2024:Q4
2025:Q1

Introduction to Innovative, Cost-Effective Plan to Fully Decarbonize MIT'S Campus by 2035

Design concept with a staged rollout that achieves zero carbon by 2035 using commercially available, off-the-shelf technology.

Working Draft

Submitted by MACA/Geo@MIT Campus Group Team

MIT Alumni for Climate Action

Ref: 24 10 29 Update to MACA Campus Decarb Intro Doc and Bus Plan

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INTRODUCTION AND PROJECT GOALS:

In the long tradition of those affiliated with MIT developing affordable, practical solutions to complex problems, the MACA/Geo Campus Team is proud to introduce a design that not only achieves MIT's goal of a zero-carbon emissions campus but could set the standard worldwide for decarbonizing clusters of buildings.

The team has been working on the proposal for well over a year. Members include students, faculty, and alumni with extensive experience in developing and installing HVAC systems.

The design achieves zero-carbon emissions from buildings by 2035. The plan can be implemented in stages. The initial stage, a Pilot Program converting six buildings, uses known, well-proven technology to "custom fit" solutions to individual buildings and achieve the zero-carbon target.

Proposed enhancements incorporate emerging, proven technologies aimed at reducing operating costs. Staging implementation achieves zero-carbon target by 2035, reducing financial risk and potential disruption to campus activities.

As you review material in this introduction document, we encourage you to challenge our assumptions and ask for more information.

Having studied all practical alternatives, including proposals by AEI, the engineering company hired by MIT, the team believes this design with the opportunity for staged implementation is the most energy efficient and the most efficient use of capital. The plan also helps MIT meet emission restrictions for the City of Cambridge (BEUDO Ordinance), thereby avoiding significant monetary penalties and likely negative publicity.

Thank you for your time. We look forward to your questions and the opportunity to share much more information about plan details. We welcome the opportunity to help MIT groups or committees working on decarbonization.

THE MACA/GEO CAMPUS TEAM
MIT ALUMNI FOR CLIMATE ACTION

Primary Contact:
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Overall Project Mission Statement/Goals

Achieve a 100% decarbonized MIT campus by:

- 2035 calendar year
- Implementing available, proven technology to meet the 2035 target
- Enabling cost-effective enhancements to be evaluated first, then implemented
- Prohibiting purchase of carbon offsets
- Minimizing risk of disruption to campus operations
- Ensuring a fiscally responsible approach, including use of Federal IRA funds

Decarbonizing: A Rubik's Cube Problem

Designing a plan consistent with the mission statement presents a multi-faceted problem, sometimes with competing dynamics. Implementing the plan in stages helps reduce complexity while:

- Achieving zero carbon emissions as soon as practicable – target is by 2035
- Eliminating all emissions from buildings – no purchase of carbon offsets allowed
- Minimizing risk of disruption to campus activities and/or facilities operations
- Allowing repurposing a building/floor without major cost for modifying HVAC
- Allowing easy and relatively low-cost upgrades to equipment over time
- Leveraging existing assets to a maximum extent, thereby reducing capital expenditures
- Coordinating HVAC installations to planned building upgrades
- Reducing financial risk, where possible by applying for funds available through the Inflation Reduction Act IRA (up to 40% CapEx).

Skepticism Encouraged – we agree there should be skepticism about the proposed plan – or any plan – and we support such skepticism, especially about the staged approach and overall plan cost. We also believe the most effective way to address that skepticism is with hard data generated by a Pilot Program.

Pilot Program to Demo, Measure Performance

A Pilot Program would reduce risk and increase confidence. A lower-cost Pilot would convert six (6) buildings on west campus to an innovative HVAC system using the same type commercially available, off-the-shelf technology as planned for other buildings on campus.

A Pilot Program on west campus would: (i) be in buildings where HVAC requirements are somewhat less complicated than east campus – Pilot buildings are mostly athletic related; (ii) cause less disruption to campus activities; (iii) make easier any adjustments required during the Pilot Program; (iv) incorporate lessons from the Met Warehouse upgrade.

Figure 1 Pilot Program Buildings

Results of a lower-cost, low-risk Pilot would:

- Generate performance data for the HVAC system design and components
- Resolve concerns about perceived complexity of the proposed approach
- Provide confirming data about system operating cost savings and lower risk.

In addition, the Pilot would help demonstrate and help build a broader understanding of:

- The process used to convert buildings to the proposed system design
- How easily the existing chilled water loop could be converted to an ambient water loop, thereby significantly reducing CapEx, time to install the system, and the disruption to campus activities
- How each building would have a "custom-fit" HVAC solution

- How HVAC systems could be modified on site if a floor or building repurposed
- How operational and financial "risks" are mitigated with the staged rollout of the proposed solution
- How the optional enhancements could be demonstrated and measured for payback.

Pilot Program Cost – While more analysis is needed, the preliminary cost for the pilot is ~$12-$15million gross (~$9-10 M with IRA funds). Importantly, regardless of which decarbonization proposal is adopted, virtually all the equipment in the pilot could remain in the buildings or installed elsewhere on campus. Pilot Program would not increase overall project cost. Some of the Pilot cost is for upgrades and changes that need to be implemented regardless. The Pilot also includes some solar.

Decarbonization Concept – Counter-Intuitive

Whereas no analogy is perfect, one might consider evaluating the proposed approach to decarbonize campus to the experience of how computer hardware and software companies had to evaluate their future as laptops became more functional and affordable.

Laptops broke the concept of centralized control of data. Laptops also meant that many functions of existing IT departments were transferred to users. For some executives, the shift was perceived as costly, complicated, and high risk.

The shift to widespread use of laptops in organizations occurred with few real hiccups. The shift increased worker productivity as enhanced hardware and/or software enabled solutions to be "custom fit" to an individual's needs.

Decentralization allowed workers to take the office home or on trips, even vacations. The value of laptops became more apparent during the pandemic, which allowed operations to continue even though most offices were closed or attendance severely restricted. The pandemic demonstrated how decentralization of computing power could markedly reduce financial risk and operational risk to organizations.

Lessons Learned from Laptops -- Systems solutions to emerging problems are often at odds with conventional wisdom in most disciplines. Innovation requires a balance between: (i) the need for new thinking and a commitment to learn; (ii) realities of transforming the organization's operations and culture.

Decarbonization Concept Overview

The following paragraphs outline key features and issues associated with the proposed approach to decarbonize campus. For those interested, more details are available, including a personal briefing.

Shift from Centralized to Decentralized Components. The proposed decarbonization plan shifts the equipment operating the HVAC system from the Central Utility Plant (CUP) to individual buildings. The decentralized approach enables a limited number of components to be used to create a "custom-fit" HVAC solution for each building or floor within the building.

The proposed design also includes equipment that captures and recycles virtually all the energy currently being lost to exhaust, especially in buildings with labs, which are the highest energy users/sq ft on campus[1]. We believe adding equipment to capture and recycle virtually all energy lost to exhaust should be part of any proposal, not just ours.

[1] Current recovery equipment is estimated by team to capture no more than 40% of exhausted heat.

TECHNOLOGY & STAGED IMPLEMENTATION

Water-Source Heat Pumps. The key component for the proposed system is a water-source heat pump (WSHP). Heat pumps will be located at the point-of-use rather than a central location, which allows heat pumps and other equipment to be "custom-fit" to the end point, operate at a higher efficiency, and eliminate distribution losses between a central location and end-use point. All WSHPs will be connected to an ambient water loop (explained below).

The decarbonization plan could be based on air-sourced heat pumps (ASHP). However, an ASHP solution would have higher OpEx for electricity due to the more electricity needed to operate ASHPs vs WSHPs for the same HVAC output.

Why WSHPs Distributed to End Use? Energy efficiency of water-source heat pumps can be 4-6x greater than a centralized system using electric boilers or fossil fuel, and 2x greater than central heat pumps. Even though WSHPs are distributed campus-wide, HVAC-related capital expenditures should be no more than a centralized system and operating cost significantly less. *(See table comparing efficiencies)*

Advanced Exhaust Energy Recovery. The single largest HVAC load at MIT is due to the vast energy currently being lost to exhaust, especially in the numerous lab buildings with continuous large volumes of exhaust.

Those losses account for a substantial portion of all HVAC-related energy consumption. Eliminating these losses is a relatively straightforward. We believe exhaust energy recovery should be part of any decarbonization effort.

Beyond the basic need for exhaust energy recovery, our plan goes further to utilize this same equipment as an air-source heat pump (ASHP) capability based on existing air flows required for building and lab exhaust. This capability is enabled by utilizing "3-way" heat pumps connected to the: (i) exhaust and supply air streams; (ii) ambient loop. Thus, energy can be flexibly exchanged between outdoor air and ambient loops as well as between exhaust and supply air streams.

Campus as a Unified HVAC District. Once complete, all the buildings will be interconnected by an ambient water loop. As the program is implemented in stages, buildings will be grouped into "HVAC districts" to help manage the transition and maintain operations of other buildings.

Using Existing Infrastructure to Reduce CapEx. By converting the existing chilled-water loop to an ambient water loop, time to convert buildings is reduced, excavating and laying new pipe eliminated and disruption to campus activities minimized. Capital requirements are also drastically reduced. The ambient loop will serve heat pumps, whether cooling or heating.

Approaches to Reduce OpEx.

Solar Panels and Thermal Collectors. Solar panels and thermal collectors have been added to the base case to help reduce OpEx. The extent to which panels/collectors can be added while maintaining the architectural integrity of key buildings is to be determined.

Initial installations will be in the proposed Pilot Program. The system likely will include some battery storage to be used during peak-demand periods. Numerous options are available for non-lithium battery packs for storage.

Ground Heat Exchange Systems. Our proposed approach to ground heat exchange (GHEX) is much different than "conventional geothermal" approaches, which require significant space and cause much impact. Our plan include four (4) complementary, cost-effective approaches designed to reduce OpEx by increasing system efficiency, thereby reducing use of electricity.

Enhancements will be digitally modeled to determine the most resilient and cost-effective mix, especially as utilities migrate to solar and wind-generated electricity.

Enhancement #1 (Base Case): Use the City of Cambridge piping that carries water and sewer as a form of thermal battery. No water or sewer is exchanged between the systems. If the water temperature for WSHPs needs to be warmed or cooled, transfer from the Cambridge pipes is completed using highly reliable, low-cost, commercial "heat exchangers."

We are pursuing a test with Cambridge Water Department to determine if a link between the MIT water loop and the Cambridge system satisfies environmental regulators and meets performance expectations.

NOTE: 2, #3, #4 are under consideration for later years. Each requires additional analysis.

Enhancement Option #2. Install thermal batteries in the ground beneath campus. Installing the thermal batteries would be achieved using drilling techniques requiring a minimal ground-level footprint. Once batteries are installed, the drilling surface area will be fully restored.

Enhancement #3. Angle Boring is a new installation technique which dramatically reduces the surface area required for installation. A firm with this capability has evaluated MIT's campus for suitable low-impact sites and identified locations throughout campus. A test is needed to determine the cost-effectiveness of this technique in MIT's specific underlying strata.

Enhancement #4. Controlled directional boring in the bottom 50' of the 100' overburden under MIT. A novel approach with the same small footprint as Enhance #2 thermal batteries. The approach seems promising but needs further evaluation for impact and cost effectiveness.

Implementation of one or more enhancements will be based on a combination of detailed analysis of building loads and power supply matched against cost effectiveness and minimal disruption to campus operations.

Decision Timeline for 2035

2035 Target -Decisions and Timing to Achieve

Given the: (a) need to convert about 80 buildings to zero-carbon emissions by 2035; (b) opportunity to coordinate decarbonization with planned building upgrades; (c) mandate to minimize disruption to campus activities; (d) benefits of conducting a pilot test for this proposal, and likely any other proposal, key decisions need to be made such that pilot program can be at least started in 2025. The likely final decision on the approach to decarbonization should be apparent part way through the pilot, ideally by not later than early 2026.

Information available for key decisions to evaluate decarbonization proposals should include:

- team members' background, experience developing and implementing similar plans
- lessons learned from previous projects
- cost of proposed technology
- energy efficiency of proposed technology in specific installation sites
- if proposed plan can qualify for IRA funds
- reasonable 10-year forecast of cash flow for CapEx and OpEx, including possible additional expenses during conversion
- ability to custom-fit HVAC solutions to specific buildings
- ability for low-cost modification of HVAC system when a building or floor repurposed
- assessment of plans to mitigate operational and financial risk
- date when zero-emissions are achieved, including target percent achievement by year

Table 1 Implementation Approval, Timeline

2025:Q1	CY2025	CY2026-27	CY2028-29	CY2030-31	CY2032-33	CY2034-35
OK Pilot	Pilot 6 Bldgs	14 Buildings	20 Buildings	15 Buildings	15 Buildings	10 Buildings
Ok Vendors	Started	25% Done	50% Done	69% Done	88% Done	100% Done

With such information, MIT staff/workgroups could approve pilot program(s) to be initiated in 2025. We believe the $15 MM estimate for the Pilot is reasonable. More discussions with Facilities Staff or the Financial Staff would help refine.

Pilot Programs as Educational Tool

Pilot programs are an ideal venue for students in a wide range of disciplines to gain real-world experience. Faculty and students could be involved in all phases – from initial evaluation of building HVAC requirements to assessing complexity of installations to measuring performance to measuring emissions savings to financial analysis. Geo@MIT students have been involved with all phases of analysis, including 3D renderings.

Results and lessons learned could be published and promoted through webinars and other media, thereby reinforcing MIT's reputation for practical solutions to complex problems.

Program Cost by Category

The top-line gross cost estimate for converting ~80 buildings is about $250 million. With IRA funds, the net cost is about $175 million, slightly higher than the estimate associated with the Geo@MIT Team submission for the DOE Competition. (Top-line timed project budget)

The project cost estimate is based in part on building data from MIT Facilities. Several members of the MACA team have extensive experience in designing HVAC systems and helping manage the transition from system design to engineering specifications, then installing the equipment. Team members also have experience developing advanced technologies associated with cost-effective building decarbonization. (More about MACA team members)

The team believes the gross cost estimate of $250 million is reasonable given the limited information that is currently available. The net cost of $175 MM assumes nearly all CapEx will qualify for a 40% rebate under the Inflation Reduction Act.

While we have not been privy to the details, based on comments from those involved in other decarbonization programs similar in scope to MIT's, costs of such programs has been 2-3x the gross cost of $250 million for this proposal.

We would appreciate an opportunity to review assumptions and calculations in more detail with MIT Facilities and MIT Financial Staff.

Why Project Cost Estimate Might Seem Low – Avoided Costs. Repurposing the existing chilled-water loop to an ambient temperature water loop avoids having to create a separate water piping infrastructure for the heat pumps.

There are about 20 buildings not connected to the chilled-water loop. Connecting those buildings to the ambient loop would cost an estimated $15 million.

Table 2 Project Cost by Category

MACA Campus Decarbonization Cost Overview

	Sq Ft Assumption			BASE CASE
	Total Campus	*Tons Req'd*		*Tons*
		1,000 sq ft		Campus
	Residential	2.0		23,954
1.25	Commercial	2.5		29,943
	Category	*$/Ton*	*Adjustment*	*(Mil)*
CapEx	Equipment/Install	$ 3,000		$ 89.8
CapEx	Exhaust Equip/Install			$ 25.0
	Sub-HVAC Equipment			$ 114.8
CapEx	Solar Panels/Collectors			$ 15.0
CapEx	Thermal Batteries			$ Optional
CapEx	CW Loop Extension			$ 15.0
CapEx	Cambridge Water Link			$ 15.0
	Sub-Infrastructure			$ 30.0
OH	Engineering / OH	10.0%		$ 16.0
OH	Other Expenses	10.0%		$ 16.0
	Sub-Total Detail			$ 191.8
	Contingency	30.0%		$ 57.5
	Total Project		$ -	$ 249.3
	Memo: Totals	Direct		w/ Cntngcy
	CapEx	$ 159.8		$ 191.8
	Overhead (OH)	$ 47.9		$ 57.5
		$ 207.8		$ 249.3
	Potential Rebates			
	IRA Rebate Assumption	~40.0%		$ (74.3)
	Net Project Cost			$ 175.0

	CW Loop Extension	**Assumptions**		
	Buildings	20		Sq Ft
	Feet / Building	750	All Bldgs	11,977,199
	Total Linear Feet	15,000	Steam	9,695,343
	Cost/Foot Pipe & Drill	$ 1,000	Chil Water	7,669,747

Table 3 Timed Budget 2025-2035

Top-Line Timed Budget for Project ($Millions)

	CY2025	CY26-27	CY28-29	CY30-31	CY32-33	CY34-35
Expenditures	$ 15.0	$ 45.0	$ 75.0	$ 50.0	$ 40.0	$ 25.0
Cumulative	*$ 15.0*	*$ 60.0*	*$ 135.0*	*$185.0*	*$ 225.0*	*$ 250.0*

Net with IRA Funds ~ $ 175M

Ref: 24 10 29 Update to MACA Campus Decarb Intro Doc and Bus Plan

Hardware and Installation: Based on information from MIT Facilities, buildings on campus have a gross footprint of nearly 12 million square feet. The footprint total was used for project estimates, recognizing cost per building will vary.

The estimated cost for hardware and installation was based on industry guidelines for purchase and installation of water-source heat pumps. For the campus estimate we assumed 2.5 tons/1,000 sq ft of space. The estimate is 25% higher/sq ft than tor residential.

Cost for purchase and installation of heat pumps was assumed to average $3,000/ton (on the high side), or $89.8 million. While the conversion of the existing chilled water loop will save considerable time and CapEx, ~20 buildings need to be added to the loop. The cost estimate of $15.0 million assumes the existing steam pipes are inadequate size for the ambient water loop.

The cost for purchasing and installing exhaust capture and recirculation equipment was estimated at $25.0 million. As noted earlier, we believe all proposals MIT considers should include exhaust recapture equipment. The extent of use of all equipment will be refined as buildings are reviewed in more detail.

Options to Reduce OpEx

Solar panels and/or solar collectors can directly reduce purchase of electricity and OpEx. The base case has been adjusted to include wider spread use of solar panels and collectors. For planning, we assumed $15.0 MM, which would include some battery storage. Some architectural concerns need to be resolved before campus-wide implementation. Some IRA funds might apply to these installations.

GHEX Option #1. A link to the Cambridge Water System would be the lowest cost and a relatively straightforward installation.

The primary unknowns are: (i) how much heat/cooling can be transferred relative to MIT needs; (ii) ability to secure agreement with the City of Cambridge. The idea has been discussed with the Cambridge Water Department, but no formal agreement has been reached. MIT's support for the proposal would increase the likelihood of an agreement.

While more analysis is needed, we believe the heat transfer system would have a gross cost of no more than $15 million ($9-$10 million with IRA funds) and could help reduce annual OpEx for electricity.

Options #2, #3, #4 Costs Not in Base Budget

Enhancement Option #2. An alternative to Cambridge Water is installing some shallow-depth thermal batteries (<100' below the surface).

Like Cambridge Water, the batteries would be linked to the ambient water loop. Installation can be coordinated with or after the heat pumps are installed. Thermal batteries could also work in tandem with Cambridge Water. This thermal battery approach has not been used widely; however, test results have been positive.

The $15.0 M cost for thermal batteries is a best guess based on discussions with an executive of drilling operations of a major oil-and-gas service company familiar with the geology of MIT's campus. Options #3 & #4 – costs to bury batteries needs more analysis.

Engineering and Other Overhead were each estimated at 10.0% of all Capital Expenditures.

Contingency: while we believe most cost estimates are conservative, we believe it is prudent to include a contingency. 30% is applied to all costs.

IRA FUNDING POTENTIAL: The opportunity exists with the IRA to reduce qualifying CapEx by up to 40%. Based on our analysis, the proposed program could qualify for $75+ million. IRA payment would be directly to MIT, not through a 3rd party. Total program cost, including optional enhancements, is ~$250 million. With IRA funds, the net cost is ~$175 million.

PROJECTING OPERATING COST SAVINGS

The standard measure of operating efficiency for HVAC-related equipment is "coefficient of performance" (COP). The higher the COP, the greater the efficiency of the unit. A COP of 4.0 is 4x as efficient as a COP of 1.0. While the COP will vary somewhat with each situation, data in the following table are representative:

Type of HVAC Decarbonization	COP
Water-Source Heat Pumps	4.0-6.5
Air-Source Heat Pumps	1.6-4.5
Electric Boilers	~1.00
Natural Gas Boilers	0.7-0.8

Table 4 HVAC Systems Efficiencies

If we compare the low-end COP of water-source heat pumps with electric boilers, WSHP's – the core of the MACA proposal – generate about 4x the heat for every unit of electricity used. Thus, for the same heat generated, WSHPs would use 25% of the electricity as electric boilers.

More Analysis Req'd to Calc OpEx Savings. Based on a projected 4-5x higher coefficient of performance for a system based on decentralized water-source heat pumps, plus other enhancements that will reduce electricity usage, we believe HVAC operating costs could be 25-30% less than a proposal based on a centralized system using hot-water heat pumps.

The estimate needs to be refined and reviewed in more detail with Facilities Staff and the MIT Financial Staff. Having more current data about operations at MIT would result in more thorough modeling and analysis.

OTHER ISSUES RE OPERATIONS

Lower-Costs for Repurposing Buildings or Equipment Upgrades. Because the HVAC equipment will be "custom fit" to the existing building or floor air-handling systems, changes to building functions (or individual floors) can be made quickly and likely at far less cost than with a centralized system. Decentralized equipment is typically easier to repair than larger central units.

As improvements to HVAC technology are introduced or equipment needs to be repaired or replaced, a decentralized approach will provide ready access to HVAC components at the use location. Ready access will reduce installation time and cost compared to a centralized system. Training required for technicians installing decentralized units is substantially less than technician training required for larger centralized units.

Component Reliability, Durability, Maintenance. Heat pumps are highly reliable. Expected life of an industrial-grade water-source heat pump is 20-25 years. Given the number of heat pumps to be installed on campus, some may need to be replaced early but others will last longer. However, ready accessibility at the site will reduce re-installation time and cost. Furthermore, the risk of interruption to campus activities will be reduced by a decentralized system.

DOES THE PROPOSED EQUIPMENT FIT?

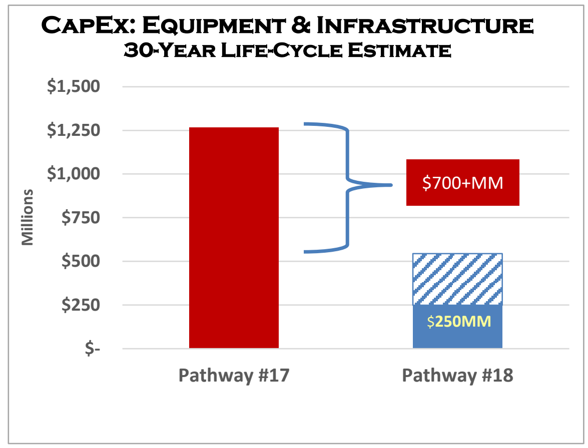
At the request of the Facilities Staff, the MACA/Geo Team conducted a "test-fit" analysis of the proposed equipment. The short definition is a check to see if the proposed equipment can: (i) be installed without major modifications to the assigned area; (ii) operate within the constraints of the existing electrical system. Answer, "Yes, it fits with minor modifications."

The analysis is extensive, including a detailed list of proposed equipment, performance specifications and some 3D modelling of minor building modifications. Both a "Summary Report" (~8 pages charts and text) and "Comprehensive Report" (75+ pages) are available for review and further explanation.

Comparison: MACA/Geo vs AEI Top-Rated Decarbonization Pathway

The charts compare selected data for "Pathway 17," the approach rated highest by AEI, hired by MIT Pathways 17 and the MACA/Geo approach, "Pathway 18." While estimates are preliminary, we believe the relative comparisons between the pathways are reasonable as are the overall cost estimates. Data for Pathway 17 are from charts presented by AEI at Workshop #9, held June 2024. We understand the AEI data are being updated but to our knowledge no date for release has been announced.

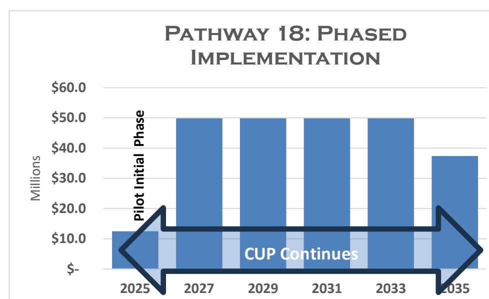
The amounts for the MACA/Geo Pathway 18 are based on a preliminary budget and the Test-Fit analysis provided to Facilities Staff. Facilities indicated the equipment list, and information would be forwarded to AEI and/or Shawmut Construction to calculate costs using a method consistent with other Pathways.



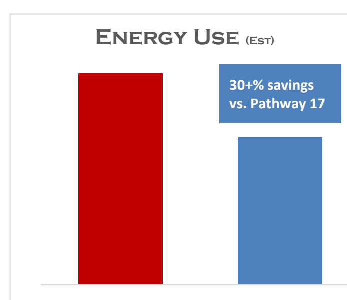
CapEx Comparison. The difference in CapEx is startling. Our estimate to initially achieve a zero-carbon campus is $250 million. As noted, the estimate excludes what could be labeled as "non-discretionary" upgrades. Such upgrades should be implemented regardless of the pathway selected.

The $250MM estimate includes: (i) water-source heat pumps distributed in all buildings; (ii) equipment to capture a higher percentage of energy currently being wasted; (iii)converting existing chilled water piping to an ambient loop and extending it to some buildings as needed.

Our Life-cycle cost assumes replacing all standalone equipment between 20-25 years (shaded area of chart), the expected useful life of WSHPs. With annual inflation of 3.0%, calculated CapEx for the initial budget and replacement equipment is about $550MM, which is $700 MM less than Pathway 17 for Infrastructure and Plant.



Timed Implementation to Eliminate Emissions by 2035. We have assumed a systematic implementation plan for Pathway 18. General timing, while somewhat arbitrary, is designed to minimize disruption to campus activities. Initial phase is the Pilot Program for the six buildings on West Campus. The budget for the Pilot is $15MM, which also includes some solar collectors and solar panels. The Pilot has been designed such that equipment can be incorporated in whatever pathway is selected. The Pilot Program would have little, if any, impact on the overall budget. Pathway 18 assumes the Central Utility Plant continues to retain certain key functions after Pathway 18 is fully implemented.



Energy Savings. Pathway 18 design includes three features that save energy usage and electricity cost: (i) locating WSHPs at the point of use eliminates heat loss when water is heated at CUP, then transmitted to the end-use point; (ii) capturing free energy when there is concurrent heating and cooling in campus buildings; (iii) using one piping system to provide water to the Pathway 18 WSHPs rather than two piping systems as with Pathway 17 and other pathways, reduces energy for pumping. Combined, the features of Pathway 18 reduce energy by at least 30% while achieving the same heating and cooling. The savings will reduce OpEx for electricity.

MIT Campus Group Members

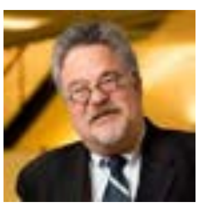
Collectively, our MACA-MIT Campus expert alumni group (geothermal energy systems, including certified geo-exchange designers (CGD certification), management, finance, extensive experience bringing innovations to scale,) has contributed an estimated 2,000 hours of volunteer time over the past 12 months to evaluate options for MIT campus decarbonization.

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.



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

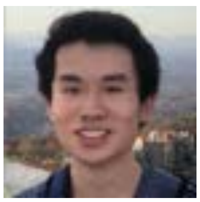
Herb Zien (Sloan SM '73) co-founded a firm that became the largest owner and operator of District Energy Systems in the US, with 21 Central Utility Plants serving 11 cities including Boston.

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.

What We Know and Don't Know

We thought it would be helpful to list what we know about key variables associated with the project and what we don't know. Obviously, there are degrees of "knowing" and "not knowing."

As recommended, we believe a low-cost pilot program on west campus will provide incredibly valuable information, adding another level of confidence to "what we know" and reducing what we "don't know."

As with other information and assumptions in this paper, we encourage you to ask questions and challenge us.

What We Know	What We Don't Know
Achieving zero emissions is multifaceted and requires a systems approach	Details of other plans being considered so we can provide objective comparison and/or help w/ analysis
Pilot program, staged implementation reduce risk, uncertainty	OpEx savings – projected 30% reduction needs to be confirmed with more current data from Facilities Staff
Distributed system benefits: ▪ Increased efficiency ▪ No major CapEx penalty ▪ "Custom fitting" to individual building, floor ▪ Easy upgrades over time	Payback – target is <10 years based on industry experience linking WSHPs to geothermal system. Need more specific MIT data and analysis to increase confidence. Pilot and staged rollout will also help build confidence.
Project cost reasonable, esp vs alternatives -- $250M gross; $175 w/ IRA	Cost of other pathways proposed is significantly higher. Part of issue lies with having no access to details supporting cost estimates for line items that should be in all proposals – building efficiency upgrades, e.g. See examples of cost differences.
Water-source heat pumps are: ▪ Highly efficient ▪ Highly reliable ▪ Durable – 20+ year life	
Converting the chilled water loop to ambient reduces CapEx and increases overall efficiency	
Optional enhancements reduce OpEx for electricity	Solar panels/collectors are the easiest to measure. Other approaches require more analysis and some test programs.
MACA team has extensive HVAC project design and implementation experience	

GLOSSARY OF TERMS/SHORT ANSWERS

- Chilled-Water Loop/Ambient Loop – The existing chilled water loop is a piping system that circulates chilled water from MIT's Central Utility Plant (CUP) to campus buildings. As WSHPs are installed, the chilled-water loop will be repurposed at marginal cost to become an "ambient temperature" water loop. For the 20 buildings on campus that are part of the steam system but not connected to the chilled water loop, it might be possible in a few buildings to repurpose steam pipes to be part of the ambient loop.
- City of Cambridge Wate/Sewer as Thermal System – the "system" refers to pipes used to transfer water and sewer to/from municipal water-treatment facilities. The proposal would not access any of the water being transported in the pipes.

  The proposal would install double-wall plate-and-frame heat exchangers to transfer heat energy to and from the municipal systems. The transfer would help regulate the temperature of water used for heat pumps, thereby reducing the electricity required.
- City of Cambridge, BEUDO Ordinance (Emissions) – regulation restricts emissions from buildings of a certain size in Cambridge, charging fees for emissions after a grace period Virtually all buildings on MIT campus will be affected.
- COP – Coefficient of Performance -- The coefficient of performance of a heat pump (refrigerator or air conditioning) system is a ratio of useful heating or cooling energy provided to electric energy input required. Higher COPs equate to higher efficiency and lower electricity consumption, thus lower operating cost. More about COP.
- Districts HVAC – a group of buildings such as a campus that share thermal energy to reduce the overall cost of heating and cooling. Even on the coldest day, there are some buildings that require cooling, labs for example, and on the hottest day heat is still needed, for example hot water.

  The heat pump "byproduct" from cooling is "heat" and the opposite for cooling. Rather than wasting this valuable energy, it is redirected via the ambient loop to units where needed. Creating a "district" allows key elements of the system to be shared among buildings, thereby reducing CapEx, OpEx.
- Electric Boilers – electric boilers are very large "electric water heaters." The heating principle is the same – a metal probe heated with electricity then heats the water. While the approach does not generate any onsite emissions, the efficiency is minimal at COP=1, consuming large amounts of electricity, possibly resulting in significant demand charges.
- Electricity, Load Demand Premium – Peak demand can represent a spike in power usage, such as turning on all the lights in a facility or starting up an electric motor in a factory. Peak demand charges can account for 30-70% of an electric bill. (More info.)

- Exhaust Recovery System – Active Exhaust Recovery equipment captures energy in normal building exhaust and directs it to ASHPs. Such systems recover 40%-70% of the energy under ideal conditions.
- Financial, CapEx – capital expenditures are for assets with a useful life of more than one year. For the MIT project, CapEx would include such items as heat pumps, piping, valves, and thermal storage batteries. Currently, some capital expenditures are eligible for a 40% rebate through the Inflation Reduction Act.
- Financial, OpEx – expenses associated with "running the business." For MIT HVAC, OpEx would include the cost of electricity, maintenance, salaries, and similar expenses. In this proposal, expenses for design, engineering and installing equipment have been designated as OpEx.

  Depending on the design of the campus-wide HVAC system, one design could have substantially higher OpEx than another. For assets with a longer life, annual OpEx can be a more important decision criterion than the cost of the equipment.
- Financial, Payback – usually expressed in years. When comparing proposals, one should calculate for each proposal the time required for the reduction in operating costs to "pay back" the CapEx. If CapEx is $100 but OpEx is reduced by $20/year, payback would be 5 years.

  Some calculations include "avoided" costs associated with the CapEx. If the existing system requires an upgrade in 2.5 years that costs say $40, then spending $100 on new equipment avoids the upgrade. Accounting for "avoided costs," the payback becomes ($100-$40)/$20, or 3 years vs. 5 years.
- Heat Pump, Air Source (ASHP) – a quick introduction (non-technical) to the basics of air-source heat pumps. Efficiency of air-source heat pumps is affected by the ambient temperature of the air drawn into the heat pump.

  Heat Pump, Water-Source (WSHP) – A water-source heat pump is a heat pump that transfers energy from water for heating and cooling rather than from air. For MIT, the water source will be the existing "chiller loop" repurposed to an ambient temperature water loop.
- Inflation Reduction Act (IRA) – an Act with numerous Clean Energy and Energy Efficiency tax credits, including specific and substantial credits for geothermal heating and cooling and for designing the same.
- Pilot Program – limited scope program to demonstrate a concept and measure performance in a real-world application. The proposed pilot for buildings on west campus would demonstrate how heat pumps would be installed in individual buildings and then linked to form a thermal district.
- Zero Carbon – zero direct emissions from campus buildings. Achieving "zero carbon" does not allow for any type of "carbon offsets" to be purchased and "subtracted" from actual emissions.