MIT Alumni/Student Campus Decarbonization Team

Formerly MACA/Geo@MIT

Summary Report

Decarbonizing the MIT Campus with a Thermal Energy Network

This document is a summary of a comprehensive "Test-Fit" analysis of a proposed Pilot Program. Among the "Test-Fit" analyses completed were whether the equipment in the proposed decarbonization solution could be installed in campus buildings: (i) using non-programmed spaces; (ii) without significant upgrades to electrical infrastructure; and (iii) without major disruption to campus activities. The report includes numerous charts, tables, 3D renderings and some financial cost comparisons to other proposed solutions.

Available downloads related to this campus-wide decarbonization proposal include:

- *Comprehensive "Test-Fit Report," which includes detailed technical analysis*
- *Slide decks of this "Summary Report" and the comprehensive "Test-Fit" Report*
- *Slide deck of 3D architectural models of buildings W20, W31-W35*
- *Business Plan including preliminary budget*

Contact information for questions, comments, additional information:

- *Primary Contact: Susan Murcott, murcott@mit.edu*
- *Backup Contact: John R. Dabels, jrdabels@alum.mit.edu, (704) 544-9907*

Note: as critical updates are made to the Comprehensive Report, the Summary Report will be updated. If you are reading the report in 2025, please check for an update.

Originally Submitted September 6, 2024

Updated Slightly 2024:Q4

(Note: There were no material changes to the report. Since the report was published two names have changed. The workgroup name "MACA/Geo@MIT" has changed to "MIT Alumni/Student Decarbonization Team." The proposed solution, *formerly called "Pathway 18" has changed to the acronym, "MITTEN" – MIT Thermal Energy Network. The text of updated Summary Report and the Comprehensive Test-Fit Report retains the original names.)*

Acknowledgements

The MIT Alumni/Student Campus Decarbonization Team is grateful for the opportunity to have partnered with MIT Facilities to explore the application of thermal energy networks on MIT's campus. We acknowledge the support of Joe Higgins, who initiated the Test Fit Project and Memorandum of Understanding, to Facilities engineers and planners Carlo Fanone, Karen Bowes, and Vasso Mathes, for providing regular expert feedback and technical support. Additionally, we would like to thank Facilities staff Kim Bigelow, Paula Tierney, and Mike Murphy for managing the logistics of buildings, rooms, and Zoom access and to our 6-building walk-through guides, Mark Cataldo, Dave Luria and Dave Goralski who had keys to every mechanical room and roof space that most rarely see. We hope success at MIT could provide a framework for other universities to assess and integrate distributed thermal energy networks into their decarbonization plans, accelerating global efforts to protect our planet, our only home.

Table of Contents

A Lower-Cost Pathway to Decarbonization

President Sally Kornbluth has reinforced MIT's goal of eliminating direct carbon emissions from the MIT campus by 2050. To help achieve this goal, a consulting firm was engaged to provide guidance and create decarbonization pathways for consideration. As sometimes happens with this type of effort, viable approaches are excluded that appear counterintuitive or where there is limited performance data of similar designs. Such an oversight appears to have occurred in AEI's analysis of possible pathways for MIT's campus.

Fortunately, a small group of alumni working with students on advanced geothermal-type projects recognized AEI's apparent oversight. In a parallel effort, the volunteer alumni (part of MIT Alumni for Climate Action) and the student group (Geo@MIT) developed a plan to achieve a 100% decarbonized MIT campus by 2035.

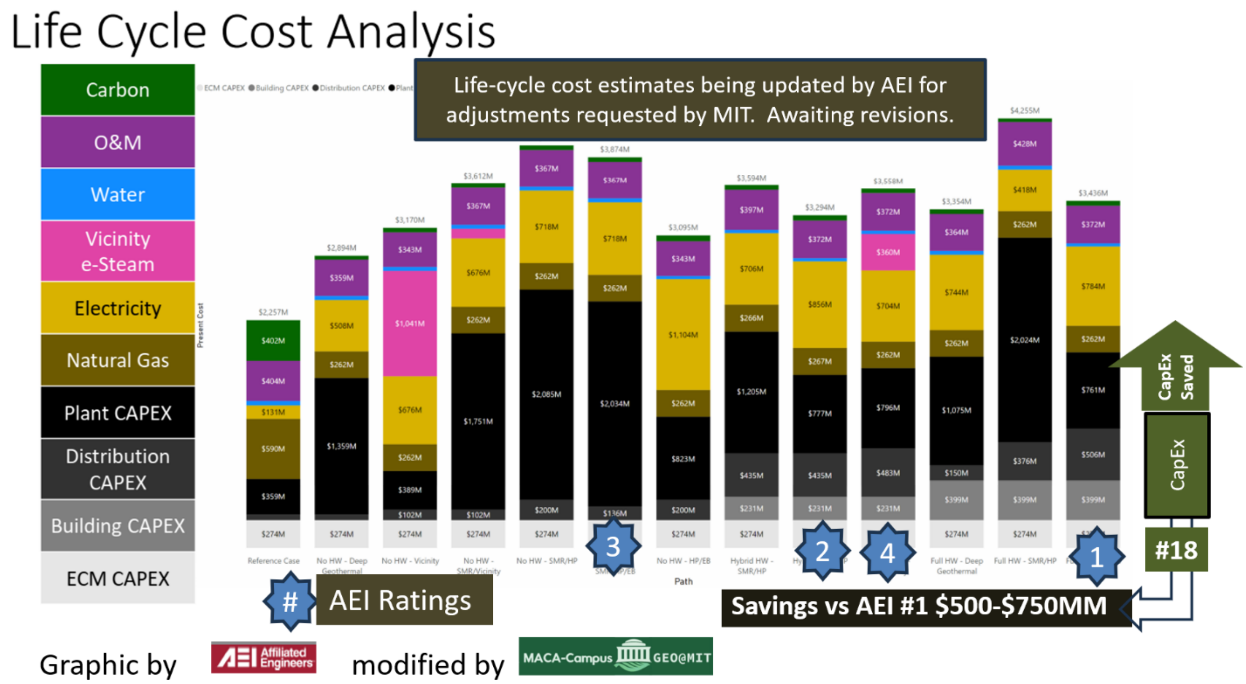
Drawing on their educational and professional experience, the MACA/Geo@MIT team explored potential technologies, including the consultant's 17 Pathways. Based on that review, the team proposed "Pathway 18," a thermal energy network, which the team believes may be the most practical, and the most cost-effective approach to decarbonize campus. The Summary Report addresses why we believe Pathway 18 should be considered "mainstream" and included in any list of decarbonization pathways being formally evaluated by MIT. We believe Pathway 18 design would help MIT demonstrate to the world a practical, affordable, and scalable approach to rapidly decarbonize.

Proposal Overview and Benefits

The proposed thermal energy network could be leveraged to maximize energy efficiency and minimize disruption as MIT decarbonizes its campus because:

- A network of distributed water-source heat pumps (WSHPs) provides both heating and cooling, eliminating the need to invest in, operate, and maintain parallel thermal distribution systems.
- WSHPs attached to an ambient-temperature water loop can leverage electric energy input with a Coefficient of Performance greater than 4.0 year-round, which is substantially more efficient than other approaches.
- Commercially available WSHPs are inexpensive and easy to maintain.
- A 2-pipe ambient loop maximizes heat pump efficiency and eliminates at least half of the pumping power used in a 4-pipe system.
- The low temperature ambient loop eliminates transmission losses from the CUP (Central Utility Plant) to campus buildings.
- Building-located heat pumps enhance the efficiency of Energy Recovery Ventilation systems to reduce HVAC loads.
- Concurrent system-wide heating and cooling significantly reduces total HVAC energy net loads and costs.

A projection of life-cycle costs suggests that Pathway 18 is dramatically more cost effective than any of the four AEI pathways rated above the minimum threshold. For example, Pathway 18 projected capital cost is $500+ million below CapEx for the top-rated proposal. Additionally, Federal, state and utility subsidies may be available to further reduce Pathway 18 CapEx. For OpEx, we estimate that the combined benefits of Pathway 18 design and equipment will reduce HVAC electric energy consumption by 25% or more compared to any other pathway.



Pilot Program to Evaluate Proposal

Under the guidance of MIT's Department of Facilities, MACA/Geo@MIT undertook a Test Fit analysis from March through August 2024. The results of the Test Fit analysis were successful, and we are recommending that MIT initiate a Pilot Program that would decarbonize six buildings on west campus with proposed HVAC equipment. The Pilot Program would: (i) demonstrate the cost-effectiveness and energy efficiency benefits of a thermal energy network and (ii) provide operational data about how the proposed system can contribute to current campus decarbonization plans.

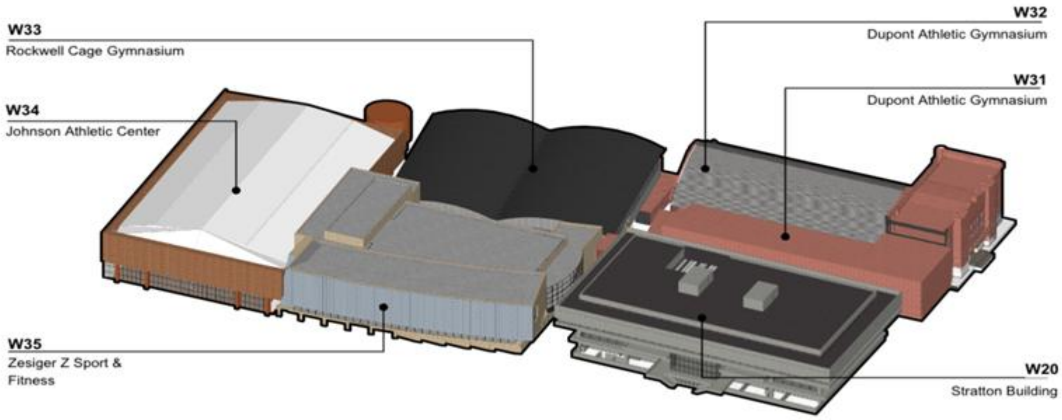
The Pilot Program we propose is a low-cost and low-risk approach to:

- Demonstrate MIT's public commitment to making the campus a testbed and moving forward "as fast as we can" with campus decarbonization.
- Generate performance data for the HVAC system design and components.
- Resolve concerns about perceived complexity of the proposed approach, both for installation and maintenance.
- Provide in-use data about system operating costs.

- Provide guidance about electrical and thermal loads during peak-use periods and whether peak-load electricity demand using WSHPs will require capacity increases for buildings or the campus grid.
- Provide guidance about possible interruption to campus activities during construction.
- Evaluate the challenges of installing and managing distributed, multiple, smaller HVAC units in separate buildings.
- Calculate system efficiency (COP) at point of use.

Test Fit Analysis[1] of Six Pilot Buildings

The six Test Fit buildings include: W20, Stratton Student Center; W31, Dupont Athletic Gymnasium; W32, Dupont Athletic Center; W33, Rockwell Cage; W34, Johnson Ice Rink; and W35, Zesiger Sports and Fitness Center.



Based on available data, the Test Fit analysis affirms:

- Paths exist for converting the chilled water loop to an ambient loop, and adding piping to buildings currently not connected to chilled water can be achieved with minimal effort.
- There is sufficient space in each building to accommodate distributed WSHPs.
- Transformer upgrades would be needed in W33.
- All proposed equipment is currently available from HVAC original equipment manufacturers (OEMs) as a regular production model and should meet or exceed all required performance specifications. No custom equipment is required.

Based on these Test Fit results, MACA/Geo@MIT recommends that MIT authorize a Pilot Program to build a thermal energy network for these six buildings. The buildings will need to be decarbonized anyway, and actual cost data from construction would influence the decision on how to best upgrade the rest of the campus. Additionally, if the project is approved and gets underway by say 2025:Q2, much of the CapEx could likely qualify for available federal, state, and utility subsidies. Federal subsidies could be 40% of CapEx, e.g.

[1] Test Fit Analysis is designed to determine what modifications, if any, are required to designated buildings and infrastructure for the proposed equipment to operate.

While more analysis is needed, the preliminary cost for the pilot is estimated to be $15 million gross and as low as $10 million with Federal construction subsidies.

Low-Hanging Fruit. Three of the six buildings are not currently on the campus chilled water loop and four have single-pane glass. MACA/Geo@MIT assumes that, regardless of the decarbonization pathway MIT selects, building envelope upgrades and additional energy recovery from Energy Recovery Ventilation systems will be implemented to reduce their heating and cooling demand.

MIT "Low-Hanging Fruit" Upgrades Regardless of Pathway

- Upgrade single-pane windows
- Upgrade all lighting to LED's
- Seal air leaks
- Enhance exhaust heat recovery (included in Pilot budget)

Building Upgrades Summary. The table summarizes the upgrades proposed in the six buildings being considered for the Pilot.

Technology/Method	W31	W32	W33	W34	W35	W20	Notes
Glazing:							
Glazing Double Pane Upgrade		■		■		■	These buildings all single pane glass
Glazing to KalWall or equiv.			■				Translucent, light weight wall panels
Inter/Intra-Bldg Loop:							
Ambient Loop Conversion				■	■	■	
Ambient Loop Extension	■	■	■			■	W20 must be isolated from CW loop
Heat Pump Equipment:							
Unitary WSHP w/hot gas reheat	RTUs	■	■	■	Alt.		AAON/others, chosen for efficiency
4-Pipe Intra Building		Alt.		■	Alt.	New coils	MultiStack MR020 (for efficiency)
PoolPak					■		Built-in energy recovery/pool heat
W-2-R VRF/Terminal Dev. WSHP	Floor 0-2						e.g. Daikin splits, small unitary WSHPs
3-way W-2-W-2-A Heat Pumps						■	Multistack
Exhaust Energy Recovery:							
W-2-A or W-2-W-2-A Heat Pumps	Old flues	■	■	■	■	■	Each exhausts not with ERV already
ERVs	Alt.	Alt.	Alt.	Alt.	Alt.	Alt.	
Electricity Upgrade:							
New/added Xfmr Required			Yes				

Mitigating Electricity Costs. When gas-fired combined-cycle turbines in CUP are decommissioned, purchasing green electricity likely will be more expensive.

In a zoom call with Colorado Mesa University, which several years ago installed a distributed WSHP thermal energy network system with key elements similar to our proposal, the Facilities Director noted that a major selling point of the program was managing electricity costs. He noted installation of solar panels and collectors would further reduce purchased electricity cost.

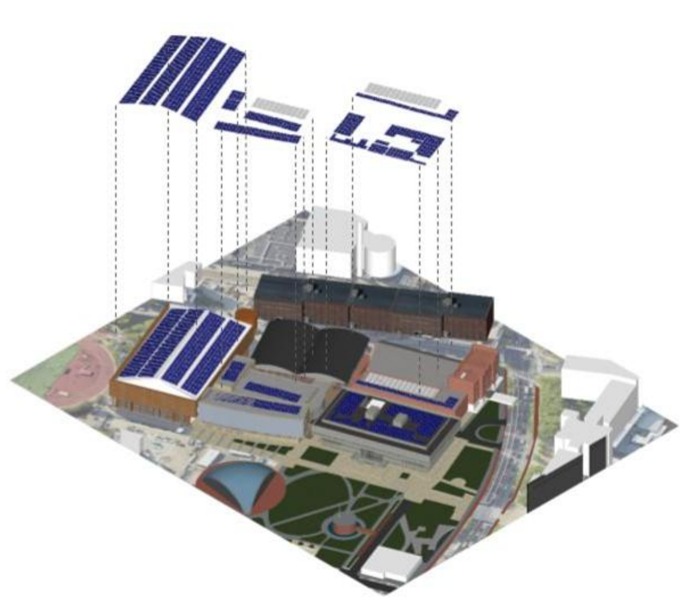
We recommend that MIT install solar panels where practical to help mitigate the impact. Also, Solar Thermal collectors would support the hot water demands of locker rooms in W32 and W35. (Panels and collectors are included in Pilot budget)

Collectors

Name Building	MODULE QTY.
W32	105
W35	77

Solar PV

Name Building	MODULE QTY.
W20	471
W32	107
W34	1280
W35	350

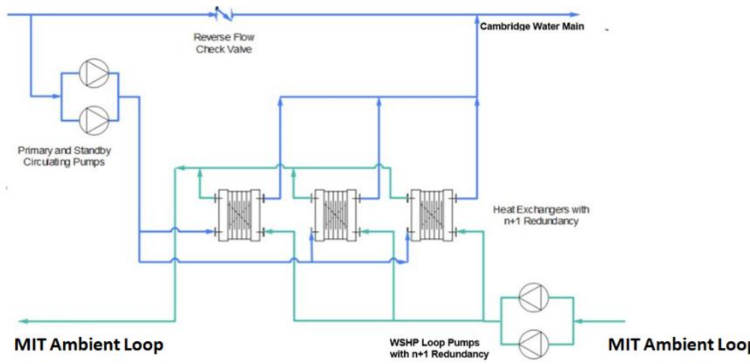


More Description of Proposed Pathway 18

Pathway 18 consists of distributed water source heat pumps in a thermal energy network to provide heating and cooling in each building through existing chilled water distribution piping, a system that would be repurposed as an ambient loop. The temperature range of normal operation in the ambient loop will vary from 45°F to 85°F, which is the range where WSHPs operate at their highest efficiency.

The ambient loop will connect all the heat pumps and other thermal assets in a distributed decarbonized heat pump HVAC system. Heat pumps that are cooling reject heat to the loop at the same time heat pumps that are heating extract heat from the loop improving the efficiencies of both. This mixed-mode heat pump operation is very common in campus buildings except, perhaps, during the winter's most extreme temperature when most heat pumps will be heating. At the summer peak, there will always be at least the heat pumps for domestic hot water that are in the opposite mode, benefiting fully from heat being rejected to the ambient loop from cooling.

Working with the City of Cambridge Water Department (CWD), we propose using existing water utility infrastructure as a thermal source and sink. As shown in the following figure, this solution involves an Energy Transfer Station connected to one or more municipal water mains. CWD would own the potable water from source to tap and operate the Energy Transfer Station, which would pump water from the utility mains through double-wall plate and frame heat



exchangers, to raise or lower ambient loop temperature as needed. The water would then be reintroduced to the main at a slightly different temperature.

The Energy Transfer Station would fit in space from the obsolete boiler in the basement of W31 or in a nearby vault. Water would be pumped from the utility mains on Massachusetts Avenue and Vassar Street. Thermal storage in the form of tanks and ground heat exchanger (GHEX) will also be evaluated.

Summary of Pathway 18 Features and Benefits

The MACA/Geo@MIT proposed Pathway 18 includes some unique features and offers MIT substantial benefits compared to other proposed approaches.

MACA/Geo@MIT Proposal Features

- Distributed WSHP system
- Converting chilled-water loop to ambient
- Minimal disruption to campus activities during installation
- Increased use of exhaust heat
- Highest efficiency of any design

MACA/Geo Benefits vs Other Pathways

- Lowest CapEx among top-rated proposals
- Reduced OpEx for electricity
- Lower maintenance complexity and projected cost
- Easy equipment replacement/upgrades

As noted earlier, we believe MIT should formally include Pathway 18 on the list of approaches being evaluated. The benefits are substantial and the capital requirements substantially less.

Thank you for your time. Please contact us with questions, comments or for further information.

MACA/Geo@MIT Team

Susan Murcott / MACA
'90, '92 Civil and Environmental Engineering

Susan is an environmental engineer specializing in sustainable water, wastewater, energy, and earth systems. For over 3 decades at MIT, she has held research and teaching/senior lecturer positions in the Civil and Environmental Engineering Department, the Department of Urban Studies and Planning, and as a Lecturer at D-Lab.

Rick Clemenzi / MACA, '81, Computer Engineering
Judy Siglin / MACA Affiliate
Rick Clemenzi is a Systems Engineer specializing in Advanced Thermal Systems. He is a Certified GeoExchange Designer (CGD) and principal engineer at Geothermal Design Center a licensed geothermal specialty engineering firm, and co-founder of Net Zero Foundation along with Judy Siglin who are working to advance rapid and cost-effective decarbonization.

John Dabels / MACA
SM '79 Sloan. A major portion of John's career has been split between: (i) helping guide the development and launch of a range of products, mostly transportation related; (ii) conducting financial analysis and/or operating as a senior financial executive in several larger and smaller companies.

Shiladitya DasSarma/MACA, '84, PhD, Biochemistry. Advisor. Professor, University of Maryland School of Medicine and Institute of Marine and Environmental Technology, Baltimore. Research concerns impacts of climate change on society and the mechanisms of cell survival after environmental stress. Founded MIT Alumni for Climate Action received the Margaret MacVicar Award for his leadership on climate action by MIT.

David T. Williams / MACA
MIT '82, Mechanical Engineering Dept.

David attended MIT from 1977-1982 pursuing a course in Mechanical Engineering with a strong interest in building systems. His 40+ year professional career is in Architecture/Engineering consulting for the premier firm in this area of design in MN, LHB Corp where he is a Principal, Senior Mechanical Engineer, and Sustainability Specialist.

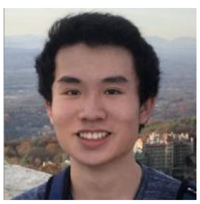
Herb Zien / MACA
'73, Management

Herb Zien (Sloan SM '73) cofounded a firm that became the largest owner and operator of District Energy Systems in the US, with 21 Central Utility Plants serving 11 cities including Boston.

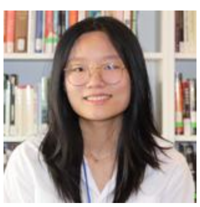
Tunca Alikaya / Geo@MIT / MACA
'24 E-MBA, Sloan. Expanding Celsius Energy, a Schlumberger New Energy start-up that provides geo-energy technology for zero-carbon heating and cooling of buildings, to the US market.

Kevin Johnson /
Harvard GSD '24, Architect, **Geo@MIT / MACA**
Kevin is an architect and current Master in Design Studies student at Harvard GSD, with a background in Urban Design and Landscape. He has significant experience in urban planning, decarbonization, and emergency management. In Chile, Kevin leads a design studio focused on climate change and urban growth, and serves as Chair of Latin GSD. He is also engaged in exploring advanced energy systems at Harvard SEAS and participating in global design competitions.

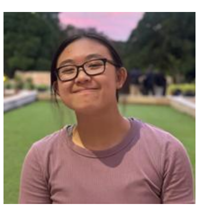
Jillian James /MACA. Jillian has a S.B. Aerospace Engineering '10 and a SM in Aero Astro Engineering '16. She is an En-ROADS ambassador, and the director of Sustainability of NetScout. Jillian also manages the MIT Climate Clock website and has been a key technical player in making the MIT Climate Clock projection on the Green Building (#54) possible.



Jason Chen / Geo@MIT
'25 Mechanical Engineering & Literature
Jason Chen is an undergraduate senior at MIT double majoring in mechanical engineering and literature and minoring in computer science, and member of student Geo@MIT team that won two DOE Geothermal Technologies Office awards. He is passionate about accelerating energy transition through research and commercialization of technologies.



Olivia Chen / Geo@MIT
'26, Mechanical Engineering
Olivia Chen is an undergraduate junior at MIT majoring in Mechanical Engineering, and member of student Geo@MIT team that won two DOE Geothermal Technologies Office awards. She is passionate about energy, sustainability, and entrepreneurship.



Megan Lim / Geo@MIT / MACA, '24, Business Management
Megan is an MIT business management graduate as of May 2024, and member of student Geo@MIT team that won two DOE Geothermal Technologies Office awards. She has spent the past 4 years involved with the Undergraduate Association, where she served as chair of the Committee on Innovation, helped run a 24/7 student space named Banana Lounge, served on the Presidential Advisory Cabinet, and worked on a wide range of student issues. She interned at the MIT Office of Sustainability during the summer and is working at MIT's Environmental Solutions Initiative.