REPORT OF THE MIT

CLIMATE ACTION PLAN REVIEW COMMITTEE

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Report of the MIT Climate Action Review Committee

Introduction

In October 21, 2015 President Rafael Reif announced the MIT *Climate Action Plan*, CAP, an ambitious community-wide initiative. This initiative was motivated by recognition of the importance of meeting the challenge of climate change for the United States and the world, the conviction that MIT has a unique set of skills to contribute to resolution of climate issues, and the widespread interest among students, faculty, staff, alumni, and research sponsors in working on these problems.[1] The MIT CAP was importantly shaped by the broad community-wide discussions sponsored by the MIT Climate Change Conversation Committee, CCCC, which issued its report in June of 2015.[2]

The October 21, 2015 *Plan for Action on Climate Change* included a mission statement for CAP:

> "Our objective: to minimize emission of carbon dioxide, methane and other global warming agents into the atmosphere, and to devise pathways for adaptation to climate change, through the active involvement of the MIT community, proactively engaged with industry, government, academia, foundations, philanthropists and the public.
> To reach that objective, we will:
>
> A. Improve our understanding of climate change and advance novel, targeted mitigation and adaptation solutions.
> B. Accelerate progress towards low- and zero-carbon energy technologies.
> C. Educate a new generation of climate, energy and environmental innovators.
> D. Share what we know, and learn from others around the world.
> E. Use our community as a test bed for change."

These five work streams are based on MIT's proven approach to addressing complex societal problems: research (A and B), education (C), and outreach (D). A new feature (E) is the intention to use the MIT campus as a test bed for change that potentially will serve as a model for other organizations about how to move toward a more sustainable community.

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[1] The October 2015 Climate Action Plan is available on the MIT Climate Action web site: http://climateaction.mit.edu/reports.

[2] The report is available at: http://web.mit.edu/vpr/climate/climatereport.html.

Many different existing MIT entities involved in energy, environmental, and climate activities were identified as part of the CAP initiative. Vice President of Research Maria Zuber was assigned the responsibility to oversee the CAP initiative, and she established the Climate Action Advisory Committee to advise the Institute wide effort.[3] On April 27, 2016 the Office of the Vice President for Research issued an *Update on the Plan for Action on Climate Change* available at http://climateaction.mit.edu/reports.

The CAP involves, but is not limited to, 15 entities mentioned in the Plan, as well as a number of community groups. Several of these entities make contributions to more than one of the five work streams of the CAP. In addition, undoubtedly many faculty and laboratories will choose to continue climate-related work without formal involvement with the CAP initiative.

The MIT CAP Review Committee

It is an enormous challenge to orchestrate the ambitious agenda laid out for CAP, the large number of MIT entities involved in complementary efforts, and the five different CAP work streams. As the CAP's second anniversary, October 2017, approached, President Reif established this review committee and gave it the following broad charge:

> "[I]t is timely to review the status, accomplishments, and opportunities for the important set of complementary activities that collectively comprise the CAP. I ask you to meet with the centers, offices and initiatives associated with the CAP in order to learn about ongoing research and educational activity, collaboration among MIT entities, their attention to policy and regulatory issues, as well as the adequacy of financial support.

The membership of the group and its charge are in Annex A.

The Review Committee did not consider it useful, at this stage of CAP's life, to reexamine the goals and organization of the initiative. The Review Committee decided to focus its efforts on assessing the status of ongoing activities, putting forward constructive recommendations for accelerating the program's progress, and identifying opportunities and risks to the success of the effort.

[3] The charter and membership of CAAC can be found on the Climate Action website at http://climateaction.mit.edu/overview-climate-action-advisory-committee.

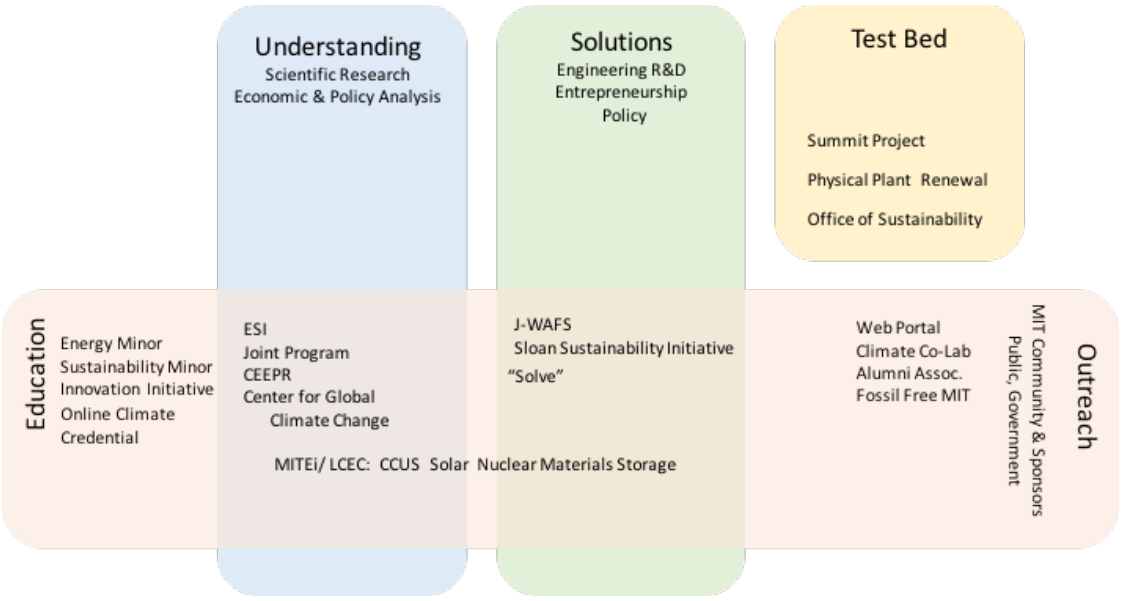
Further, the Committee did not believe it practical or necessary to examine the activities of each entity at a depth sufficient to reach firm judgments about quality and performance. The Committee's effort was spent on understanding the interactions between the major CAP entities and selected a few topics to examine in greater depth.

The Committee began its work by dividing its members into pairs to visit with most of the CAP participating entities. At each visit a common list of questions was used to structure discussions with the entity leaders. See Annex B for the list of questions. Committee deliberations then set the agenda of items for deeper consideration.

The remainder of this report consists of (1) a summary of Committee findings about the status of the CAP work streams at the two-year mark; (2) a discussion of key issues, and (3) recommendations. The Committee presents its findings by the five work streams because this is the way the administration decided to organize the CAP. But the work stream activities are not independent and the Committee presents an alternative framework below that expresses with greater clarity the synergy among the work streams.

Committee Findings on the Status of CAP Work Streams

The section addresses the activities of only some of the MIT participating entities that the Committee believe deserve mention. The five CAP work streams described in the 2015 *Plan for Action on Climate* provide a framework for reviewing the various CAP activities. The attached figure shows the relationship between the CAP work streams and participating entities that vividly illustrates the challenge of integrating activities that are at the same time complementary and disparate.



Education of young researchers and the dissemination of research are core to the MIT mission and cut across all of the CAP activities. The work stream focused on developing basic scientific understanding (for example of climate processes) or economic models is distinct from the work stream focused on translation of fundamental research into new technologies, new products, and new business models. However, many of the research activities focused on energy necessarily also cut across the various boundaries between fundamental research, development, and economic and policy analysis.

A. Improve Understanding of Climate Change and Advance Targeted Mitigation and Adaptation Solutions.

The CAP in many ways builds on the foundation of the MIT Energy Initiative (MITEi), which was established in 2006 and successfully engaged a very large number of faculty, staff and students in energy-related research, education and outreach. MITEi established strong relationships with industry, and its programs overwhelmingly address the low carbon energy future that is needed to mitigate climate change risks. As such, MITEi serves as a "cornerstone" for the CAP.

Environmental Solutions Initiative

CAP assigns MIT's Environmental Solutions Initiative (ESI) responsibility for catalyzing integrated research across disciplines, focused on dismantling obstacles to progress in reducing the risks of climate change. MIT provided ESI $5 million in funding over 5 years at

the time of its establishment in 2014, of which $3.5 million is programmed for cross-disciplinary seed grants across the Institute; ESI has completed one round of seed grants.

Under the guidance of John Fernández, ESI is formulating a new agenda.[4] Professor Fernandez sent a thoughtful letter to the Review Committee expanding on the objectives of ESI and how he is approaching its development but, in brief, the broad scope he envisions includes "technologies and policies that advance effective mitigation of carbon emissions and adaptation to the consequences of climate change, catalyze a renaissance of science, engineering and design toward sustainable and humane cities, and offer next generation methods for sustainable resource extraction, production, and consumption."

This statement of the ESI's mission clearly overlaps the MIT Energy Initiative mission statement: "Our mission is to create low- and no-carbon solutions that will efficiently meet global energy needs while minimizing environmental impacts and mitigating climate change."[5] Clarifying and harmonizing this overlap between the efforts between ESI and MITEi should be addressed at some point in the future since significant overlap can be confusing to sponsors. The challenge is how best to produce faculty and student opportunities for research and education without too much duplicative overlap between the many different MIT entities working on the climate problem.

Fernández has several exciting examples of possible ESI program initiatives that are of interest to MIT faculty that explore new climate change solutions and have no overlap with the work currently underway at MITEi or its Low Carbon Energy Centers. Here are three, briefly stated:

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[4] The ESI agenda is available at https://environmentalsolutions.mit.edu/esi-agenda/.

[5] http://energy.mit.edu/ The main web page state MITEi: "Linking science, innovation, and policy to transform the world's energy systems. The MIT Energy Initiative is MIT's hub for energy research, education, and outreach."

- Develop small, mobile, robotic sensors capable of collecting massive amounts of data on GHG fluxes from natural land system such as forests, wetlands, coastlines. Use machine learning to gain insights in the effect on climate.

- Develop life cycle accounting for metal and mineral material flows in order to forecast extraction rates for primary metals and other strategic minerals and the energy intensity of consumption.

- Study the toxicity of industrial substances sources in order to understand the air and water dispersion rate of key toxic substances in urban and rural settings.

Oceans and The Abdul Latif Jameel World Water and Food Security Lab (J-WAFS)

A holistic view of earth's systems includes oceans, land, air and near space. The Review Committee believes greater attention should be given to ocean science, technologies, and policy analysis in the MIT Climate Action Plan going forward. The goal should be to advance understanding the role of oceans in climate change and in novel, targeted mitigation and adaptation solutions.

Fundamental research on the role of the oceans in climate and climate change is ongoing at MIT in EAPS, CEE, ME (Ocean), AeroAstro as well as other departments. The research spans the discoveries of important microorganisms in the ocean ecosystem to pioneering understanding and modeling of oceanic mixing and rates and consequences of general circulation to studies exploring Greenland and Antarctic glaciers to Pacific coral atolls to understand complex Earth systems. To understand the global climate system, it is necessary to investigate the interactions at all scales between ocean, land, and atmosphere.

MIT has an educational partnership with the Woods Hole Oceanographic Institute (WHOI). Consideration should be given to include the WHOI director in the CAAC; enhanced educational and research collaborations could result.

Quite properly, J-WAFS, led by Professor John Lienhard, is part of the CAP. J-WAFS seeks environmentally benign, energy efficient and scalable solutions for water and food systems across a range of regional, social and economic contexts by incubating technologies and fostering innovative regional collaborations. What pathways will the world find to supply

needed water and food to a growing population as the pressures of climate change increase? The inclusion of J-WAFS shows that MIT is taking the broadest possible view of climate change.

The Center for Global Climate Change Science

The Center for Global Change Science studies complex environmental issues requiring large state of the art collaborative efforts. The Center has become a significant interdisciplinary force on campus exemplified by three of its large initiatives: (1) The multinational Advanced Global Atmospheric Gases Experiment measures the rates of increase of over 50 environmentally harmful trace gases at high frequency using automated mass and laser spectrometers in 12 countries over the globe; (2) the Joint Program on the Science and Policy of Global Change investigates complex interactions among the human and natural components of the earth system using unique Integrated Global System Models (IGSM) that produce probabilistic coupled economic and environmental projections for impacts and informing decision-making; and (3) the Climate Modeling Initiative develops high-end ocean and climate models using novel scientific and computational approaches.

Transportation

The economic, social welfare, pollution/health, and climate impacts of the current and possible future transportation system are immense. Because of its importance, the MIT faculty has been broadly and effectively engaged in numerous aspects of transportation research and education in many different departments and centers for many decades; for a partial summary of the current situation see the Transportation@MIT website http://transportation.mit.edu/.

As with many fields, the transportation research landscape is fragmented into many specialties, in part because of different research sponsors interests. MIT's strength in different subfields waxes and wanes as talented faculty are hired, establish strong research groups but then eventually leave or retire so MIT's faculty hiring and tenure decisions strongly affect its capability to address climate change. Currently, MIT has relatively few tenured faculty working in automotive research, combustion, or transportation policy compared to the situation in years past.

Recognizing the importance of transportation for climate change, the CAP proposed MITEi organize a *Mobility of the Future study*, whose report would "serve as balanced, fact-based, and analysis-driven guide to key topic areas in energy for a wide range of decision makers in government and industry". MITEi successfully organized an interdisciplinary team (four Engineering, Architecture, and Sloan faculty, an emeritus faculty member from Engineering, plus research staff from MITEi, Sloan, the Intelligent Transportation Systems Lab and the New England University Transportation Center, plus about a dozen graduate students and postdocs) to conduct this study, with an industrial consortium to provide all the funding. The project started in September 2016, and the report is expected to be issued in late 2019.

This CAP initiative illustrates some strengths and weaknesses of the current situation with climate related research at MIT. On the positive side, MITEi was able to secure firm external funding to initiate a multi-million dollar climate-related project from scratch in just two years. On the negative side, there was no active tenured MIT faculty member working in this important area of future ground transportation because there was no natural faculty leader for the project. Instead, the project team is being led by engineers with limited economics/policy experience relying on research staff to fill several key roles. Without enough faculty experts on climate-related policy issues, it seems unlikely that MIT research will have as much impact on government policy as envisioned by the CAP. But regardless of immediate policy impact, the results of these MITEi projects will be of interest to decision-makers in industry, and critical for meeting CAP goals.

B. Accelerate progress on low carbon energy technologies

CAP calls for the establishment of eight Low Carbon Centers (LCC). Bob Armstrong and his team at the MIT Energy Initiative, MITEi, were given the assignment to create, seek funding, and manage the centers. The focus of the LCCs is in MIT's sweet spot: exploring new technical concepts that have promising important real-world application. In practice, market deployment of new technology depends on achieving a competitive cost. However, in general, cost analysis and design for cost are not strengths of MIT, especially in past energy technology research. A stronger focus on cost reduction and cost competitiveness across the LCCs projects would be distinctive and likely very welcome by CAP sponsors.

The Committee gives its assessment below of the status of each of the LCCs that are

underway; the prospectus for the LCCs is on the MIT website at http://energy.mit.edu/lcec/.[6]

1. Carbon Capture Utilization and Storage (Professors T. Alan Hatton and Bradford Hager) This LCC is focusing on carbon capture and underground seismic characterization of potential long-term CO_2 storage sites. Initial projects include organic-metallic frameworks for CO_2 capture, on-board vehicle CO_2 capture systems, and use of CO_2 in the production of non-fuel products.

2. Solar Energy (Professors Vladimir Bulovic and Moungi Bawendi) The Tata Trust has made a five-year commitment for $15 million to support an extensive thin-film solar photovoltaic research program targeting developing world applications, called "GridEdge." This LCC is likely to focus more on early stage fundamental research than any of the other LCCs.

3. Energy Storage (Professors Jeffrey Grossman and Yang Shao-Horn) The goal is the development of new energy storage technologies with the technical performance and cost characteristics needed to provide power sustainably at any place, at any scale, and at any time. Projects are now being defined in such areas as (a) novel metal ion batteries, (b) flow batteries, (c) Improving oxygen-redox kinetics, and (d) solar to fuels.

4. Advanced Nuclear Systems (Professor Jacopo Buongiorno and Dr. John Parsons). This LCC builds on the Department of Nuclear Engineering's *Center for Advanced Nuclear Systems* that develops system-oriented knowledge that helps integrate nuclear fission technology into the electricity grid. Important initial support has come from Exelon Corporation to support research which could transform the performance of the fuel cladding in Light Water Reactors (LWRs).

5. Electric Power Systems (Professor Chris Knittel and Dr. Frank O'Sullivan). This LCC is in the process of being launched.

[6] The three future LCCs are: Materials in Energy & Extreme Environments (Professors Bilge Yildiz and Ju Li), Fusion (Professors Anne White and Dennis Whyte), and Energy Biosciences (Professors Angel Belcher and Kristala L.J. Prather).

6. Funding. The Institute did not provide any new discretionary funds to support the effort to launch and grow these Low Carbon Energy Centers (LCECs). The MIT Energy Initiative, MITEI, recruited both new and existing industry members to participate –in the latter case, this involves the redirection of some of their existing commitments to one or more LCECs. Professor Robert Armstrong has been remarkably successful in this effort. As the following table shows over $50 million of commitments have been received from 12 existing and new firms participating in the MITEi. [7]

The MITEi target for an industry three-year LCEC research commitment is $750k and for a three-year membership commitment is $450k. The annual $150k membership obligation includes $50k for the LCEC directors' discretionary support for seed activities, $50k for MITEi administration, and $50k for techno-economic studies to support the LCEC. Existing MITEi Founding and Sustaining Members receive an average discount of $25k per year off of the membership obligation.

The evaluation of technological and institutional solutions to address climate change is an important MITEi support activity since the LCEC directors do not typically have expertise in carrying out such studies. (The CANES --Center for the Advanced Nuclear Energy Systems-- LCEC is an exception). Currently, under the leadership of Frank O'Sullivan, four post-doctoral fellows are supported from LCEC funds. Each focuses on an LCEC-specific techno-economic study (which might better be termed a "technical and economic evaluation") that addresses economic or regulatory issues. Useful studies ("evaluations") have been completed or are underway for the CCUS, EPS, Solar and Storage LCECs. Membership and research obligations (as of 9/27/17) for these centers and CANES/Fission are immediately below.

[7] In addition, there are commitments for $4 million for the materials LCEC and $400 k for the fusion LCEC.]

Member	CCUS	CANES (Fission)	Solar	Energy Storage	EPS	Total
Aramco	$1,125,000	$0	$150,000	$0	$0	$1,275,000
Cenovus	$1,200,000	$0	$0	$0	$0	$1,200,000
Corning	$150,000	$0	$0	$0	$0	$150,000
Eni	$3,708,093	$0	$5,161,936	$1,979,828	$60,000	$10,909,857
ENN	$0	$0	$0	$1,200,000	$0	$1,200,000
Exelon	$0	$8,872,335	$1,388,586	$0	$400,000	$10,660,921
ExxonMobil	$3,128,828	$360,000	$858,860	$0	$970,822	$5,318,510
GE	$1,108,333	$0	$1,108,333	$1,108,333	$375,000	$3,699,999
Iberdrola	$0	$0	$0	$0	$2,000,000	$2,000,000
Shell	$616,665		$0	$1,125,000	$183,333	$1,924,998
Statoil	$0	$0	$1,125,000	$1,125,000	$0	$2,250,000
Tata	$0	$0	$15,000,000	$0	$0	$15,000,000
TOTAL	**$11,036,919**	**$9,232,335**	**$24,792,715**	**$6,538,161**	**$3,989,155**	**$55,589,285**

Note 1. The "rack rate" for membership in a center is $450,000 membership + $750,000 for research for a total of $1.2 million over three years. Existing MITEi members get discounts usually a $375,000 membership fee over three years.

Note 2. The Alfred P. Sloan Foundation, EDF, and Shell have provided a total of $1.75 million for a Future of Nuclear study in the nuclear engineering. However, they are not members of CANES.

In sum, significant progress has been made is establishing the LCECs, finding industry partners to provide support for their research programs, and beginning to build project teams with participating faculty and students.

LCEC leaders commented that it has proven difficult to translate the commitment made at a high level in the companies to a contract and agreement on a work plan. MITEi has taken steps to add part-time staff with industry experience to facilitate the process; hopefully this will make difference. Industry participants have noted that agreement to join the MIT CAP initiative is of interest not only because of the opportunity to participate in projects but also because of the potential exposure to the broader range of technical, economic and policy issue that influence the pace of clean energy innovation.

C. Educate New Climate Scholars, Practitioners, and Innovators

The MIT CAP places special emphasis on education. Educating a new generation of individuals devoted to work that helps avoid the deleterious consequences of climate change

is consistent with the Institute's tradition of preparing its graduates to address important social issues. The MIT CAP calls for (a) developing an environment and sustainability minor by the end of 2017, involving subjects from all five schools; (b) developing an on-line climate change and sustainability credential through edX; and (c) exploring broad adoption of principles of benign and sustainable design through new cooperative efforts between the School of Architecture and Planning (SA+P) and the School of Engineering. All three of these items are being addressed and several more have been developed that are in the spirit of the CAP.

New CAP educational initiatives are building on significant educational advances in energy and environment in recent years. In 2009, MITEi established a cross-school undergraduate minor in Energy Studies with the goal of providing students with "subject-specific knowledge and an integrative understanding of the complex reality of energy issues.

Over the past 18 months, MITEi has sharpened the focus of the Minor and MITEI's other education programs on the dual challenge of providing more energy to a growing world population while at the same time dramatically reducing carbon emissions from energy sources. A revised curriculum for the Minor will be submitted to the Committee on Curriculum this December. MITEi has undertaken a number of additional initiatives including (a) funding summer UROPs, (b) a Freshman Pre-Orientation Program for a week devoted to introducing renewable energy, energy-efficiency, and climate-change-policy concepts; (c) a trip to California during spring break where students learn to help install PV on low-income housing, and (d) digital and TA course development for the undergraduate and graduate sustainable energy subject.

In September 2017, ESI successfully launched the Environment and Sustainability Minor (item (a) above) with the ambitious objective to offer "flexible pathways for students in all majors to harness the knowledge needed to forge a better future." With foundation support, ESI has thus far funded eight new classes and three adapted classes for the new Minor. ESI is also leading an effort to infuse a range of GIRs with content on climate and environment, starting with 8.01, Physics I. At the graduate level, ESI administers and is working to expand the 20-year old Martin Family Society of Fellows for Sustainability. In 2017 ESI started a modest summer research grant program for doctoral students in SHASS. ESI is working with student

leaders and the Global Education and Career Development office to raise the visibility of job and internship opportunities with environmental impact, particularly those available at major corporations. ESI led data gathering and analysis on MIT's academic programs in environment and sustainability. Additionally, ESI maintains a list of undergraduate majors and minors related to environment and sustainability,[8] and a list of undergraduate and graduate subjects on sustainability issues[9].

ESI has undertaken a number of additional initiatives: (a) in collaboration with NGO Conservation International, ESI is preparing a field experience program for students that will focus on nature-based solutions to climate change and work with local stakeholders in less developed countries; (b) over IAP, ESI has run two "Hackathons for Climate," engaging students, faculty, and alumni in learning about and generating creative solutions to climate challenges, (c) In partnership with the International Policy Lab, ESI initiated a science communication training for graduate students to teach them how to bring their methods and results more effectively to public and policy audiences; and (d) the Offices of Digital Learning and the Vice President for Research and ESI have begun discussions about the MITx credential on climate change (item (b) on page 11). Student research –funded through UROP, MITEI,[10] and ESI,[11] has a strong educational component, as do student organizations (for example, the Energy Club), and various lecture series (e.g., the People and the Planet series). Nine academic departments offer courses in energy, environment, and climate matters.

Finally, ESI is partnering with SA+P in the development of a design competition focused on sustainable urban form. The competition, which will be launched in late fall 2017, is open to all MIT students; winners will be announced on Earth Day 2018. Partial sponsorship is provided by the Leonardo DiCaprio Foundation.

Additional notable activities include (a) the Technology and Policy Program (TPP) master's degree for the past 40 years with a majority of student and faculty research and education

[8] https://environmentalsolutions.mit.edu/degree-programs/
[9] https://environmentalsolutions.mit.edu/wp-content/uploads/2017/09/Copy-of-EnvironmentSustainabilityClasses.pdf
[10] http://energy.mit.edu/urop/
[11] https://environmentalsolutions.mit.edu/esi-urops/

focused on energy and environment sociotechnical policy analysis, (b) the research and education of the MIT Innovation Initiative (MITii) spans all five MIT schools with; notably, in September 2016, MITii launched the new Entrepreneurship and Innovation (E&I) minor, which has grown to be one of the most popular minors at the Institute. The minor is accessible to any undergraduate student at MIT; it formally reports to the SoE and Sloan; (c) the Sustainability Certificate offered for Sloan MBA's by the Sloan Sustainability Initiative; (d) incorporation of campus sustainability research and activities into education via the Living Laboratory program at the MIT Office of Sustainability; (e) Terrascope's increasing focus on sustainability, including this year's focus on "Preparing the World for Climate Change"; and (f) the ClimateX platform coordinated by the Office of Digital Learning and MITACAL, a group of MIT alumni dedicated to climate action.

There has been much progress on energy, environment, and climate education, in addition to the initiatives highlighted in the CAP. These activities both leverage and enhance the wide array of climate-related research activities at the Institute, in diverse departments as well as focused labs and centers, which bring students and faculty together for both scholarship and learning. The recent burst of educational activity on climate change is encouraged by CAP but reflects a longer-term trend of growing interest among faculty and students, interest in deep understanding of problems in energy and the environment as well as in helping to craft pathways toward solutions for those problems.

D. Share What We Know, and Learn from Others

CAP properly emphasizes the importance of sharing its results with the public. Communication should reach many different audiences: the campus community, the City of Cambridge, public officials at the state and national levels as well as those in other countries and international organization. The CAP announcement suggests several mechanisms for accomplishing this outreach under the coordination of the Environmental Solutions Initiative that goes well beyond normal efforts of MIT investigators to publish results and keep sponsors interested and informed.

The 2015 CAP framework document[1] speaks about MIT's outreach role:

> "…as an independent voice in contentious, technically grounded policy

debates …. to offer the public a trusted source of climate change information, to engage leaders and citizens in the effort for solutions..."

There is a thin line between offering technically sound factual information and analysis in a policy debate and engagement intended to influence the views and actions of participants in the policy debate in a particular way [policy advocacy]. In fact, while there may be a "shared goal to mitigate climate change and meet the 2°C limit on global warming" at MIT, there are enormous differences in views about the policies that should be adopted now, or who should pay for implementing these policies, or how they will be deployed globally. Alternative views must be respected.

CAP will be most successful in influencing the views of the public, elected officials, and industry partners through sound and innovative technical analysis. It is a mistake to believe or suggest that MIT's purpose is to support one course of action or work directly to change the values or views of individuals or organizations with other interests, though some faculty and some groups affiliated with the CAP clearly think otherwise. There is great value in MIT being seen by all sides as an institution that is informed, impartial, non-partisan expert not advocating one solution in the climate policy debate (although individual faculty are free to do so as long as they make clear they are not speaking for MIT).

The Review Committee believes it is important for the MIT administration to clarify the intent of "engagement" and "working with industry and government leaders." Does the administration intend to go beyond normal outreach to the community, sponsors, government officials, and the public to proposing and advocating policy actions as an institution?

E. Use of MIT as a Test Bed for Change

This work stream is enormously popular with MIT students and faculty who believe that MIT should "walk the talk" and implement projects and programs that improve sustainability (however defined) on the MIT campus and thereby serve as a model for others.

Julie Newman, the head of MIT's Sustainability Office (the only entity in CAP that is supported by the general budget), coordinates this work stream. She has brought

enthusiasm and skill to an area where MIT is catching-up with other universities,[12] and is pursuing distinctive directions. The Office of Sustainability has produced a *MIT Campus Greenhouse Gas Reduction Strategy*[13] and works with MIT's Department of Facilities and others to implement GHG reduction projects. More recently the Campus Sustainability Task Force issued a report setting out a *Pathway to Sustainability Leadership by MIT.*[14] MIT Vice President Israel Ruiz, who is responsible for this office, is a strong advocate for it; he sees it as focusing broad MIT community understanding and support for the Institute's ongoing sustainability efforts.

1. Open Data Platform, Data Analytics, and Evaluation

CAP calls for the establishment of an open data platform that provides information about campus energy use and on the analysis and evaluation of projects undertaken to reduce GHG emission. The Energize MIT (Beta) site is an early step to make MIT energy system and GHG emissions data available.[15] The Review Committee strongly endorses this effort. Public scrutiny will give confidence that MIT's efforts are giving an honest account of the cost and benefits of its efforts. A successful project that is data driven and with a publicly available analytic basis is more likely to be a model adopted by others.

2. Campus Carbon Emission Reduction

CAP calls for at least 32% reduction in campus GHG emissions by 2030 from a 2014 base, with further reductions if possible. 98% of these emissions come from providing electricity and heating/cooling to MIT buildings. The electricity is both purchased and produced by the MIT's Central Utility Plant. (The emission burden includes both emissions from campus generating facilities and those imputed from the mix of generation purchased by MIT). The Review Committee has the impression that less attention has been given to the energy efficiency of the mix of vehicles owned and operated by MIT.

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[12] For example, see U. Cal Berkeley's *Bending the Curve,* available at http://uc-carbonneutralitysummit2015.ucsd.edu/_files/Bending-the-Curve.pdf.

[13] Available at: http://sustainability.mit.edu/mit-campus-greenhouse-gas- emissions-reduction-strategy-published.

[14] Available at: http://web.mit.edu/cstfreport-pre/index.html.

[15] Available at: https://tableau.mit.edu/#/views/Energize_MIT/Energize_MIT.

The CAP states the 32% target was selected "after careful study." The Review Committee agrees that a final choice of a reduction target and the collection of projects needed to achieve target should not be taken until a thorough analysis has been made of the cost and the risk of alternative courses of action. Such analysis should be transparent to interested parties, based on verifiable data, and publicly available. Opinions will differ about whether and how much MIT should spend to reduce its emissions beyond regulatory requirements. But the debate should be informed by knowledge of the costs to the Institute.

The several paths that MIT intends to follow to reduce its GHG footprint are described in *MIT's GHG Reduction Strategy*:[8] (a) Introduce efficiency measures to reduce energy use. (b) Reduce emissions from on-campus electricity generation by deploying renewable energy sources and reducing the carbon intensity of the (mostly natural gas) fossil fueled campus co-generation plant. (c) Undertake off-campus projects, unrelated to MIT energy use, that achieve verifiable reductions in carbon emissions that are effective offsets of GHG burden of MIT activities. This last, off-campus option is based on the most sensible principle for public or private entities to select the lowest cost option to achieve a desired objective – in this case CO_2 reduction.[16] Other ancillary benefits are put forward for these off-campus projects such as encouraging new technology and providing learning opportunities for MIT faculty, students, and staff, but it is difficult to measure these outcomes and hence establish their value. Vice President Israel Ruiz informed the review committee of the MIT Central Utilities upgrade project that will expand electricity and steam service to the campus more efficiently and with lower carbon emissions.[17]

The Review Committee believes the MIT community is insufficiently aware of the logic and structure of the 60 MWe North Carolina Summit Farms solar photovoltaic project. The Summit project is a good example of how MIT should be approaching off-site carbon

[16] This is a local realization of international mechanisms; fundamentally a precursor to emissions trading. The UN Framework Convention on Climate Change (UNFCCC) that encourages in the Kyoto Protocol:
- Joint Implementation (JI) Allows an Annex I country to "earn"emission reduction units (EURs) from an emission reduction project undertaken in an Annex I country.
- Clean Development Mechanisms (CDM) Allows an Annex I country to "earn" ERUs from an emission reduction project undertaken in an non-Annex I country

[17] http://powering.mit.edu/

reducing projects.[18] See Annex C for a summary of this project. Joe Higgins of MIT's Office of Facilities Management has led the development of this project, undertaken extensive economic analysis of the cost and anticipated benefits of the project, including extensive sensitivity analysis. The analysis suggests a positive net present value benefit over the lifetime of the project of $11 million and that it will be responsible for roughly half of the total 32% carbon reduction target sought by MIT. Vice President Israel Ruiz informed the review committee that MIT intends to seek similar opportunities but there will be stiff competition, both from private sector investors and from other universities that are pursuing projects that have positive net present value.

Internal carbon price

CAP calls for use of a shadow price on CO_2 emissions in new and renovation capital projects. In designing such a project, the net present value of upfront investment in energy efficiency is balanced against the cost of fuel over the project lifetime. It is prudent and reasonable for the Institute in the projection of future fuel costs to examine cases where a carbon emission charge will be imposed on fossil fuel use. The Review Committee believes this is the best way to think about shadow carbon pricing.

CAP goes further to suggest the study of selected aspects of end-user carbon pricing on our campus, to provide data that students and faculty can use to study what policies would best reduce carbon emissions by changing habits and behaviors. The Review Committee cautions that this will be very contentious both on principle and certainly on possible measures.

One possibility that deserves to be pursued is to establish a number of small research projects to explore how MIT users would respond to different end use charges and socialize this information with other universities.

3. Designing green buildings

MIT buildings should be designed to attract students and faculty as compelling structures that are beautiful and effective in providing occupants the inspiration and functionality they

[18] (MIT has worked with the Summit Project to provide opportunity for MIT researches to test operation of new device concepts in this realistic grid environment.)

require. The design, construction, and operation of the facility should break new ground in demonstrating sustainability. Of course, MIT's aspirations in this regard are shared by many other leading universities, whose students and communities also aspire to having a sustainable campus.

Generally, sustainability in campus buildings is measured through point-based systems such as LEED. In this system, a higher energy product or building component is switched out in favor of a lower energy one. Actual progress towards reducing carbon emissions may or may not be optimized within this rating system, since it does not account for the embodied energy used in sourcing, manufacturing and transport of that component.

Requiring that MIT buildings be certified as LEED Platinum or LEED Gold (as is the current practice) is no longer an innovative or cutting-edge standard of building sustainability: today, it is what we see on almost every campus as a "best professional practice".

MIT's Executive Vice President is committed to assuring that new and major renovation building construction on the academic campus achieve the best possible energy efficiency. He points out that cost will be much reduced if attention to energy efficiency begins at the point of initial design. While cost and building budgets are important considerations, exceeding base building budgets may be necessary if MIT aims to innovate in sustainability. The "test bed" concept is appealing, as it offers a MIT an innovative pathway to push forward an intensified sustainable agenda for campus buildings, engaging research, education and public outreach.

The key question going forward is to identify how MIT might genuinely lead in the area of sustainable architecture and campus planning. There is an opportunity to consider both operational and embodied energy in MIT's building projects. This would involve greater consideration and use of local and renewable materials and sourcing. Building interior fit-out "standards" could be revised to create more distinctive and less generic qualities of space as an integral part of the MIT experience. CAP entities such as ESI, MITEi and the Low Carbon Energy Centers could more closely engaged with MIT's SA+P curriculum and faculty to address opportunities to integrate innovation, design and engineering to advance coordinated interdisciplinary efforts for campus sustainability.

Closing Remark on MIT as a Test Bed

MIT students and faculty generally support the use of MIT as a test bed. There is the hope that local activities at MIT and elsewhere, which demonstrate the practical and economic success of carbon avoiding technologies and practice will collectively serve as an example that will help move the world to more rapid action on climate change.

Policy Analysis

All acknowledge that progress on climate change requires significant policy analysis to assess in quantitative terms, based on real world data, the costs and benefits of alternative course of action. Such policy analysis requires the integration of technical, economic, political, and regulatory considerations including elucidation of who are the winners and losers and impacts on different countries.

MIT is in a better position than many other universities to undertake such policy analysis because of the breadth of expertise of its faculty and its tradition of addressing the world's great challenges. However, the Institute must recognize that it has an extremely limited number of faculty members who have the proficiency and experience to address the enormously wide range of complex issues involved in climate change as well as a willingness to lead or participate in demanding interdisciplinary studies of these matters. Despite having a first-rate economics department and management school, MIT does not have sufficient numbers of active faculty specializing in economic analysis of energy and environmental issues such as electric power and transportation systems.

The MIT CAP is deficient in not addressing this fundamental issue of this scarcity of faculty members with genuine experience and expertise relevant to policy analysis. The Review Committee believes that the relatively limited capability for carrying out high quality energy and environment policy analysis limits severely the success of the initiative.

Attracting faculty with this capability is not an easy matter as decades of history at MIT and other leading universities make evident. Faculty appointments are in academic departments that favor disciplinary excellence over inter-disciplinary participation making the road to tenure more difficult to traverse. Domain knowledge about industry activities and

government regulation are often less valued than methodological studies involving real data, but both are needed for deep understanding of policy choices.

An important subsidiary point that came up several of the discussions with CAP entities is the absence of a framework or context of analyzing cross domain interactions, for example, between water, energy, and food or intermittent generation, storage, and electricity distribution. CAP should explore new mechanisms for breaking out of stovepipe thinking.

This fundamental issue of the scale of policy analysis capability at MIT goes beyond energy and the environment to other critical social problems such as health care, poverty, and national security. The Review Committee does not offer a solution to this problem but concludes that CAP should be very deliberate about its agenda for policy studies. An indifferent policy study damages MIT's reputation as much as an excellent policy study enhances it. Greater use of Professors of the Practice might be part of a solution.

CAP envisions four studies "of the future:" (Utility of the Future, Mobility of the Future, Flight of the Future, City of the Future). These are "a new series of reports being produced by the MIT Energy Initiative (MITEI) to serve as balanced, fact-based, and analysis-driven guides to key topic areas in energy for a wide range of decision makers in government and industry." The new studies "of the future" build on MITEi's earlier "future of" studies but have different sponsorship and scope.

The success of many MITEi "future of" studies was due to a number of factors including (a) timing (there was less interest in energy a decade ago, (b) faculty members with deep domain knowledge willing to contribute significant time to the effort, (c) integration of technical, economic, political, and regulatory matters, and (d) formulating policy recommendations that congressional and executive branch officials found practical and actionable.

The Research Committee believes that rigorous criteria should be applied in the planning and execution of proposed "of the future" studies to maintain the value of this MIT "brand." The "future of" brand is unique and of value to MIT. Use of the "future of" brand should continue to be restricted to studies that have comprehensive scope, diversified sponsorship, and a genuine policy focus. Other studies that go deeply into some aspect of climate change

deserve prominence in MIT's CAP plan and an effort should be made to develop an agenda and a distinctive trademark for these activities as well. The Review Committee suggests adopting a different phrase to replace "of the future" for this new category of studies to enable it to build a distinctive trademark and avoid confusion with "future of" studies.

CAP intends "Building on MITEI's influential 'Future of' reports, … commissioning an accelerated study to produce a roadmap of the coordinated scientific, technological and policy approaches it will take to best protect the world from exceeding the "guardrail" temperature rise of 2°C—in effect, a 'Future of Life as We Know It' report, which we will share aggressively with government leaders at every level."

Constructing a roadmap of such dramatic scope, in the view of the Review Committee, is not feasible. The 2°C challenge (defined in the work plan of the faculty leads as global warming below two degrees with 50% probability and below three degrees with 90% probability) inherently involves multiple factors (energy supply and use, land use, industrial processes, multiple GHGs, and more), globally variable responses in different countries and regions (climate, level of economic development, public attitudes, governance, and more), and resolution of unknowns (such as uncertainty of climate response to increasing GHG concentrations, especially at the local and regional level). MIT can best bring focus to the 2°C challenge by building on its significant efforts to understand the status and needs for scientific, technological and policy elements that must be woven together in different ways domestically and internationally. The work statement proposed by the faculty leaders has some of these elements.

Synthesis and Future of the CAP Initiative

At the end of two years, it is not too early to think about how the outcome of the MIT CAP initiative will be integrated and communicated to many interested constituencies: the public, policymakers, the scholarly and technical communities, as well as the research sponsors and the MIT audience. The Review Committee has deliberated two matters: how best to draw the results of the different work stream activities into effective reports at end of the five-year period and what comes after CAP?

<u>Expectations</u>

The MIT CAP is only a small part of the tremendous amount of activity that is underway at leading universities and research centers on global climate change. Of course, MIT has a distinctive approach to these problems, but it is unlikely that after five years the results of the CAP initiative will be sufficiently new and well-founded to make a major impact. The results of the CAP initiative will have greater and lesser impact. MIT's expectation should be that the CAP's contributions have moved forward understanding of the risks of climate change and how these risks can be reduced. We should resist setting unrealistic goals for our work and expecting blockbuster results.

And it is important to remember that MIT faculty and students who have been involved in the initiative will go out in the world and introduce the knowledge and insights learned into a multitude of communities. This external benefit of university scholarship is perhaps more important than the immediate research output.

Presentation of Results

Five different work streams with several activities in each presents a challenge for reporting the results of the CAP initiative. A considerable amount of effort will be required to knit the individual results together in an accessible presentation that does justice to what has been done. Thought needs to be given now about the organization and execution of this integration effort.

The Review Committee suggests a report consisting of three volumes and an executive summary supplemented by papers and issue briefs presented on the CAP website. Volume (1) should address Fundamental Research and Technology Development that is MIT's core strength and has spent the largest fraction of sponsored research support. Volume (2) should address New Integrated Policy Analysis and Insights that will prove to be of great interest to public policy decision makers, industry leaders, and the public. The Review Committee, here again, emphasizes its view that the purpose here should be to inform not to proselytize and notes again the limited number of people on campus who could help produce this volume. Volume (3) should address Changes at MIT that will be of great interest to the MIT community of students, faculty, and staff. There is a lot to cover here: education, sustainability, outreach.

The Executive Summary should weave the three volumes together and relate the reported results to the vision motivating the creation of CAP. Of course, it needs to describe next steps

Next Steps

There are three possible choices:

- Conclusion of the CAP initiative without special actions.
- A second five-year Phase II to CAP.
- Transition of CAP activities into the academic structure.

Recommendations

1. Outreach efforts of MIT research studies should focus on providing results and analysis of valid and useful policy-relevant information, aiming to inform policy rather than to influence policy positions.

2. All LCECs should have comprehensive websites that identify faculty and staff participants, their related teaching and research activities, and public events like workshops and invited speakers. Incentives are needed to get more research groups to affiliate with the LCEC centers with common research interests in order to build broader research communities.

3. MIT needs to add faculty in the areas of (a) energy and environmental policy analysis and (b) technical analysis of electric power *systems*. Because of limited interest, Economics, Sloan, and EECS may not be the only suitable departments, an alternative home or homes will likely need to be found.

4. Begin immediately to encourage cross-cutting research activities on low-carbon solutions between the LCECs and other units where appropriate. This may be of interest to sponsors.

5. Transportation accounts for a large fraction of GHG emissions and these emissions will continue to increase in developing countries. Research is underway in several MIT schools on innovative transportation technologies such as electric vehicles,

"smart" cars and more. Consideration should be given to establishing a transportation LCEC.

6. Confirm and explain the constructive approach MIT is taking to reducing its GHGs emission in the short and long term. This includes identifying and explaining cost-effective measures such as Summit Farms and the use of a carbon price in MIT facilities planning.

7. Because of the interest in climate change within the broad MIT community, it is important to begin now to develop an integrated report that communicates CAP's accomplishment at the end of its five-year term in 2020. It is also important to plan for what Institute-wide climate initiative, if any, comes after 2020.

8. Particularly in light of the numerous related efforts underway elsewhere and the extreme intellectual breadth and depth they would require, replace the grand "future of everything" or "two-degree" capstone studies with more focused summary studies, perhaps along the lines of the discussion on page 22 of the report.

9. MITEi should work to develop different trademarks for broad "future of" studies that intend to inform policymakers about the trends and choices the country faces and other worthwhile studies that address narrower subjects that interest industrial sponsors.

10. The VPR and CAAC should consider creating a small full-time faculty group (less than five individuals) with the authority and responsibility to implement decisions taken by CAP leadership, particularly as regards capstone studies and planning for what, if anything, comes after the CAP.

11. The broad MIT community will welcome more information on the progress of CAP, what it has done, what it is doing and what it is not doing. A regularly updated record of accomplishments and plans should be widely disseminated. It is important that the CAP initiatives be presented as parts of single integrated effort rather than a collection of unconnected activities.

Annex A – Membership and Charge of the Review Committee

Members of the Review Committee:

1.	John Deutch, (Chair)	Institute Professor of Chemistry, Emeritus
2.	William Green	Hoyt C. Hottel Professor of Chemical Engineering
3.	Paul Joskow	Elizabeth and James Killian Professor of Economics, Emeritus
4.	Sheila Kennedy	Professor of Architecture
5.	Ernest Moniz	Cecil and Ida Green Professor of Physics and Engineering Systems Emeritus
6.	Dava Newman	Apollo Program Professor of Astronautics
7.	Rajeev Ram	Professor of Electrical Engineering
8.	Richard Schmalensee	Howard W. Johnson Professor of Management & Economics Emeritus
9.	Jessika Trancik	Associate Professor in Energy Studies

Charge to the Committee:

From: "L. Rafael Reif" <reif@mit.edu>
Subject: Climate Action Plan Review Committee
Date: April 28, 2017 at 4:03:19 PM EDT
To: jmd@mit.edi, William Green <whgreen@mit.edu>, pjoskow@mit.edu, "Ernest J. Moniz" <ejmoniz@mit.edu>, rajeev@mit.edu, Richard Schmalensee <rschmal@mit.edu>, trancik@mit.edu

John, Bill, Paul, Ernie, Rajeev, Dick and Jessika,
Thanks for agreeing to participate in a review of MIT's Climate Action Plan, and particular thanks to John for chairing the effort.

MIT's *Plan for Action on Climate Change (CAP),* released in 2015, a comprehensive strategy for accelerating and coordinating MIT's research, education, convening, and campus operations efforts to address global climate change. CAP activities extend across the Institute and include the MIT Energy Initiative, Environmental Solutions Initiative, Office of Sustainability, and many others.

Because of the urgent need to address the challenges of global climate change, and the widespread interest among MIT faculty, students, staff and alumni, it is timely to review the status, accomplishments, and opportunities for the important set of complementary activities that collectively comprise the CAP. The current uncertainty about the federal role in climate and clean energy makes this review most timely.

I ask you to meet with the centers, offices and initiatives associated with the CAP in order to learn about ongoing research and educational activity, collaboration among MIT entities, their attention to policy and regulatory issues, as well as the adequacy of financial support.

The objectives of the committee are:

- To assess and inform the MIT community about progress made by participants in the MIT climate action plan;
- To recommend new mechanisms, e.g., the possibility of establishing a standing external advisory/visiting committee, and,
- To stimulate dialogue at MIT about the best ways to accelerate progress of climate, energy and sustainability activities.

For your convenience, I list in the attached sheet a list of Energy and Climate Groups at the Institute.

I request that you complete your work by the end of the 2017 fall term and to report your findings and recommendations to Vice President for Research Maria Zuber for appropriate implementing actions.

With thanks in advance for your effort.

Rafael

Annex B - List of Committee Questions Posed to CAP Participants.

1. Do you have a mission statement or statement of goals?
2. Describe your research activities and plans (include faculty and student involvement)
3. Describe your educational activities.
4. Describe activities in your area at other leading academic institutions
5. Does your center have policy work ongoing?
6. Describe your unit's interaction with other units in CAP initiative.
7. What funds has MIT provided to your unit since the start of CAP in 2015?
8. What is the research support of your unit – amount and sources?
9. How would your unit employ greater resources?
10. Describe your outreach activities.
11. What are your unit's MIT Test Bed activities, if appropriate.
12. What's your strategic advice for advancing CAP, both through your program and more broadly?

Annex C – Review Committee Summary of MIT Summit Photvoltaic Project.
In the fall of 2016 MIT entered into a 25-year power purchase agreement (PPA) contract with Dominion Resource, a Virginia utility, to purchase approximately 107,000 MWe-hr/year, approximately 2/3 of the electricity generation of the 60MWe North Carolina Summit Farms single axis tracking solar polysilicon photovoltaic (PV) plant, with panels manufactured by Hanwha.

The cost of the purchased electricity is 4.5 ¢ per kWe-hr with 2% annual escalation. This electricity is immediately liquidated in the spot or day-ahead NC electricity market. MIT's analysis of the project economics, assuming 3% escalation of NC electricity prices and a 5% discount rate, gives a positive net present value of the project of $17million. Of course, MIT is taking market risk and the results could be higher ($112 million at 10% annual escalation) or lower (-$33 million at -10% NC annual electricity price decline).

MIT receives one Renewable Energy Credit (REC) for every 1MWe-hr power purchased. These RECs allows MIT to claim 1 MWe-hr of emission free generation, offsetting the CO_2 emissions incurred by MIT's electricity use electricity supplied by the grid in Massachusetts. This PPA will reduce the MIT carbon footprint by 17%, more than half of the 32% committed in MIT's CAP. Of course, if the REC is sold, (approximate market value of $10 each), there is no net emission reduction.

There are two additional benefits from the project. First, electricity purchased and generated by MIT is very dependent on natural gas. The Summit project hedges the adverse effect of a NG price rise because NC electricity prices are highly correlated with NG prices. Second, MIT gets credit for carbon avoidance in Massachusetts, but the renewable electricity generated in NC that enters the NC grid, is displacing electricity with greater carbon content, so the true carbon avoidance is 65% greater.

Several universities and not-for profit organizations have similar large-scale renewable energy projects (LSRE). The motivation for such projects is two-fold: to reduce the institutions carbon footprint and to demonstrate to internal community and the broader public practical ways to encourage clean energy electricity generation.

This NC based PV project was selected by MIT after consideration of many other LSRE opportunities such as wind project in New England or renewable energy projects that would supply MIT directly, thus displace purchase power. After thorough review involving many MIT stakeholders, the Summit project was judged to have the best balance between risk and return. A positive result of the MIT CAP is that additional LSRE projects will be sought and undertaken. Publication of all the analysis justifying such projects should be made widely available in order to advance CAP's outreach and engagement objective.

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December 21, 2017