will allow our students and faculty to move farther and faster than colleagues other institutions. By working to enhance global understanding of the dynamics of the Earth system from this unified perspective, and using that knowledge to better manage the environment, it will provide a natural focus for environmental educational efforts across the Institute.

From a practical standpoint, many of the elements required for the success of this endeavor already exist. MIT is in a favorable position to build on our strengths in science, engineering, humanities, design, and applied social science. However, acquiring top national stature and competing effectively with ongoing programs at peer institutions (Appendix 4) will require investment to provide infrastructure, seed promising ideas, provide graduate fellowships, and support instructional efforts. However, the most important step is to develop immediately an effective organizational structure that facilitates communication and interaction across the campus. The following sections address research, education, public service and structural pathways to success.

III. RESEARCH

MIT's engagement with the study of the environment and sustainability has five dimensions. First, MIT scientists analyze the characteristics and function of the Earth's natural systems, with emphasis on how this knowledge may improve responses to environmental challenges. Second, MIT engineers develop technologies to address environmental challenges, with emphasis on how technologies may improve our ability to observe and analyze environmental threats and inform our responses. Third, MIT management faculty seek to enhance the attention of private enterprise to issues of environmental sustainability. Fourth, MIT social scientists and humanists analyze how economic markets, political institutions and cultures use and respond to information on environmental challenges and emerging technologies. Finally, MIT architects, urban designers, and planners work with a variety of institutions and communities to seek synthetic solutions to a variety of environmental problems, at scales ranging from the local to the regional to the global. The MIT commitment to the environment must emphasize the integration of these thrusts. Drawing together the research, practice, and teaching strengths of all five MIT Schools should provide a competitive advantage over other top universities that have developed cross-cutting environmental programs that lack MIT's full range of expertise.

The *Sustainable Earth Initiative* is rooted in and unites fundamental ideas from a number of ongoing and nascent research initiatives across the Institute. The School of Science has a series of research efforts aimed at modeling the interactions among atmospheric, oceanic and terrestrial systems at the global scale to study Earth's climate. For example, groundbreaking work predicting an increase in the frequency and intensity of tropical cyclones due to global warming illustrates the promise of improved scientific understanding of natural systems to inform changing climate. Such important work must continue but expand in scope to address interactions in a sufficiently quantitative manner to develop mitigating strategies. Another significant effort is addressing how to use reaction chemistry (catalysis) to replenish/remove fundamental elements to maintain natural chemical cycles. The next step is to assimilate data on geochemistry and biology in addition to physical variables to map sources and sinks in the Earth system.

Many faculty members in the School of Engineering are pursuing research driven by environmental concerns such as the need for new materials, substitutions for existing materials, changes in new devices for increasing product efficiency and reducing materials use, new energy storage, sources and demand reduction, and better, more holistic design methods. Our engineering faculty are building detailed models of water and other systems as well as tools for forecasting the environmental impacts and managing the costs associated with infrastructure improvements in transportation, electricity, waste disposal and other systems. In addition, investigators are bringing new methods for incorporating environmental and resource concerns into engineering design at the product, process and large-scale system level. Environmental genomics is a frontier field and a particular strength at MIT. Microbes are by far the most significant agents of biogeochemical cycles, yet their diversity and abundance are largely unknown. Understanding their metabolic functions and controls on their populations requires new tools and new frameworks for understanding.

The Sloan School of Management has pioneered the application of systems dynamic modeling to complex sustainability choices in an effort to support more effective collective decision-making. Faculty within the School are studying how private enterprise can reconcile current rules of commerce and management practice with major environmental challenges facing the world. They are addressing the compelling need to develop an understanding of how business can not only operate in a sustainable fashion but also play a positive role in the regeneration of the planet and the support of human health and welfare. Scholars there also study the organizational dynamics that often thwart or delay the adoption of innovative technologies, emphasizing how firms and other organizations can successfully implement large-scale changes in technology and practices that determine the impact of business on the environment.

The School of Architecture and Planning has worked through the Media Lab and the Departments of Urban Studies and Planning and Architecture to improve visualization, urban design and public participation tools to help communities imagine more sustainable patterns of urban development. The MIT-USGS Science Impact Collaborative, through a range of action-research projects is testing joint fact finding strategies aimed at changing the way federal science agencies interact with elected and appointed officials and a wide range of stakeholder groups. The Urban Information Systems Group and the SENSEable City Lab are developing a variety of new technologies linked to advances in human-ecosystem simulation and modeling that will allow decision-makers to track and evaluate trends and impacts in real time. In recent years, MIT researchers have worked closely with a range of groups in New Orleans to learn about designing more resilient cities. Researchers from across the School have developed projects aimed at enhancing the energy efficiency and environmental sustainability of buildings, cities, and regions, including a special focus on the extreme challenges facing China and other rapidly urbanizing countries.

The School of Humanities, Arts, and Social Science, through a variety of Departments, has focused on the analysis of the costs and benefits associated with various environmental protection strategies as well as literary and other efforts to attach meaning to various environmental resources and human activities. Efforts address the impacts of regulation, economic costs of climate change and the influence of organizational structure on sustainability.

Some campus interdisciplinary efforts are already well established and are meeting with great success. Of particular note is the multi-school Center for Global Change Science that implements the Joint Program in the Science and Policy of Global Change. CGCS addresses fundamental questions about climatic processes with the goal of identifying critical thresholds in the climate system and accurately predicting changes in the global environment. Modeling and data analysis from this effort are figuring significantly in policy discussions, and the program is expanding to address directly influences on the environment from current and future energy sources. However, other interdisciplinary efforts have had great difficulty "gaining traction" and obtaining sustained research support. Frequently such multi-disciplinary funding is constrained by the restrictions imposed by more highly focused disciplinary research thrusts. By bringing common threads together under the rubric of the *Sustainable Earth Initiative*, multidisciplinary funding efforts ought to be enhanced.

MIT's *Sustainable Earth Initiative* will require seed funding (in much the same way that the Institute has been raising funds to support its Energy Initiative) for promising new integrated projects. Government research grants and corporate sponsors enlisted through the Industrial Liaison Program can also provide future sources of support, though environmental programs seem more likely to appeal to private and foundation sources than programs in energy studies, for which corporate interest is much greater.

IV. EDUCATION

The Institute currently offers strong undergraduate majors in environmental science (EAPS) and environmental engineering (CEE), as well as an outstanding minor in public policy (DUSP/Political Science), which has an environmental policy track. Scattered but excellent subject offerings are available in other departments/schools at both the undergraduate and graduate level such as (but not limited to) chemical engineering, material science, chemistry, and management. A full list of environmental subject offerings – indexed by school and department – is maintained on a campus-wide website (See http://enviroclasses.mit.edu) and is reproduced in a slightly modified form in Appendix 5.

While individual faculty members and students sometimes lament the lack of critical (faculty and/or curricular) mass of environmental activities in their disciplines, the sense of the Committee was that while gaps exist the more important problem at present is a lack of coordination among existing efforts. The top near-term priority should be to establish clearer connections and more effective joint management among these majors and minors. Jointly, all the interested departments and centers should identify both existing and additional subjects that can enrich the total quality of what is available to all students. Meetings of various education committee chairs (*i.e.,* Graduate School Policy Committee, Undergraduate Committee on Instruction, and others) along with faculty designees of interested departments/divisions would go a long way towards opening the lines of communication.

One specific area in which there was a strong belief that a gap exists is in the field of sustainability engineering/sustainable development (now called Sustainability Science in Europe and Japan). The sentiment is sufficiently strong, particularly among students, that an interdisciplinary minor and/or major in sustainability ought to be seriously considered. The need for increased instruction in this crosscutting area is broadly held but not universal, and there are different interpretations of what sustainability actually means and what the interdisciplinary study of this topic should entail. An obvious question concerns the "home" of such a major or minor given the broad scope of the topic. A model analogous to the Biological Engineering Division may be worth considering.

In addition to new courses and a new major or minor, other educational innovations are desired. For example, an exciting initiative would be to develop an Institute-wide Biomimickry Studio with a physical space, state-of-art laboratory equipment and cadre of UROP students. The idea would be to learn from nature's design, with concepts including self-regulation, thermodynamic efficiency, symbiosis, recycling, etc.

Understanding lessons from nature and mimicking aspects of it in a lab setting would be an extraordinary learning experience.

There was discussion among the Committee about how to teach most effectively subjects at both the undergraduate and graduate levels in environmental science/engineering and sustainability, given the wide range of complex inputs required. The Committee notes numerous successes that should be used as models in moving forward. For example, the Terrascope freshman experience provides out-of-the-box thinking about environmental problem solving from the first day students arrive at MIT. Another is D-Lab, an interdisciplinary offering, which uses case studies and projects enabling students to understand challenges to sustainable development. A third is Sloan's Laboratory for Sustainable Business (S-Lab), a subject in which student teams collaborate with volunteer clients to meet environmental and social challenges in business models. The Department of Urban Studies and Planning offers an international environmental practicum that takes students (after a semester of problem-focused study in collaboration with overseas partners) into the field for a month-long problem-solving effort.

Despite these and other (Appendix 5) excellent educational offerings, there are challenges to effectively integrating our educational programs. Discussions with faculty across the Institute reveal a strong feeling that students would benefit from taking outstanding subjects, even when offered outside their home department. However, in practice, students are often discouraged from taking courses elsewhere in the Institute because departments are awarded teaching assistants on the basis of registration numbers. This practice, which also encourages duplicative course offerings, is hardly restricted to environmental topics and it limits the potential to develop new courses. A new approach to resource allocation that encourages departments to adopt and students to take the best courses available without financial penalty to departments would encourage new interdisciplinary courses to be developed.

With its multidisciplinary focus, environmentally related subjects face an uphill battle to obtain development and teaching assistant support. It is difficult to get TA support for cross-department/cross-school subjects and nearly impossible to gain teaching release time to develop such courses because individual departments or deans of schools hold these resources. In practice, faculty members who want to develop or offer a new course need to either do it in addition to their regular teaching load or approach multiple department heads and/or deans to obtain financial support. Practicality dictates that administrators place top priority on core courses in existing majors rather than interdisciplinary studies. But removal of structural barriers such as these is a necessary condition for successful education programs in multidisciplinary studies such as the environment or energy. The problem could be solved by having the Institute establish a source of funds, ideally controlled by the Dean of Undergraduate Education and the Dean of the Graduate School, that would be available for TA support and the development of interdisciplinary courses. The deans or a faculty committee appointed by them could evaluate requests for support.

Committee members observe that today's engineering and science students are keenly interested in courses in policy-making and environmental literacy. They know that knowledge of these areas is a prerequisite to achieving practical solutions to environmental and sustainability problems. Engineering and science departments need to be aware of this trend and consider how students can pursue this interest while accomplishing requirements for the major. Similarly, students in humanities, design, management and social science need to be able to augment their science and engineering background as part of the undergraduate major or graduate degree. Right now, many of them are blocked from taking highly relevant courses because they don't have the full set of prerequisites expected of majors taking these courses.

The prominence and reputation of MIT's engineering program gives it both the potential and the responsibility to take the lead in redefining engineering design principles and methods across all engineering disciplines to adequately address the complex and expanding environmental problems our world is facing. Specifically, a statement from the president and/or Dean of Engineering that environmental compatibility should be a fundamental aspect of engineering design would send a powerful message that might well result in a fundamental change to engineering education, particularly if coupled with curricular and subject information on *OpenCourseWare*.

Advising at both the undergraduate and graduate levels needs considerable improvement to make students aware of interdisciplinary educational opportunities. The Committee heard numerous reports from students who frankly had no idea where to get advice on course selection and were more or less left to their own devices. These reports were primarily from students interested in sustainability, which has no home department at present. It is also appropriate to note that student-initiated activities dealing with sustainability and environmental protection abound at the Institute. While these do not fit within the formal education framework, they contribute to our students' educational experience and they benefit from faculty advising. The coordination of environmental efforts discussed below could provide an accessible pool of informed, interested faculty who would be available for all manner of advising.

V. ORGANIZATION AND INFRASTRUCTURE

Numerous high-quality environmental research programs and course offerings are available at the Institute, but communication and coordination among the faculty and the administrative units involved is insufficient. Until July 2007 a modest level of coordination of environmental activities occurred within the Laboratory for Energy and the Environment (LFEE). LFEE had few resources to allocate, but it did provide information and an address for students with an environmental interest. In association with the LFEE there was an Environmental Council, which was in essence an *ad hoc* collection of interested senior faculty who met regularly to exchange information and ideas. The group had no official mandate, no decision-making authority, no budget, and no fundraising priority. That this Council persisted for over twelve years attests to its utility as a forum for productive interaction. However, this organizational entity did not have what it needed to grow an Institute-wide environmental effort. The Environmental

Council needs to be replaced by an administrative structure that is empowered and designed to connect and energize the full participation of all members of the Institute community who share interest in the environment.

In considering how to best organize for success, it is instructive to note the common characteristics of successful programs at our peer institutions (Appendix 4): (1) their programs are multidisciplinary; (2) they are organized under an umbrella organization (*e.g.,* Institute, School, Center) that provides coordination and visibility, with most having a physical "home", in several cases a "green" building; and (3) all have had a significant infusion of funding, most commonly though not exclusively from private donors. The Committee feels that to realistically compete with these top programs, MIT's effort must share these fundamental characteristics. At the same time, MIT's effort must also capitalize on unique strengths that differentiate us from our peers.

The first order of business in establishing a new and effective structure is to integrate with MIT's Energy Initiative. In her inaugural address President Susan Hockfield highlighted Energy and the Environment as a great challenge:

> *"A second great opportunity, and a great obligation, is our institutional responsibility to address the challenges of energy and the environment. Over the last thirty years, these two words -- energy and the environment -- have gotten a little tired, not from overuse but from lack of progress. The time for that progress is now. I believe that the country and the world may finally be ready to focus on these matters seriously. Again, it is our responsibility to lead in this mission."*

The Committee feels that in order to implement President Hockfield's vision, Energy and the Environment studies at MIT must be coordinated to the extent possible. The Committee recognizes that not every environmental problem is energy related. However, work in the two areas shares enough commonality that each will clearly benefit considerably from coordination with the other. A truly integrated energy-environment effort will distinguish MIT from its peers, where such programs are commonly listed under a single banner but in practice operate distinctly.

The Committee also believes that the optimal administrative structure must be at once "top down", ensuring buy-in from the senior Administration, and "bottom up", enabling faculty members to claim ownership and best serve their research, teaching and public service needs.

From the "bottom up" perspective, the Committee recommends the formation of a grassroots Faculty Environmental Network. This should include all interested faculty across the Institute who want to formulate cooperative teaching, research, and public service strategies at the grassroots level. Outputs from this group ought to be regular inputs to the work of a potential new joint Energy and Environment Council or to a new Environmental Council. The Network will have the advantage of being inclusive, assuring "buy in", and would particularly welcome junior faculty who would benefit from meeting and interacting with colleagues from across campus. With modest support, the Network will be particularly accessible to students seeking input and advice about environmental interests.

Although admittedly deviating from the Committee Charge, the Committee notes that a grassroots Faculty Energy Network formed under similar auspices as the Faculty Environmental Network could provide a parallel organizational structure and a "bottom up" input and buy in from faculty interested in energy.

From the top-down perspective, there are several possible organizational structures that could conceivably work and three examples are given in Figure 1. A new Environmental Council similar to the existing Energy Council could be formed with the Directors of each serving as members of the other Council to assure coordination. Or the Energy Council could be expanded to an Energy and Environmental Council and its membership augmented to encompass environmental interests. Either co-directors representing energy and environment or a single director with deputy directors in each area is possible. The Committee encourages the senior administration to choose a structure on the basis of maximizing effective communication and operation.

As in the case of research fostered thus far under the Energy Initiative, research in the *Sustainable Earth Initiative* will occur in home Departments or existing Centers of involved faculty. However, it is important that the initiative have a physical "home", and ideally it should be co-located with Energy. Required administrative support staff should be coordinated/shared with Energy to the extent possible.

VI: LOOKING TO THE FUTURE

The *Sustainable Earth Initiative* is a vision that should have considerable appeal for attracting resources. By all accounts interest in the environment will continue to increase and MIT must prepare appropriately to lead in this mission. In the same way that the Institute's Energy Initiative envisioned new cross-cutting faculty appointments for which departments and schools could compete, faculty lines set aside for new appointees whose research and teaching are crucial to implementation of the *Sustainable Earth Initiative* Is appropriate. There certainly must be a separate set of potential donors who will be inclined to support the "environmental side" of Energy and Environment.

With the new analytic tools developed as part of the *Sustainable Earth Initiative,* MIT will have an important opportunity to assist policy makers in the public and private sectors around the world, including the wide range of multilateral institutions that have been created over the past three decades to coordinate global efforts to promote sustainable development. Whether on a contract basis or through other forms of partnership, MIT can enhance its profile as a "neutral ground" in which contending groups can seek balanced scientific and technical analysis. At the same time, the internship and public service opportunities for MIT students would be greatly enhanced. This would allow us to compete for the best students with environmental interests who are currently not coming to MIT.

VII: RECOMMENDATIONS

In summary, the Committee offers seven recommendations:

1. The Institute's Energy and Environmental initiatives should be organizationally integrated to the extent possible in order to capitalize on intellectual synergies.

2. The Institute should advocate a new vision: *Creating a Sustainable Earth: An MIT Research, Teaching, and Public Service Initiative for Understanding, Restoring and Managing the Environment.* This vision should be an institutional priority for new resources. As for the Energy Initiative, the environmental branch of MIT's Energy and the Environment initiative should include support for faculty lines to enhance interdisciplinary and cross-school cooperation in implementing the research, teaching and public service objectives.

3. The Institute should support a new faculty-initiated Faculty Environmental Network. This group should be highly visible so students interested in research, teaching and public service aspects of environmental studies and sustainability can find appropriate faculty advisors.

4. The Institute should take action to identify ways to make it easier for both undergraduate and graduate students with interests in multidisciplinary areas such as environment or energy to take advantage of campus-wide teaching and research opportunities, regardless of their major or degree program.

5. The Institute should explore the desirability and feasibility of initiating a campus-wide, interdisciplinary minor and/or major in sustainability.

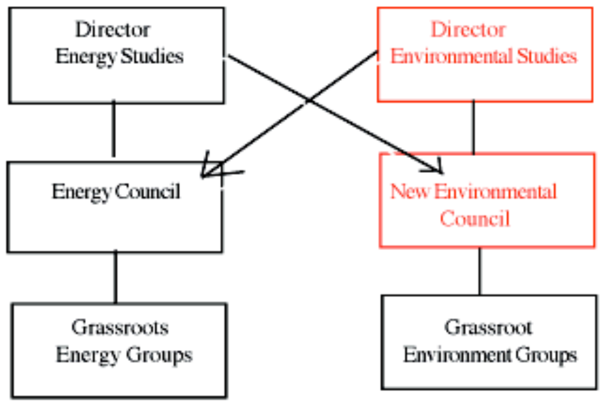
6. MIT should establish a new paradigm for engineering design that includes environmental compatibility as a core principle.

7. A fund should be established to underwrite the appointment of teaching assistants for multi-departmental courses and to support (on a competitive basis) curriculum development initiatives in interdisciplinary courses in energy and the environment. This effort should be implemented in cooperation with the Energy Education Taskforce.

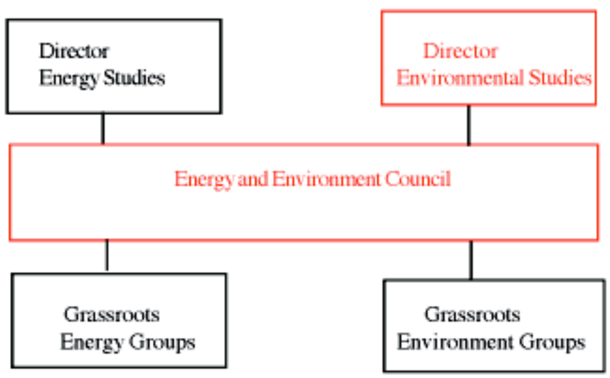
8. MIT as an Institution must raise its visibility in matters relating to the environment. In addition to the improved organization and enhancement of campus research and education efforts discussed in this report, steps should include public statements from senior administrators and a proactive posture on campus sustainability efforts.

ENVIRONMENT/SUSTAINABILITY STUDIES AT MIT:
THREE ADMINISTRATIVE ALTERNATIVES

A.



B.



C.

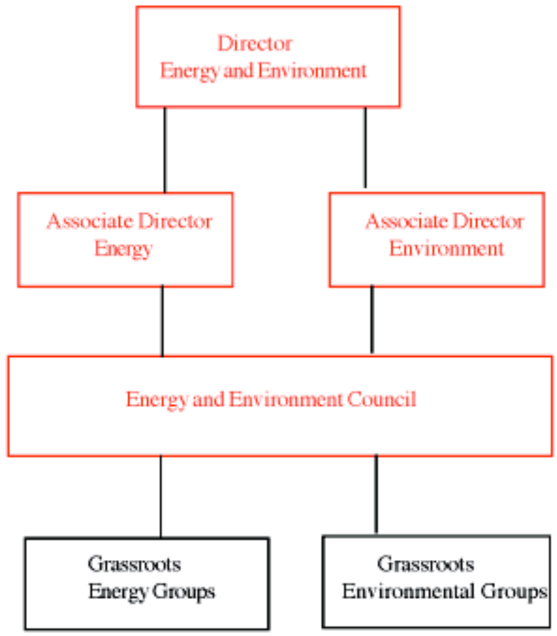


Figure 1. Possible organizational structures for MIT's Energy and Environment efforts.

APPENDIX 1: CHARGE TO THE COMMITTEE

Charge to Committee
To Assess
Environmental Activities
At MIT

In the last 15 years, MIT has amassed considerable faculty strength in matters related to the environment. This strength is reflected in faculty in more than a dozen departments. Over the years, these faculty have produced major results and educated a generation of environmental scientists and professionals. There is still a considerable portfolio of research as well as strong educational programs and growing students interest.

Despite these assets, we need to build on our strength. A strategic assessment is necessary to refresh the research and education effort, identify new strategic thrusts, renew departmental commitments, strength educational programs, and connect the environmental efforts with those in other MIT research areas - from energy to IT, and from basic science to important issues of policy and development. In short, we need to refresh the value proposition of our environmental enterprise.

We have charged the committee below with the following tasks.

1. Review and assess the status of environmental research and education at MIT, including the available assets (e.g. faculty, courses, research projects, initiatives, fellowship, endowments, etc.) Identify our strengths and opportunities, and benchmark our assets against those of our peers.

2. Consider how best to engage a broader set of faculty in environmental programs and teaching, including new faculty and faculty who do not normally consider themselves in the environmental domain.

3. Consider and recommend alternative models organizing environmental research at MIT

4. Consider and make recommendations for how to mobilize more effectively undergraduate education on the environment and energy

5. Consider how to advance community among environmental stakeholders including what role for the Council on the Environment or a similar group should serve in the future

A report to the Provost and Chancellor is due by June 1, 2007. In addition to the points above, the final report should outline a vision and a strategy to advance the environmental domain at MIT and the resources required to advance the strategy.

Faculty Members:

D. Entekhabi
P. Chisholm
L.Susskind
E. Eltahir
J. Tester

R. Bras
D. Marks
P. Jaillet
V. Bulovic
W. Green
J. Sterman
K. Oye
J. Steinfeld
E. Boyle
P. Rizzoli
D. Nocera
L. Vale
M. Zuber (Chair)
C. Canizares (Ex Officio)

Student Members:

Kendra Johnson
Kate Parrot

APPENDIX 2: OPERATION OF THE COMMITTEE

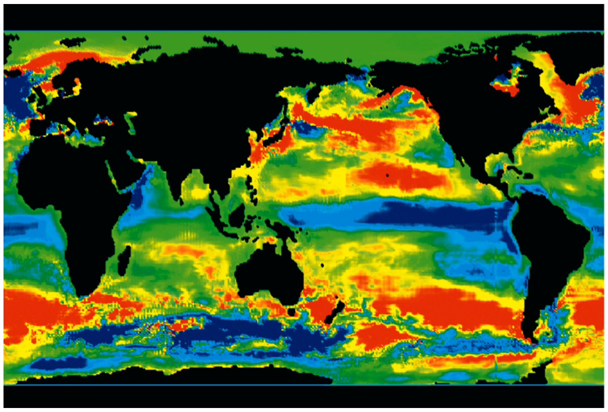
The Committee began work at the beginning of spring semester 2007 and met once or twice per week during the semester. Early meetings were spent developing a plan of action and making lists of knowledgeable individuals who could inform the committee on current activities. In addition the Committee Chair met with other individuals on campus who either could not or did not desire to meet with the Committee. Every effort was made to accommodate requests to meet with the Committee or Committee Chair. The Committee was fortunate to have available two individuals, Dr. Terry Hill and Dr. Amanda Graham, who took minutes and assembled data on MIT research, peer institutions, and educational activities. At each meeting the Committee met with one or two individuals or groups where they were asked, "what works?" "what doesn't work?", and "what is missing?" The Committee did not address infrastructure ("green campus") issues because a "walk-the-talk" committee is in place with that charge. At the end of the spring semester the Committee held a retreat over two half-days where the report recommendations were developed.

APPENDIX 3: MIT'S VIRTUAL EARTH PROJECT[1]

MIT's "Virtual Earth" is a concept for an immersive, software portal environment that will enable the user to access data and models that describe the physical, chemical and biological characteristics of Planet Earth. From a single user friendly entry point, users will be able to access the latest data and modeling tools regarding climate projections, hydrology, weather observations and forecasts, surface temperatures, and a wide variety of data regarding the health and functions of the Earth System.

The future of life on Earth is critically dependent on our ability to measure, monitor and understand the co-evolution of the physical chemical and biological processes that collectively make our planet habitable. This ability has rapidly expanded in recent years with the advent of new global and regional remote sensing tools; and with the increasing deployment of small sensor systems and networks. The Earth is increasingly a "wired" environment, and we need to develop ways to visualize, interpret and analyze the large quantities of data that these sensors and systems provide.

The bottleneck to our understanding and ability to predict future trajectories for the Earth System now lies on our failure to fuse and integrate all these disparate observations, at a multitude of temporal and spatial scales, within a consistent and integrative system. But the computational tools, the modeling tools and the systems tools are increasingly available, allowing us to formulate a framework for data assimilation and prediction that will unify our observations and our understanding of the Earth. The Virtual Earth will be a digital data repository and modeling framework that will force the community to reconcile their data and their models at all times and across all scales.



We propose to construct such a system, which we call the MIT Virtual Earth. The team will leverage MIT's advanced research abilities in data assimilation, visualization, and high-performance computing, as well as leverage other elements underway in Japan; the US National Labs, and in commercial products of Google, Microsoft and various GIS companies. The result will be a software environment that couples a useful, intuitive user interface with the ability to access and process diverse and expansive datasets

Ultimate Deliverable

The MIT Virtual Earth will be an operational model environment, capable of ingesting a wide variety of Earth System data and making observations and predictions of all processes at all time and space scales. The model will be interactive and display output in appealing, understandable visual formats.

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[1] Developed under the auspices of MIT's Earth System Initiative.

APPENDIX 4: MIT PEER UNIVERSITIES SUPPORTING SIGNIFICANT ENVIRONMENT/SUSTAINABILITY EFFORTS

To comply with the charge of benchmarking MIT's education and research programs against peers, the Committee began by asking each member to identify a small number of Institutions that they consider being competitive with their own Department or program. The initial survey included 29 schools, many with a particular strength in a particular academic area. The Committee elected to focus on a representative cross-section of competitive programs that were viewed to have multiple strengths.

The following summary, based on readily available information from websites, include the stated missions of the programs; the range of topics they encompass; their facilities; what degree programs, if any, are offered; what departments, centers, and labs are involved; and other factual information.

University of California, Berkeley: College of Natural Resources

As a state school, UC has a responsibility to include the study of the state's vast natural resources and agriculture. In 1974, UC combined its agriculture and forestry schools into the College of Natural Resources. The College has evolved to serve society by:

- Generating and disseminating knowledge in the biological, physical, and social sciences in order to provide the tools to both protect the Earth's natural resources, and
- Ensure economic and ecological sustainability for future generations.

Faculty and students in the College still pursue research in agriculture and resource economics, but its focus has expanded to include environmental science, policy, and management; plant and microbial biology and nutritional sciences and toxicology. These disciplines are applied as needed to issues of sustainability, and social demands for environmental quality.

The College offers three majors, including 13 subspecialties. Students take courses in several departments to meet the requirements of these majors. Each of the interdisciplinary majors emphasizes basic science (*e.g.,* biology, chemistry, mathematics, physics, economics), and in the last two years, statistics, research methodology, environmental modeling, and a research-based thesis.

The Department of Environmental Science, Policy, and Management offers Ph.D. and M.S. degrees. The Berkeley students also have access to the large faculties at the other eight UC campuses.

Certificate programs include an Executive Environmental Program, a cooperative effort with the Mexican government geared to increasing the capabilities of Mexico's environmental agencies. The program is part of the Executive and International Programs at the Goldman School of Public Policy. Another mid-career certificate opportunity is the Beahrs Environmental Leadership Program. Funded with seed money from a family foundation in 2000 and now also supported by several other private donors, the freestanding program draws faculty from several Berkeley departments to train environmental leaders internationally and maintain an active alumni network.

The Berkeley Institute for the Environment oversees environment-themed minors and specializations for students all across campus. The BIE provides opportunities for students to launch their own research and participates in campus-wide efforts to green the U.C. Berkeley campus through initiatives by students, faculty, and staff.

Student activism is widespread. The UC website lists 28 student organizations convened around environmental and sustainability themes.

As is apparent from examining founding dates and directions of the environmental and sustainability-oriented research, education, and participatory opportunities at Berkeley, it is clear that initiatives have sprouted up in and across many departments and independently. The existence of the college, and the environment department gives this area of inquiry an identifiable home, and a place to start exploring the UCB kaleidoscope of offerings. These organizational units receive the same support from the administration as any other comparable units.

Columbia University: The Earth Institute

The overarching goal of Columbia's Earth Institute is to "help achieve sustainable development primarily by expanding the world's understanding of Earth as one integrated system." As areas of study, the Institute has identified nine interconnected global issues: climate and society, water, energy, poverty, ecosystems, public health, food and nutrition, hazards, and urbanization.

The Institute offers eight master's degrees master's programs in cooperation with other departments: Earth and Environmental Science Journalism (with the department of Earth and Environmental Engineering); Climate and Society (With the Graduate School of Arts and Sciences); Conservation Biology (with the Dept. of Ecology, Evolution, and Environmental Biology and the Center for Environmental Research and Conservation);Earth Resources Engineering (with the Dept. of Earth and Environmental Engineering); Climate and Society; Climate and Society (with Graduate School of Arts and Sciences); Environmental Health Sciences (with the School of Public Health); a 12-month program in Environmental Science and Policy (12-month program with the School of International and Public Affairs); Environmental Policy Studies (also with the International School); and International Energy Management and Policy.

The Institute claims participation by 850 scientists, postdoctoral fellows and students working in and across more than 20 Columbia research centers. It links to 24 undergraduate and graduate courses of study. The website includes prominent links to the departments where these degree options are listed or co-listed. In fall 2007, a new undergraduate Special Concentration in Sustainable Development is being launched with input from seven departments, and including two newly developed integrative courses.

In 2003, the Earth Institute established the Cross Cutting Initiatives program as a means to tackle complex multi-disciplinary problems related to sustainable development. It guides the investment of seed funding and coordinates a seminar series on sustainable development. It is overseen by a Steering Committee of 14 faculty from eleven different departments. In the last round of competition, eight projects were granted a total of $200K.

The Earth Institute is the closest organization to the MIT Virtual Earth idea to be found at any of these peer universities, in that it starts from the premise of an integrated, complex system and works to orient ongoing and stimulate new research to understand it more fully. The Institute site conveys its nature as a facilitator of relationships among Columbia's departments, labs, and centers. It has its own suite of offices, but functions mainly "virtually".

The Earth Institute places considerable emphasis on outreach. It Institute is led by a very prominent person, Jeffrey Sachs, and has a 10-person external advisory board of equally well-known leaders in their fields, *e.g.,* Norman Borlaug, Edward O. Wilson, and Bono. In addition to Mr. Sachs, four senior administrators oversee general operations, strategic initiatives, finance and administration, and communications. The outreach aspect of the Earth Institute is very strong--five people handle communications and events.

Duke University: Nicholas School of the Environment and Earth Sciences
The School offers the Ph.D. in its three research divisions: Earth and Ocean Sciences, Environmental Sciences, and Policy and Marine Science and Conservation**.** Its two professional degree programs include a Master of Environmental Management (MEM) and a Master of Forestry (MF). Students can also earn an MEM degree online. Undergraduates may earn an AB and BS in Environmental Sciences, and the AB and BS in Earth and Ocean Sciences. Faculty members in 20 cooperating departments and schools teach courses for the majors. Undergraduate directors and advisory committees representing the various areas and cooperating departments administer the degrees. The Duke Environmental Leadership Program offers a range (currently nine) mid-career short courses, which may also be applied to some certificate programs, *e.g.,* the NEPA certificate.

The ten research centers in the Nicholas School are, by design, flexible, multidisciplinary units. They do not offer degrees, but function as loci staffed by interdisciplinary faculty from Duke, collaborating universities, public and private research units and employing student research assistants and appropriate staff. The centers do not offer courses or degrees but provide students, scientists and other professionals an opportunity to participate in research through collaboration with affiliated faculty.

In 2005, also funded by an alumni gift of $70M, the Nicholas Institute for Environmental Policy Solutions at Duke University was founded to engage with decision makers in government, the private sector, and the nonprofit community. In addition to providing good data relevant to pressing problems, one of the aims of the Nicholas Institute is to function as an "honest broker" between stakeholders on all sides of environmental issues.

The Institute is housed with the Nicholas School on the Duke campus. A state-of-the-art "green building" (Nicholas Hall) to house both groups is in the planning stage. The Institute also will soon open an office in Washington, D.C. The goal is to enable Duke to assume environmental leadership and to achieve world-class status and impact.

Some key aspects of the Duke program map onto MIT's *modus operandi*—flexibility, extensive interaction with nonacademic partners, commitment to "honest brokerage" in applying science to public policy, and adherence to its disciplinary strengths. Short courses have the look and feel of MIT summer courses. At Duke, a major donor was pivotal in getting the entire, integrated Nicholas project (School, Institute, building) underway.

Harvard University Center for the Environment
The Harvard University Center for the Environment focuses on six research areas: climate, business and environmental policy, ecology and biodiversity, energy, environment and development, and human health. It supports seven academic areas: architecture and design, economics, government and social science, ethics and religion, humanities and the environment, law and business, and public health and medicine.

The structure of the Center involves a steering committee currently comprised of representatives from the law school, organismic and evolutionary biology, earth and planetary sciences, public health, and government; faculty associates members by choice, numbering in the dozens; and six Environmental Fellows funded for two years of post-doctoral study at $50K per student. The Fellows program is two years old. The Center has its own space at Harvard, which provides office and meeting space for faculty and students.

One unusual activity Harvard center began in 2003 is the funding of faculty research awards "to support preliminary explorations of environmental issues that show promise for further scholarship." The awards are ~$25,000 (per faculty member—several faculty working on a project may apply separately). In 2007, $200k is budgeted for this activity, which seeds interesting ideas and provide publicity and esprit.

In addition to these participants, the Center has a professional staff of five, including the Director, an executive director, a director of publications and events, a financial person, and a receptionist. The space also houses the coordinator for the undergraduate concentration (major) in environment and public policy.

The Center's mission regarding education seems to indicate an emphasis on non-environmental specialists as well as on research: The Center seeks to provide the next generation of Harvard-educated researchers, policymakers and corporate leaders with a comprehensive interdisciplinary environmental education, while fostering linkages and partnerships amongst different parts of the University as well as between the University and the outside world.

The Center site lists six student organizations. One of these, the Harvard Energy Journal Club has drawn active participation from MIT students. The Center posts a list of environment/sustainability courses from all Harvard departments; it also includes subjects cross-listed with other universities including MIT and Tufts. As early as 1995, a $100k grant from Harvard's Provost enabled a project cataloguing all library materials pertaining to the environment.

University of Michigan: School of Natural Resources and the Environment
The University of Michigan's School of Natural Resources and the Environment is focused on management for sustainability, and emphasizes application. Faculty of NRE have expertise in environmental policy and law; environmental economics, behavior, psychology, and anthropology; integrating environmental knowledge with business and engineering; landscape design and natural resource planning; modeling, geospatial analysis, and environmental statistics; and terrestrial and aquatic ecology.

However, in framing research objectives, NRE faculty "eliminate the use of traditional academic departments and focus rather on areas of study." NRE has identified four basic areas: Ecosystem Management and Conservation Biology, Climate Change, Enabling Sustainable Production and Consumption, and Great Lakes Basin and Ecosystem Dynamics. Nine Centers of Excellence at the university are associated with NRE; each is focused on one or more of the four areas of study.

A public institution like Berkeley, the NRE has strong civic obligations. Its outreach programs, directed toward local and regional audiences, present issues in Environmental and Science Literacy; Aquatic Invasive Species; Aquatic Habitat; Coastal Communities and Economies; and Fisheries.

NRE is located in a large, greenly retrofitted building on the Ann Arbor campus, a facility shared with several of the Centers of Excellence mentioned above. Also in this building are the offices of the undergraduate Program in Environment, which, in partnership with the College of Literature, Science and the Arts, administers an array of concentrations, minors, and either a BS or BA option.

Students in the M.S. program may specialize in one of eight fields of study: Aquatic Sciences: Research and Management ; Behavior, Education and Communication; Conservation Biology; Environmental Informatics; Environmental Justice; Environmental Policy and Planning; Sustainable Systems; or Terrestrial Ecosystems. Two- and three-year landscape architecture programs with an environmental or sustainability focus are also available as are several dual degree options with other schools and departments.

The faculty's research agenda can best be described as "Global Change broadly defined." Ph.D. students in Natural Resources and the Environment can choose either highly focused course of study or one that broadly addresses complex, interdisciplinary issues.

Though Michigan is a public school, NRE depends greatly on gifts. The website has a button on the navigation bar for donors and alumni, and there is a prominently featured Donor Recognition Program. The School publishes a glossy, professionally produced alumni magazine, and renamed *Stewards* this year, as an outreach, networking, and fund-raising tool.

Princeton Environmental Institute

The Princeton Environmental Institute (PEI) coordinates environmental education, research and outreach activities at Princeton University. More than 65 faculty members from the natural sciences, engineering, social sciences, and humanities are involved in its programs

A focal point of PEI activities is the Program in Environmental Studies, a multidisciplinary forum for the study of the scientific, political, humanistic, and technological aspects of environmental problems. Two courses have been developed to pull together an environmentally oriented course of study for students majoring in any department on campus. An executive committee of 12 faculty members from seven departments oversees the Program.

As at MIT, Princeton graduate environmental education emphasizes fundamental disciplinary strengths; students are admitted through the academic departments. Once admitted, students can take advantage of a wide range of coursework and research to structure a curriculum that meets their needs. Most environmental graduate students are concentrated in the physical sciences, engineering, and in policy (through the Woodrow Wilson School).

The Institute website takes particular note of the opportunity for science and engineering students to learn about policy making, and for social science, management, and humanities students to learn basic science related to their thesis topics. The PEI Science, Technology, and Environmental Policy program, known as PEI-STEP, is a two-year fellowship program (half-support per year) enables participating graduate students to add a policy dimension to their basic science or technology work.

The Institute is home to four research centers, in which students also participate. These are the Princeton Climate Center /Cooperative Institute for Climate Science; the Center for Environmental Bioinorganic Chemistry; the Center for BioComplexity ; and the Carbon Mitigation Initiative. Interdisciplinary environmental research is organized mainly through these centers. At Princeton, this research is focused chiefly in the sciences, with particular strengths in global change, biogeochemical cycles, molecular geochemistry, biodiversity and conservation, and environmental science and policy.

In terms of outreach, PEI is very active in support of campus sustainability efforts. Along with Princeton undergraduates, graduate students, faculty and administrators, PEI affiliates study and monitor the University's environmental performance on campus and in the surrounding community. PEI –based outreach efforts are aimed at local schools and the general public. The four research centers each sponsor activities related to their topic areas.

PEI works with a variety of undergraduate environmental groups at Princeton, providing funding for activities and events, as well as publicity for these activities. Six groups are listed. The Institute is located in Guyot Hall.

Elements of the PEI-STEP program are reminiscent of TPP, though the Princeton program augments the education of graduate students actively pursuing studies in their home departments, rather than just being admitted through a department and following the TPP curriculum. Like MIT, Princeton implements a discipline-based approach to environmental education.

Stanford Initiative on the Environment and Sustainability

The Stanford Initiative on the Environment and Sustainability got underway in 2001 as a way to organize the broad resources of its faculty to bear on the environment, and explicitly to "raise the university's visibility as a world leader in environmental research and education." Its first activities were to build a centralized website providing quick access to the "vast array" of environmentally oriented research ongoing at Stanford, and to establish a new interdisciplinary doctoral program in environmental studies.

The initiative concept had been in play since the mid-1990s when then-Provost Condoleeza Rice assembled a committee to evaluate the benefits of integrating environmental research at Stanford.

The university's particular strengths lie in environmental law, population studies, geochemistry, agricultural economics, sustainability, energy policy, biodiversity, and world health. The senior administration took a first step toward curricular reform by offering an environmental MS to undergraduates in the schools of law, business, and medicine for a fifth, specialized year of study. The first students were enrolled in 2002.

The Initiative, now focused on "creating a sustainable ecosystem" through "a sophisticated collaboration from many disciplines" encompasses all seven schools and 30 departments (though some, *e.g.,* "Classics", are kind of a reach), and 41 Interdisciplinary Research Centers and Programs. The focal areas of the Initiative are energy and climate, land use and conservation, oceans and estuaries, and fresh water.

At Stanford, a top-down initiative gave structure to existing resources. There are however, other, smaller environmental projects ongoing within other units that operate independently.

Environmental research in several areas has been stimulated by some major gifts. For example a $30M gift from an alumnus funded the newly formed (October 2006) research initiative, the Precourt Institute for Energy Efficiency. Another alumni gift underwrites the Goldman Honors Program focused on project-focused undergraduate seminars bringing together the schools of Humanities and Sciences, Engineering, and Earth Sciences.

Yale School of Forestry and Environmental Studies

The Forestry School, founded in 1900 by Gifford Pinchot, added "Environmental Studies" to its name in 1972. An extensive staff and about 60 faculty members are involved in its programs. Looking at the office locations and areas of specialization of these faculty members, it is clear that they are not tangential but actively spending much of their research and teaching time on environmental studies. The School recently created and filled a new position, associate dean for research. The new dean will promote F&ES as a research institution, including contract and research grant proposal management.

At present, around 400 undergraduate and undergraduate students are working on degrees based in F&ES. The School offers six master's-degree options, including a mid-career and joint master's options. Joint degrees are available in anthropology, architecture, management, public health, international relations, development economics, divinity, and law. Two doctoral degree options, one of them a joint degree with the department of anthropology, are directed by F&ES faculty and conferred by the School. This unit also includes its own career-placement office.

The Yale School is housed in Kroon Hall, a showcase of the latest developments in green building technology, designed to be the new center of environmental activities on the Yale campus and an anchor for long-term sustainable development of Science Hill. Nine donors are "charter contributors" to the building, which opened in June 2007.

Keeping alumni involved is clearly a major objective for this unit. On the website, they are integrated into the list of affiliates along with faculty, staff, and students. Since 2001, the School has published *environment: Yale*, a substantial (four-color, glossy, around 50-page, professionally edited) journal and alumni magazine. It publishes news of interest to the school's alumni (including classic networking information) and general interest articles, *cf.* the impact of the biophilia concept on building design.

The magazine is an expensive product, but attracts a great deal of attention. F&ES's website designer and management are the best of any of those surveyed for this commentary.

APPENDIX 5: CURRENT MIT ENVIRONMENTAL CLASS OFFERINGS

Subjects Listed in EnviroClasses as of 7 August 2007
Note that the listed subjects either have a primary focus or strong connection to environmental and/or sustainability issues and concerns.

See http://enviroclasses.mit.edu for subject descriptions, interactive database, and selection criteria

Course Numbers	Subject Title	Instructor(s)
4.116	Advanced Architecture Design Studio	Architectural Design Staff
4.242J/11.331J	Advanced Seminar in City Form	J. Beinart
11.308J/4.213J	Advanced Seminar: Urban Nature and City Design	A. Spirn
4.662	Advanced Study in the History of Urban Form	D. H. Friedman
1.721	Advanced Subsurface Hydrology	C. Harvey
1.082	Air Pollution: Processes and Controls	Staff
12.213	Alternate Energy Sources	M. N. Toksoz, F. D. Morgan
21H.206	American Consumer Culture	M. Jacobs
21H.103	American Indian History From Columbus to the Present	N. Buchanan
STS.011	American Science: Ethical Conflicts and Political Choices	Staff
11.014J/21H.232J	American Urban History II	R. M. Fogelson
4.427J/2.67J	Analysis and Design of Heating, Ventilating, and Air Conditioning Systems	L. K. Norford, L. Glicksman
12.119	Analytical Techniques for Studying Environmental and Geologic Samples	S. Bowring, E. Boyle, F. Frey, T. Grove
11.481J/1.284J/ESD.192J	Analyzing and Accounting for Regional Economic Change	K. R. Polenske
3.982	The Ancient Andean World	H. N. Lechtman
3.983	Ancient Mesoamerican Civilization	D. Hosler
1.149/2.63/5.00/10.579/22.813 /ESD.174	Applications of Technology in Energy and the Environment	J. Deutch, R. Lester
1.012	Approaches to Civil and Environmental Engineering Design: Principles and Practice	H. H. Einstein
1.76	Aquatic Chemistry	Staff
4.423J/2.661J	Architectural Thermal and Fluid Dynamics	L. Glicksman, L. K. Norford
12.306, 12.806J/10.571J	Atmospheric Physics and Chemistry	R. G. Prinn, G. J. McRae
7.47	Biological Oceanography	L. Mullineaux, H. Sosik, J. Pineda, S. Dyhrman, E. Webb (WHOI)
11.370	Brownfields Policy and Practice	J. Hamilton
4.464	Building Technologies IV: Energy in Building Design	L. Glicksman, L. Norford
4.411	Building Technology Laboratory	L. K. Norford
4.481	Building Technology Seminar	J. Fernandez, L. R.

		Glicksman, L. K. Norford, J. Ochsendorf, M. Andersen
4.175	Case Studies in City Form	M. Dennis
1.725J/ESD.151J	Chemicals in the Environment: Fate and Transport	P. Shanahan
4.001J/11.004J	CityScope	J. Fernandez, P. Thompson
11.363	Civil Society and the Environment	J. Carmin
12.842	Climate Physics and Chemistry	C. Wunsch, E. Boyle, K. Emanuel
21W.781J/1.588J/3.070J/22.002J/ESD.032J	Communicating About Technology: Colossal Failures in Engineering	T. Eagar, W. Haas, A. Kadak, P. Lagace
1.016	Communicating Complex Environmental Issues: Designing and Building Interactive Museum Exhibits	R. L. Bras, A. Epstein
11.526J/1.251J	Comparative Land Use and Transportation Planning	C. Zegras
11.265	The Comparative Politics of Urban Policy	D. E. Davis, J. P. Thompson
17.559, 17.560	Comparative Security and Sustainability	N. Choucri
SP.722J/2.722J	D-Lab: Design	A. B. Smith, J. K. Vandiver, D. R. Wallace
SP.721J/11.025J	D-Lab: Development	A. B. Smith, B. Sanyal
SP.723	D-Lab: Dissemination - Implementing Innovations for the Common Good	S. E. Murcott
4.430	Daylighting	M. Andersen
1.819J/4.447J	Design for Sustainability	J. Connor, J. Ochsendorf, E. Adams
2.019	Design of Ocean Systems	C. Chryssostomidis, N. M. Patrikalakis
MAS.665	Developmental Entrepreneurship	A. Pentland
11.365	Disaster, Vulnerability, and Resilience	J. Carmin
4.406	Ecologies of Construction	J. Fernandez
1.018J/7.30J	Ecology I: The Earth System	S. W. Chisholm, E. Delong
1.020	Ecology II: Engineering for Sustainability	D. McLaughlin, D. Entekhabi, D. H. Marks
3.080	Economic and Environmental Materials Selection	R. Kirchain
2.964	Economics of Marine Transportation Industries	H. L. Kite-Powell, H. S. Marcus
21L.449	End of Nature	A. Kibel
STS.038	Energy and Environment in American History	Staff
14.44, 14.444	Energy Economics and Policy	P. Joskow
11.369J/17.398J	Energy Policy for a Sustainable Future	J. D. Raab
ESD.126	Energy Systems and Economic Development	R. D. Tabors, Staff
5.92	Energy, Environment, and Society	J. I. Steinfeld, J. W. Tester
10.04	Energy: An Intellectual History	B. L. Trout, L. D. Perlman
1.155/2.963/3.577/6.938/10.81	Engineering Risk-Benefit Analysis	G. E. Apostolakis

6/16.862/22.82/ESD.72		
1.041J/ESD.01J	Engineering System Design	J.Sussman
1.080	Environmental Chemistry and Biology	M. F. Polz, Staff
1.107	Environmental Chemistry and Biology Laboratory	M.Polz, S.Frankel, P. Gschwend
STS.320J/21A.800J	Environmental Conflict and Social Change	C. Walley
1.715	Environmental Data Analysis	E. A. B. Eltahir
12.102	Environmental Earth Science	S. A. Bowring
12.120	Environmental Earth Science Field Course	S. Bowring, T. L. Grove
14.475	Environmental Economics and Government Responses to Market Failure	M. Greenstone
1.106	Environmental Fluid Transport Processes and Hydrology Laboratory	H. M. Nepf, D. Entekhabi
12.214	Environmental Geophysics	F. D. Morgan
12.507	Environmental Geophysics	F. D. Morgan
1.083	Environmental Health Engineering	P. Shanahan, Staff
11.368	Environmental Justice	J. Carmin
1.801J/11.021J/17.393J, 1.811J/11.630J/ESD.133J	Environmental Law, Policy, and Economics: Pollution Prevention and Control	N. Ashford, C. Caldart
11.362	Environmental Management Practicum	Staff
1.89	Environmental Microbiology	M. F. Polz
1.83, 1.831	Environmental Organic Chemistry	P. M. Gschwend
11.372	Environmental Planning Methods Modules	EPP Staff
14.42	Environmental Policy and Economics	M. Greenstone
17.32	Environmental Politics and Policy	Staff
20.104J/1.081J/ESD.053J	Environmental Risks for Common Disease	W. Thilly, R. McCunney
21A.342	Environmental Struggles	C. Walley
2.813, 2.83	Environmentally Benign Design and Manufacturing	T. G. Gutowski
20.215	Epidemiology, Population Genetics and Cell Biology of Human Cancers	W. G. Thilly
12.335	Experimental Atmospheric Chemistry	R. Prinn
12.105	Experimental Investigations of the Charles River	EAPS Staff
12.114	Field Geology I	B. C. Burchfiel, Staff
12.115	Field Geology II	Geology and Geochemistry Staff
17.422	Field Seminar in International Political Economy	N. Choucri
1.63J/2.21J	Fluid Dynamics	C. C. Mei, G. H. McKinley, T. R. Akylas, R. Stocker
21A.265	Food and Culture	H. Paxson
2.28	Fundamentals and Applications of Combustion	A. F. Ghoniem
2.60, 2.62J/10.392J/22.40J	Fundamentals of Advanced Energy Conversion	A. F. Ghoniem, M. Kazimi, Y. Shao-Horn, J. Tester
4.42J/1.044J/2.66J	Fundamentals of Energy in Buildings	L. R. Glicksman
2.00AJ/16.00AJ	Fundamentals of Engineering Design: Explore Space, Sea and Earth	A. H. Techet, A. H. Slocum, D. Newman,

		E. F. Crawley
21A.338J/SP.457J	Gender, Power, and International Development	C. Walley
12.007	Geobiology	R. Summons
1.071J/12.300J	Global Change Science	E. A. B. Eltahir
15.023J/12.848J/ESD.128J	Global Climate Change: Economics, Science, and Policy	H. D. Jacoby, R. G. Prinn
17.440	Global Governance	D. Singer
17.411	Globalization, Migration, and International Relations	N. Choucri
1.72	Groundwater Hydrology	C. Harvey
1.562	High-Performance Structures MEng Project	J. J. Connor, Jr.
3.987	Human Origins and Evolution	H. V. Merrick
ESD.123J/1.814J/3.560J	Industrial Ecology	R. Kirchain, J. Clark, F. Field
10.492	Integrated Chemical Engineering Topics I	K. F. Jensen, R. S. Langer, H. H. Sawin, B. S. Johnston, R. E. Cohen, N. Maheshri
10.493	Integrated Chemical Engineering Topics II	T. A. Hatton, K. F. Jensen, R. S. Langer, D. A. Lauffenburger, G. McRae, H. H. Sawin, B. S. Johnston
10.494	Integrated Chemical Engineering Topics III	K. F. Jensen, D. I. C. Wang, H. H.Sawin, R. E. Cohen, N. Maheshri, P. I. Barton
2.61	Internal Combustion Engines	W. K. Cheng
11.364	International Environmental Negotiation	L. E. Susskind
4.401	Introduction to Building Technology	M. Andersen
1.101	Introduction to Civil and Environmental Engineering Design I	Staff
1.102	Introduction to Civil and Environmental Engineering Design II	H. F. Hemond, J. Germaine, Staff
21H.421	Introduction to Environmental History	H. Ritvo
11.601	Introduction to Environmental Policy and Planning	L. Susskind
12.001	Introduction to Geology	EAPS Staff
1.070J/12.320J	Introduction to Hydrology	D. Entekhabi
7.440	An Introduction to Mathematical Ecology	M. Neubert, H. Caswell (WHOI)
3.091	Introduction to Solid-State Chemistry	D. R. Sadoway/D. Paul
1.201J/11.545J/ESD.210J	Introduction to Transportation Systems	J. Sussman, N. H. M. Wilson
11.001J/4.250J	Introduction to Urban Design and Development	Staff
11.301J/4.252J	Introduction to Urban Design and Development	D. Frenchman
1.713J/12.826J	Land-Atmosphere Interaction	D. Entekhabi
11.305	Landscape Ecology and Urban Development	Staff
11.367	The Law and Politics of Land Use	J. Stearns
11.166, 11.496	Law, Social Movements, and Public Policy:	B. Rajagopal

	Comparative and International Experience	
ESD.132J/15.655J	Law, Technology, and Public Policy	N. A. Ashford, C. C. Caldart
11.493	Legal Aspects of Property and Land Use	B. Rajagopal
1.75	Limnology and Wetland Ecology	H. F. Hemond
20.102	Macroepidemiology and Population Genetics	W. G. Thilly
11.002J/17.30J	Making Public Policy	J. Layzer, Staff
22.812J/ESD.163J	Managing Nuclear Technology	R. K. Lester
12.111	Mechanics of Sedimentary Processes	EAPS Staff
10.393	Multiscale Analysis of Advanced Energy Processes	J. W. Tester, M. Golay, E. Drake
21H.968J/STS.415J	Nature, Environment, and Empire	H. Ritvo
22.033	Nuclear Systems Design Project	A. C. Kadak
22.77	Nuclear Waste Management	R. K. Lester, Staff
2.24	Ocean Wave Interaction with Ships and Offshore Energy Systems	P. D. Sclavounos
12.301	Past and Present Climate	C. Wunsch, E. Boyle, K. Emanuel
21H.909, 21H.969	People and Other Animals	H. Ritvo
12.109	Petrology	T. L. Grove
1.64	Physical Limnology	H. M. Nepf
12.003	Physics of the Atmosphere and Ocean	J. Marshall
11.306	Planning Studio	Staff
11.366J/1.817J	Planning, Participation and Consensus Building for Sustainable Development	D. Fairman
11.374	The Politics of Ecosystem Management	J. Layzer
12.834	Prediction and Predictability of the Atmospheres and Oceans	J. Hansen
1.82	Problems in Environmental Microbiology and Chemistry	S. W. Chisholm, E. DeLong, M. F. Polz, E. J. Alm, J. Thompson, P. M. Gschwend, H. F. Hemond
2.744J/ESD.64J	Product Design	D. R. Wallace
1.011	Project Evaluation	Staff
14.41	Public Finance and Public Policy	J. Gruber
11.007	Public Policy Disputes	J. Layzer
11.482J/1.285J/ESD.193J	Regional Socioeconomic Impact Analyses and Modeling	K. R. Polenske
1.802J/11.022J, 1.812J/11.631J/ESD.134J	Regulation of Chemicals, Radiation, and Biotechnology	N. Ashford, C. Caldart
17.547, 17.548	The Rise of China	E. Steinfeld
11.375	Role of Science and Scientists in Collaborative Approaches to Environmental Policymaking	H. Karl
11.373	Science, Politics and Environmental Policy	J. Layzer
17.310J/ESD.103J/STS.482J, 17.31J/STS.082J	Science, Technology, and Public Policy	K. Oye
1.67	Sediment Transport and Coastal Processes	O. S. Madsen
12.110	Sedimentary Geology	J. B. Southard
12.085	Seminar in Environmental Science	D. H. Rothman
11.304J/4.255J	Site and Urban Systems Planning	E. Ben-Joseph

11.122	Society and Environment	J. Carmin
12.000	Solving Complex Problems	S.A. Bowring, R. Bras
ESD.934-ESD.938	Special Graduate Studies in Engineering Systems Division	Information: R. de Neufville
17.950-17.953	Special Graduate Topic in Political Science	Staff
4.439	Special Problems in Architectural Lighting	M. Andersen
11.941-11.955	Special Studies in Urban Studies and Planning	L. Vale
20.901	Special Topics in Toxicology and Environmental Health	Staff
11.403	Springfield Community Studio	C. McDowell, Staff
12.103	Strange Bedfellows: Science and Environmental Policy	EAPS Staff
1.714	Surface Hydrology	E. A. B. Eltahir
ESD.137J/1.813J/11.466J/15.657J	Sustainability, Trade, and the Environment	N. A. Ashford
17.181, 17.182	Sustainable Development: Theory, Research and Policy	N. Choucri
10.391J/1.818J/2.65J/11.371J/22.811J/ESD.166J	Sustainable Energy	M. W. Golay, J. W. Tester, J. P. Freidberg
4.235	Sustainable Settlement Design in Developing Countries	R. Goethert
1.045	Systems Design and Optimization	C. Barnhart, P. Jaillet
STS.036	Technology and Nature in American History	J. Pietruska
10.805J/ESD.136J	Technology, Law, and the Working Environment	N. A. Ashford, C. C. Caldart
7.431	Topics in Marine Ecology	H. Caswell, R. Harbison (WHOI)
STS.002	Toward the Scientific Revolution	Staff
1.061, 1.61	Transport Processes in the Environment	H. M. Nepf
1.253J/11.543J/ESD.222J	Transportation Policy and Environmental Limits	J. Coughlin, F. Salvucci
SP.35UR	Undergraduate Research in Terrascope	Staff
20.UR, 20.URG	Undergraduate Research Opportunities	S. Manalis, Staff
4.163J/11.332J	Urban Design Studio	J. Beinart, J. P. de Monchaux, M. Dennis, A. D'Hooghe
11.540J/1.252J/ESD.225J	Urban Transportation Planning	F. Salvucci, M. Murga
1.34	Waste Containment and Remediation Technology	P. Shanahan
11.479J/1.851J	Water and Sanitation Infrastructure in Developing Countries	Consult Department Headquarters
1.85	Water and Wastewater Treatment Engineering	P. Shanahan
1.77	Water Quality Control	E. E. Adams
1.731	Water Resource Systems	D. McLaughlin
21W.775	Writing about Nature and Environmental Issues	K. Boiko