



# **ROLE OF MATERIALS IN ADDRESSING CLIMATE CHANGE AND SUSTAINABILITY MATERIALS DAY**



**MIT  
MATERIALS  
RESEARCH  
LABORATORY**



## MATERIALS DAY AT MIT

# Role of Materials in Addressing Climate Change & Sustainability

October 20, 2021

Materials play a central role in all aspects of new technologies needed to achieve sustainability goals and address climate change. New materials are needed for exploitation of renewable carbon-free energy sources and for energy storage that supports efficient use of energy. Materials designed for efficient use through recycling and reuse, or designed to be biodegradable to minimize environmental impact are also needed. Development of new reduced-carbon processes for making materials, especially those made in large quantities, will also be critical in achieving climate goals. Examples of ongoing research on innovative approaches to these challenges will be highlighted in this year's Materials Day symposium.

Materials Research Laboratory  
Massachusetts Institute of Technology  
77 Massachusetts Avenue  
Room 13-2106  
Cambridge, MA 02139  
<https://mrl.mit.edu>  
email: [mit-mrl@mit.edu](mailto:mit-mrl@mit.edu)

# Materials Day Agenda

**8:00am**

## **Registration**

**9:00 - 9:15am**

## **Welcome**

Carl V. Thompson

Director, Materials Research Laboratory

Professor, Department of Materials Science & Engineering, MIT

## **Overview**

Elsa Olivetti

Associate Professor, Department of Materials Science & Engineering, MIT

## **Session I:**

**9:15 - 9:50am**

## **Early Assessment of Environmental and Technical Performance to Guide Sustainable Materials Design**

Desiree Plata

Associate Professor, Department of Civil & Environmental Engineering, MIT

**9:50 - 10:25am**

## **Challenges and Opportunities for Materials in the Textile Industry**

Gregory C. Rutledge

Professor, Department of Chemical Engineering, MIT

**10:25 - 11:00am**

## **BREAK**

**11:00 - 11:35am**

## **Towards Structure-Property Relationships for Biodegradable Polymers**

Bradley Olsen

Professor, Department of Chemical Engineering, MIT

**11:35 - 12:10pm**

## **Materializing Sustainable Architecture: New Methods for Design and Construction of Low-carbon Buildings**

Caitlin Mueller

Associate Professor, Department of Civil & Environmental Engineering, MIT

**12:10 - 1:30pm**

## **LUNCH**

Stratton Student Center, 3rd Floor

Twenty Chimneys/Mezzanine Lounge (Building W20-306 & 307)

## Agenda cont'd

### Session II:

- 1:30 - 2:05pm**      **Towards Profitable Sustainability via Liquid-Metal/Molten-salt Electrochemistry**  
Donald R. Sadoway  
Professor, Department of Materials Science & Engineering, MIT
- 2:05 - 2:40pm**      **Thermal Batteries**  
Asegun S. Henry  
Associate Professor, Department of Mechanical Engineering, MIT
- 2:40 - 3:10pm**      **BREAK**
- 3:10 - 3:45pm**      **New Paradigms for Sustainable Materials Processing**  
Antoine Allanore  
Associate Professor, Department of Materials Science & Engineering, MIT
- 3:45 - 4:20pm**      **Electrifying and Decarbonizing Cement Production**  
Yet-Ming Chiang  
Professor, Department of Materials Science & Engineering, MIT
- 4:20 - 4:30pm**      **Closing Remarks**



Do you have questions for the speaker?  
Scan this QR code with your phone and type in your question.

A moderator will post the selected questions on the screen.

## Welcome and Overview

**Biography:** Professor Thompson is the Director of the MIT Materials Research Laboratory and the Stavros Salapatas Professor of Materials Science and Engineering. He received an S.B. in Materials Science and Engineering from MIT and a Ph.D. in Applied Physics from Harvard University and joined the MIT faculty in 1983. He previously directed the MIT Materials Processing Center and co-chaired the Materials for Micro- and Nano-systems program of the Singapore-MIT Alliance for twelve years. He has had visiting positions at Cambridge University, the Max-Planck-Institut für Metallforschung in Stuttgart and the Karlsruhe Institute of Technology, and is a past president and Fellow of the Materials Research Society. Professor Thompson's research interests include processing of thin films and nanostructures for applications in microelectronic, microelectromechanical and electrochemical systems. Current activities focus on development of thin film batteries for autonomous microsystems, the reliability of IC interconnects and GaN-based devices, and morphological stability of thin films and nano-scale structures.

### Carl V. Thompson

Director, Materials Research Laboratory  
Stavros Salapatas Professor of Materials  
Science and Engineering  
Department of Materials Science and  
Engineering, MIT

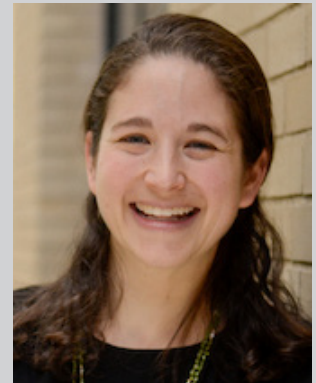


**Biography:** Elsa Olivetti is the Esther and Harold E. Edgerton Career Development Professor in the Department of Materials Science and Engineering (DMSE) co-director of the MIT Climate and Sustainability Consortium at the Massachusetts Institute of Technology. Her research focuses on reducing the significant burden of materials production and consumption through increased use of recycled and waste materials; informing the early stage design of new materials for effective scale up; and understanding the implications of policy, new technology development, and manufacturing processes on materials supply chains. Dr. Olivetti received her B.S. degree in Engineering Science from the University of Virginia in 2000 and her Ph.D. in Materials Science and Engineering from MIT in 2007.

**Elsa Olivetti**

Associate Professor

Department of Materials Science and Engineering, MIT



## Early Assessment of Environmental and Technical Performance to Guide Sustainable Materials Design

**Abstract:** Novel materials can unlock previously inaccessible performance parameter spaces and are poised to overcome long-standing challenges in environment, climate, and society. However, some of the intended benefits of the technologies could be offset by negative environmental impacts without careful evaluation of the manufacturing processes. This talk will focus on approaches to enhance early assessment of environmental and technical performance to guide economically viable sustainable materials design, with emphasis on chemical environmental impacts and quantitative tools to enable simultaneous optimization strategies. In particular, we will focus on an example of carbon nanotube synthesis, where emissions measurements directly inform mechanistic understanding. This illuminates routes to achieve the dual objectives of enhanced atomic-level control and reduced environmental impact. While there are no one-size-fits-all design solutions, guiding principles and assessment tools will be presented. Put into practice, these tools seek to help ensure that nanomaterials achieve their noble goals of providing transformative, impactful technologies to advance the environment, technology, and society.

**Biography:** Plata is Gilbert Winslow Career Development Associate Professor of Civil and Environmental Engineering at the Massachusetts Institute of Technology. Previously, Plata served as John J. Lee Assistant Professor of Chemical and Environmental Engineering at Yale University and Associate Director for Research in the Center for Green Chemistry and Green Engineering at Yale. She is an NSF CAREER Awardee, a two-time National Academy of Engineers Frontiers of Engineering Fellow, a two-time National Academy of Sciences Kavli Frontiers of Science Fellow, and has been recognized for excellence by the Odebrecht-Braskem Sustainability Award, the Gordon and Betty Moore Foundation, Caltech's Resnick Sustainability Institute, and with MIT's Bose Teaching Award and Edgerton Faculty Award. She holds an undergraduate degree in Chemistry from Union College and a PhD in Chemical Oceanography and Environmental Chemistry from MIT and the Woods Hole Oceanographic Institution. Her work focuses on the development of novel chemicals, materials, and engineered systems to include performance, cost, and environmental metrics, especially to guide design.

### Desiree Plata

Associate Professor

Department of Civil and Environmental Engineering, MIT



## Challenges and Opportunities for Materials in the Textile Industry

**Abstract:** The textile industry is a global commercial enterprise, with major sectors in apparel (~75%), technical (~12%) and household textiles (~9%). An estimated 80 to 100 billion articles of clothing, or about 62 million tons, are produced and sold each year. Quite literally, the textile industry touches every human on the planet. It is also one of the most polluting and wasteful industries on earth. The environmental challenges faced by the textile industry are several, from the massive consumption of water and the chemicals used, to the shedding of microplastics and landfilling of an estimated 11 million tons of textile waste annually in the US alone. The industry is also responsible for an estimated 4 billion metric tons of CO<sub>2</sub> equivalent (CO<sub>2</sub>e) per year, or 5-10% of global greenhouse gas emissions. In this talk, we discuss some of the specific challenges this industry faces in reducing its environmental and carbon footprints and strategies for addressing them, with a focus on those where the material itself plays a key role. Examples include the selection and sourcing of raw materials, the manufacture of fibers and fabrics with various properties, and the design of products for greater longevity and circularity. A few case studies serve to illustrate research opportunities in the materials space where a change from “business as usual” could move the needle on the sustainability and climate change impacts by this industry.

**Biography:** Gregory C. Rutledge is the Lamot du Pont Professor of Chemical Engineering at the Massachusetts Institute of Technology (MIT) and the Lead PI for MIT in AFFOA, a Manufacturing Innovation Institute focused on functional fabrics. He served as Director of the Program in Polymer Science and Technology and as Executive Officer in the Department of Chemical Engineering at MIT. He is a Fellow of the American Institute of Chemical Engineers, the American Physical Society, and the Polymer Materials Science and Engineering (PMSE) Division of the American Chemical Society. He is a recipient of The Founders Award of the Fiber Society, and was the H.A. Morton Distinguished Visiting Professor in Polymer Science at the University of Akron, and a Thinker in Residence at Deakin University in Geelong, Australia. Prof. Rutledge’s research on molecular engineering of soft matter examines relationships between processing, structure and properties of engineered polymers and fibers, using statistical mechanics and knowledge of their molecular structure. His expertise includes both computations and experiments. His group has been instrumental in the development of molecular level modeling of polymer crystals, crystallization kinetics, and the structure and properties of semicrystalline materials. Since 2001 he and his coworkers have published extensively on the fabrication, properties and applications of ultrafine polymer fibers formed by electrospinning. Prof. Rutledge is an editor for the Journal of Materials Science and serves on several editorial boards.

### Gregory C. Rutledge

Professor

Department of Chemical Engineering, MIT



## Towards Structure-Property Relationships for Biodegradable Polymers

**Abstract:** Humanity is headed for a series of sustainability crises, and our pace of innovation and technology transition must substantially accelerate to avoid their worst effects. In particular, our widespread adoption of polymers, which has enabled an era of unprecedented increase in the global standard of living due to clean water, uncontaminated food, and wider provision of health care, has led to a waste crisis of daunting proportions that is accelerating exponentially with our growing polymer production. Addressing this issue without compromising on the societal benefits that polymers bring urgently demands the discovery of materials.

To accelerate the pace of sustainable material innovation, we are exploiting new informatics tools and high-throughput approaches to facilitate the development of quantitative structure-property relationship (QSPR) predictions for degradability in polymers. Using parallel batch synthesis, we have prepared a library of ~500 different polyesters from ~100 unique monomers representing all major routes to polyesterification and a diverse set of heteroatom functionalities. We have then adapted the clear zone assay for bacterial screening into a high-throughput assay for polymer biodegradation, allowing the entire library to be screened in a matter of months. Using new polymer informatics tools to ingest and organize the data, we can then apply different models for prediction of degradation rates based on chemical structure. The goal is that this technique can be used in order to predict the biodegradability of polymers synthesized using proposed new monomers derived from biosynthetic pathways even before the monomers have been synthesized.

**Biography:** Bradley Olsen is the Alexander and I. Michael (1960) Kasser Professor in the Department of Chemical Engineering at MIT. He earned his S.B. in Chemical Engineering at MIT, his Ph.D. in Chemical Engineering at the University of California – Berkeley, and was a postdoctoral scholar at the California Institute of Technology. He started at MIT in December 2009. Olsen's research expertise is in materials chemistry and polymer physics, with a particular emphasis on molecular self-assembly, polymer networks and gels, protein biomaterials, sustainable polymers, and polymer informatics. He is a fellow of the ACS and member of APS and AIChE.

### Bradley Olsen

Professor

Department of Chemical Engineering, MIT



## Materializing Sustainable Architecture: New Methods for Design and Construction of Low-carbon Buildings

**Abstract:** Energy and carbon emissions embodied in construction materials have a substantial environmental impact, given the scale of the built environment and the rapid urbanization expected to accelerate in the coming decades. Until recently, this impact was often overlooked, and performance in terms of embodied carbon and global warming potential varies widely across buildings. Among the multi-faceted solutions under consideration, this talk focuses on technology-enabled design for embodied carbon minimization in architecture and infrastructure. Geometry and material are two key design decisions that architects, engineers, and owners can directly engage with to reduce embodied carbon in buildings. This talk presents emerging techniques for early-stage design that promote low-carbon outcomes within a holistic design framework that also considers broader design concerns, along with new digital and robotic fabrication techniques that can make low-carbon structures economically viable to construct.

**Biography:** Caitlin Mueller is a researcher and educator who works at the creative interface of architecture, structural engineering, and computation. She is currently an Associate Professor at the Massachusetts Institute of Technology's Department of Architecture and Department of Civil and Environmental Engineering, in the Building Technology Program, where she leads the Digital Structures research group. Her work focuses on new computational design and digital fabrication methods for innovative, high-performance buildings and structures that empower a more sustainable and equitable future. Mueller earned a PhD in Building Technology from MIT, an SM in Computation for Design and Optimization from MIT, an MS in Structural Engineering from Stanford University, and a BS in Architecture from MIT. Her research is funded by federal agencies and industry partners, including the National Science Foundation, FEMA, the MIT Tata Center, the Dar Group, Robert McNeel & Associates, and Altair Engineering. In 2021, Mueller was awarded the ACADIA Innovative Research Award of Excellence by the Association for Computer Aided Design in Architecture.

**Caitlin Mueller**  
Associate Professor  
Department of Civil & Environmental Engineering,  
and Department of Architecture, MIT



## Towards Profitable Sustainability via Liquid-Metal/Molten-Salt Electrochemistry

**Abstract:** A sustainable future is axiomatically a carbon-free electric future. Emerging technologies that will usher in this new economy necessarily include electrochemical innovations in energy storage and in steelmaking. Electricity storage is critical to widespread deployment of carbon-free but intermittent renewables, solar and wind, while offering huge benefits to today's grid: improving security and reducing price volatility. Invented at MIT, the liquid metal battery provides colossal power capability on demand and long service lifetime at very low cost. In 2019 worldwide steel production generated 10% of total CO<sub>2</sub> emissions. Invented at MIT, molten oxide electrolysis represents an environmentally sound alternative to today's carbon-intensive thermochemical process. Instead of CO<sub>2</sub> as the by-product of steel, molten oxide electrolysis makes tonnage oxygen while offering better metal at lower cost without many of the negative environmental impacts of current technology. In the narratives of both of these emerging technologies, liquid metal battery and molten oxide electrolysis, there are lessons more broadly applicable to innovation: how to pose the right question, how to engage young minds (not experts), establishing a creative culture, and inventing inventors in parallel with inventing technology.

**Biography:** Donald R. Sadoway is the John F. Elliott Professor of Materials Chemistry in the Department of Materials Science and Engineering at the Massachusetts Institute of Technology. His B.A.Sc. in Engineering Science and Ph.D. in Chemical Metallurgy are from the University of Toronto. He joined the MIT faculty in 1978. The author of over 180 scientific papers and inventor on 35 U.S. patents, his research is based on extreme electrochemistry directed towards new battery chemistries for grid-scale storage and electric vehicles and towards environmentally sound metals extraction technologies. His accomplishments include the invention of the liquid metal battery for large-scale stationary storage and molten oxide electrolysis for carbon-free steelmaking. He is the founder of six companies, Ambri, Boston Metal, Avanti Battery, Pure Lithium, Lunar Resources, and Sadoway Labs. Online videos of his chemistry lectures hosted by MIT OpenCourseWare extend his impact on engineering education far beyond the lecture hall. Viewed more than 2,400,000 times, his TED talk is as much about inventing inventors as it is about inventing technology. In 2012 he was named by Time magazine as one of the 100 Most Influential People in the World.

### Donald R. Sadoway

Professor

Department of Materials Science & Engineering, MIT



## Thermal Batteries

**Abstract:** Climate change is arguably the most important problem in the history of mankind. To mitigate climate change there are a myriad of things that have to be done, and one of the single most impactful steps is to decarbonize the electricity sector, which is responsible ~25% of emissions. This could then enable deep decarbonization of the transportation sector, by switching to electric vehicles charged by a renewable grid. Since the transportation sector is responsible for ~15% of emissions, decarbonization can ultimately lead to a 40% reduction in emissions. The cost of solar and wind has dropped dramatically over the last decade but the penetration of renewables onto the grid is limited by not having energy storage. As a result, there is an international race to develop a low cost energy storage technology that can enable full penetration of renewables. This talk will review a new technology invented and being developed in Professor Asegun Henry's lab, termed thermal batteries, that is one of the least expensive approaches currently under development.

**Biography:** Dr. Asegun Henry started as an Associate Professor in the Department of Mechanical Engineering at MIT in 2018, where he directs the Atomistic Simulation & Energy (ASE) Research Group. Prior to MIT, he was an Assistant Professor in the Woodruff School of Mechanical Engineering at Georgia Tech from 2012 to 2018. He holds a B.S. degree in Mechanical Engineering from Florida A & M University as well as an M.S. and Ph.D. in Mechanical Engineering from MIT. Professor Henry's primary research is in heat transfer, with an emphasis on understanding the science of energy transport, storage and conversion at the atomic level, along with the development of new industrial scale energy technologies to mitigate climate change. Professor Henry has made significant advances and contributions to several fields within energy and heat transfer, namely: solar fuels and thermochemistry, phonon transport in disordered materials, phonon transport at interfaces, and he has developed the highest temperature pump on record, which used an all ceramic mechanical pump to pump liquid metal above 1400°C. This technological breakthrough, which is now in the Guinness Book of World Records, has opened the door for new high temperature energy systems concepts, such as methane cracking for CO<sub>2</sub> free hydrogen production and a new grid level energy storage approach affectionately known as "Sun in a Box", that is cheaper than pumped hydro.

**Asegun S. Henry**  
Associate Professor  
Department of Mechanical Engineering, MIT



## New Paradigms for Sustainable Materials Processing

**Abstract:** A large fraction of the GHG and environmental impact of materials can be attributed to the sourcing, supply and transformation of raw materials into semi-finished products. And yet, the production rate and purity of the semi-finished products such as metal or inorganic compounds feedstocks has achieved unprecedented levels. This legacy, along with the low value added inherent to the sector, makes incremental solutions unlikely to mitigate the environmental impact while maintaining the highest standards. In this context, transformative solutions are needed. Our research group develops engineered solutions for chemical conditions that mitigate the environmental and GHG impact of metals and minerals extraction and processing. We target high productivity methods, while leveraging long term trends in energy and electrification. Recent developments related to the separation of non-ferrous and critical metals, from primary or secondary sources, will be presented.

**Biography:** Antoine Allanore is Associate Professor of Metallurgy at the Massachusetts Institute of Technology. After several years of service with ArcelorMittal working on GHG-reduction in the steel industry, he teaches metallurgy in the Department of Materials Science & Engineering and conducts research on sustainable metals and minerals processing. Prof. Allanore earned his engineering degree from the Ecole Nationale Supérieure des Industries Chimiques (ENSIC, Nancy, France), and MSc. and PhD from University of Lorraine (France). He was awarded the TMS DeNora Prize in 2012, recognizing outstanding contributions to the reduction of environmental impacts, especially focused on extractive processing, and TMS Early Career Faculty Award in 2015.

### Antoine Allanore

Associate Professor

Department of Materials Science & Engineering, MIT



## Electrifying and Decarbonizing Cement Production

**Abstract:** Addressing climate change will require decarbonizing the industries which manufacture the material world around us. Of the staggering 33% of global anthropogenic greenhouse gases emissions that arise from the manufacturing of products essential to modern life, 8% (~3 gigatons CO<sub>2</sub> per year) originates from cement production. Portland cement, produced by firing ground limestone (CaCO<sub>3</sub>) with aluminosilicates at high temperature, results in the stoichiometric emission of CO<sub>2</sub> as well as thermal emissions from burning fossil fuels, primarily coal, such that each kilogram of cement produced emits 0.93 kilograms of CO<sub>2</sub>. However, the rising abundance of very low-cost (but intermittently generated) renewable electricity suggests that new electrical processes could be one pathway to decarbonizing cement production. This talk will discuss an initiative at MIT in which acid and base reagents produced by ambient temperature electrolysis is used to decarbonate limestone and produce cementitious calcium silicates, simultaneously generating concentrated pure gaseous co-products which could be used to fuel the high temperature processes or upcycled to other products such as synthetic fuels. This electrochemical approach also has potential applications in materials recycling and mining.

**Biography:** Yet-Ming Chiang is Kyocera Professor in the Department of Materials Science and Engineering at MIT, where he conducts research on materials, electrochemical storage, and clean energy technologies. He is a member of the National Academy of Engineering and a Fellow of the Electrochemical Society, the Materials Research Society, the American Ceramic Society, and the National Academy of Inventors. He has published about 300 scientific articles and 14 book chapters and edited volumes, and holds about 85 issued U.S. patents, of which more than 60 have been licensed to or are held by practicing companies. In addition to his academic research, he has founded seven companies based on research from his MIT laboratory, five of which are in the energy sector.

**Yet-Ming Chiang**

Professor

Department of Materials Science & Engineering, MIT



## Materials Resources

The Materials Research Laboratory (MRL) serves interdisciplinary groups of faculty, staff and students, supported by industry, foundations and government agencies to carry out fundamental engineering research on materials. Research topics include energy harvesting, conversion and storage; quantum materials and spintronics; photonic devices and systems; metals processing; integrated microsystems; materials sustainability; solid-state ionics; complex oxide electronic properties; biogels; and functional fibers.  
<https://mrl.mit.edu>

The MRL MRSEC (formerly MIT MRSEC) at MIT is one of a nation-wide network of Materials Research Science and Engineering Centers sponsored by the National Science Foundation (NSF).  
<https://mitmrsec.mit.edu>

The Crystal Physics and Electroceramics Laboratory is devoted to the modeling, processing, characterization and optimization of energy related devices (sensors, batteries, fuel cells, solar/photolysis cells) and the integration of sensor, actuator and photonic materials into microelectromechanical (MEMS) systems.  
<http://electroceramics.scripts.mit.edu/>

The Microphotonics Center builds interdisciplinary teams, focused on collaborative research for the advancement of basic science and emerging technology pertaining to integrated photonic systems.  
<https://mphotronics.mit.edu>

The Sustainability and Health Initiative for NetPositive Enterprise (SHINE) is an initiative at the Massachusetts Institute of Technology and the Harvard T.H. Chan School of Public Health.  
<https://shine.mit.edu/>

The Materials Systems Laboratory is a research group at MIT that studies the strategic implications of materials and materials processing choices.  
<https://msl.mit.edu/materials-systems-laboratory>

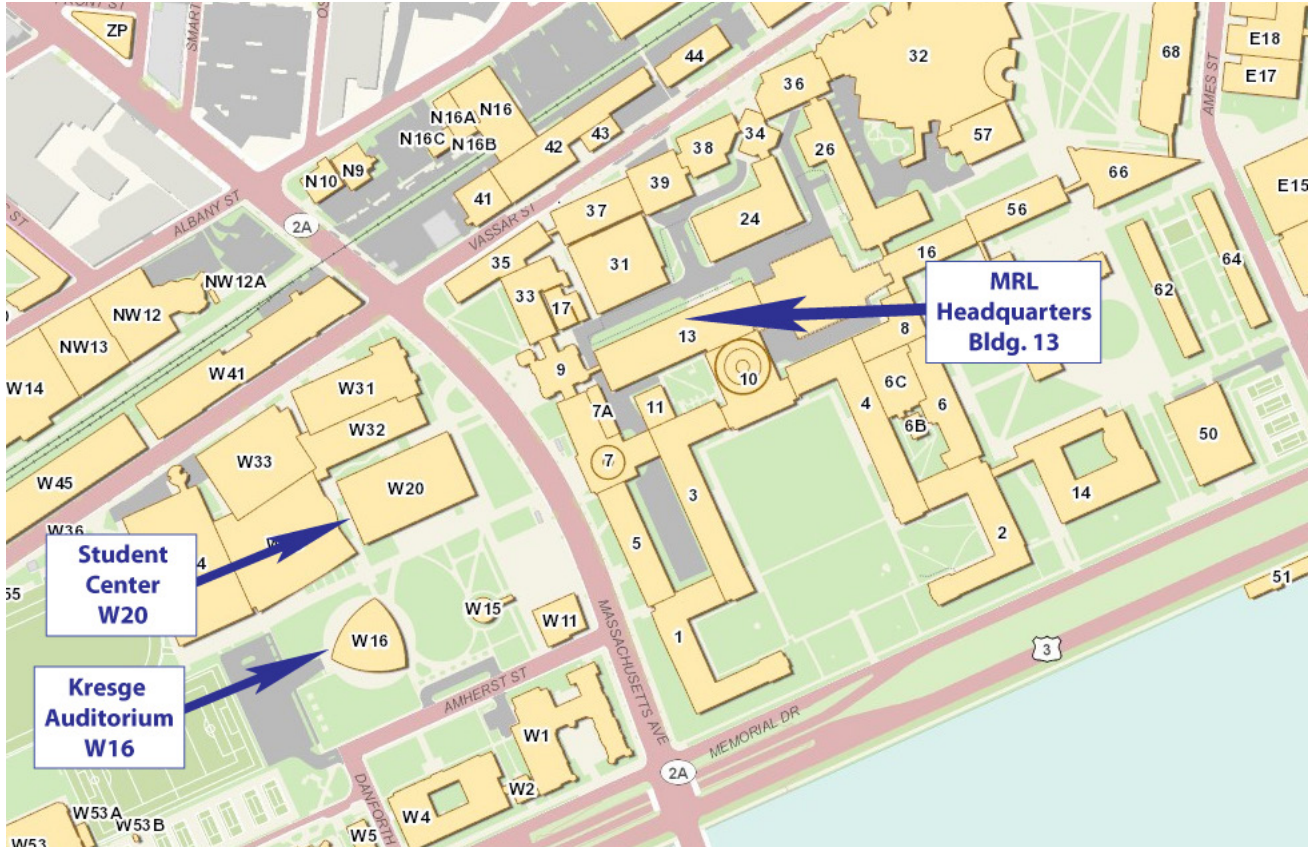
The SMART Low Energy Electronic Systems IRG aims to identify new integrated circuit technologies that becomes the new added value for reduced energy per function, lower power consumption and higher performance in our electronics infrastructure.  
<https://smart.mit.edu/research/lees/about-lees>

Advanced Functional Fabrics of America (AFFOA) is a national public-private consortium that aims to accelerate innovations in fibers and fabrics.  
<https://fabric-ideas.mit.edu/>  
<https://affoa.org/>

The REMADE Institute enables the early stage applied research and development of key industrial platform technologies that could dramatically reduce the embodied energy and carbon emissions associated with industrial-scale materials production and processing.  
<https://remadeinstitute.org/>

Department of Materials Science & Engineering is known as the world-wide leader in its field, pioneering advances in engineering sciences and technologies.  
<https://dmse.mit.edu>

## Kresge Auditorium - W16 Stratton Student Center - W20



### Dates for future Materials Day events:

October 19, 2022

October 18, 2023



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Scan this QR code with your phone and type in your question.

A moderator will post the selected questions on the screen.

# NOTES



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