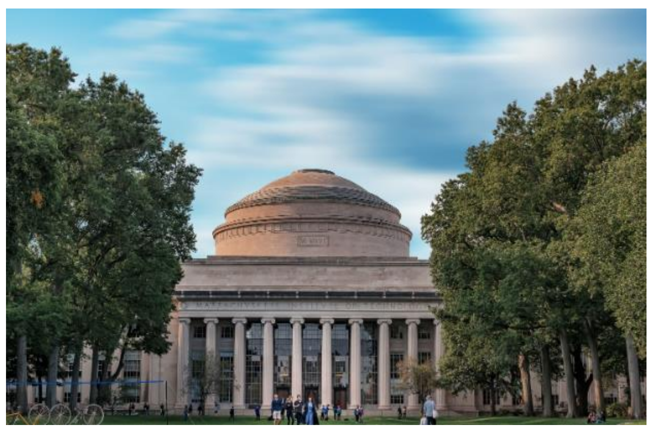
2024:Q1/Q2

Introduction to an Innovative, Staged, Cost-Effective Plan to Fully Decarbonize Campus

Design concept that is staged and achieves zero carbon using commercially available, off-the-shelf technology by 2035.



Working Draft

Submitted by MACA Campus Group Team

MIT Alumni for Climate Action

Ref: 24 03 06 MACA Campus Decarb Intro Doc and Bus Plan

Contents

Introduction and Project Goals:

In the long tradition of those affiliated with MIT developing affordable, practical solutions to complex problems, the MACA Campus Team is proud to introduce a design concept 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 over a year. Members include students, faculty, and alumni with extensive experience in developing and installing HVAC systems.

The concept achieves zero-carbon emissions from buildings by 2035. The concept enables implementation in stages. The initial stage uses known, well-proven technology to "custom fit" solutions to individual buildings and achieves the zero-carbon target.

Proposed enhancements to the system incorporate emerging technologies aimed at reducing operating costs. Staging the implementation achieves the zero-carbon target by 2035, reduces 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, MACA 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 and consideration. We look forward to your questions and the opportunity to provide more details. We also welcome the opportunity to help any of the MIT groups or committees working on decarbonization.

The MACA Campus Team
MIT Alumni for Climate Action

Primary Contact:
Susan Murcott
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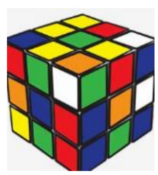
Overall Project Mission Statement/Goals

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, often with sometimes 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 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 where possible to planned building upgrades
- Reducing financial risk by achieving a payback of <10 years, in part by ensuring eligibility for IRA funds (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 low-cost pilot would convert six (6) buildings on west campus to an innovative HVAC system that uses the same 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 and Kresge; (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 low-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 and 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 was 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 ~$10-11 million gross ($7-8 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.

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 the 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 with them 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.

PROPOSED PROGRAM: CONCEPT OVERVIEW

The following paragraphs outline key features and issues associated with the proposed system. For those interested, more detail is available, including a personal briefing.

Custom-Fit with Limited Components. The proposed decarbonization plan shifts the operation of 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 as 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 substantial power needed to operate ASHPs, including peak-load demand charges.

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 appear to account for up to 50% of all HVAC-related energy consumption. Eliminating these losses is a relatively straightforward application of WSHP's. 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.

Given that 100+ buildings on campus were included in decarbonization planning, our preliminary estimate is for 10 districts, each with about 10 buildings. We have sketched out preliminary districts, but the proposed building assignments need to be reviewed in more detail with Operations Management. The "districts" will disappear once the campus-wide system is complete.

Using Existing Infrastructure to Reduce CapEx. By converting the existing chilled-water loop to an ambient water loop, time to convert buildings is reduced, disruption to campus activities minimized and capital requirements reduced. The ambient loop will serve heat pumps, whether cooling or heating.

Ground Coupling Enhancement Options to Significantly Reduce OpEx.

Modern decarbonized buildings reduce potential system OpEx by utilizing some amount of ground heat exchanger (GHEX). What we are proposing as a ground heat exchange is much different than "conventional geothermal" approaches, which require significant space and cause much impact.

Our plan utilizes low impact options that can be installed incrementally and spread "invisibly" throughout campus.

Our proposal includes four (4) complementary, cost-effective "enhancement" 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: 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 the WSHPs needs to be warmed or cooled, transfer from the Cambridge pipes is completed using highly reliable, low-cost, commercial "heat exchangers."

A test performed with Cambridge Water Department is scheduled spring 2024 to determine if a link between the MIT water loop and the Cambridge system satisfies environmental regulators and meets performance expectations.

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

NOTE: #3, #4 are under consideration for later years. Both require additional analysis.

Enhancement #3. Angle Boring is a new installation technique which dramatically reduces the surface area required for installation. A firm with this ability 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 to precision directional boring 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 over 100 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 in 2024 and a pilot program started in 2025. The likely final decision on the approach to decarbonization should be apparent part way through the pilot, ideally by the end of 2025.

Information available for key decisions to evaluate proposals should include:

- availability 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 of a building is repurposed
- assessment of plans to mitigate operational and financial risk
- date when zero-emissions will be achieved, including target percent achievement by year
- team members' background and experience developing and implementing similar plans.
- lessons learned from previous projects.

TIMELINE FOR APPROVAL AND STAGED IMPLEMENTATION

CY2024	CY2025	CY2026-27	CY2028-29	CY2030-31	CY2032-33	CY2034-35
OK Pilot	Pilot 6 Bldgs	20 Buildings	20 Buildings	20 Buildings	20 Buildings	20 Buildings
Ok Vendors	Measure	20% Done	40% Done	60% Done	80% Done	100% Done

With such information, MIT staff and some workgroups could approve in 2024 for pilot program(s) to begin in 2025. Expenditures by period are reasonable estimates for discussion. More analysis and discussions with Operations Management 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.

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 113 buildings is about $250 million. With IRA funds, the net cost is about $175 million, slightly higher than the estimate associated with the MIT GeoTeam submission for the DOE Competition. (Top-line timed project budget)

The project cost estimate is based in part on building data from MIT Operations. 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 net cost estimate of $175 million is reasonable given the limited information that is currently available. The net cost assumes nearly all CapEx will qualify for a 40% rebate under the Inflation Reduction Act.

However, we also believe the cost estimate is reasonable even without the IRA funds. 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, cost 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 Operations 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 source for the heat pumps.

However, there are 20 buildings not connected to the chilled-water loop. If those steam pipes cannot be repurposed, connecting to the ambient loop would cost an estimated $15 million.

Table 1 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	Thermal, Drilling			$ 7.5
CapEx	Thermal Batteries			$ 7.5
	Sub-GHEX System		$ -	$ 15.0
CapEx	CW Loop Extension			$ 15.0
CapEx	Cambridge Water Link			$ 15.0
	Sub-Infrastructure			$ 30.0
OH	Engineering / OH	15.0%		$ 24.0
OH	Other Expenses	15.0%		$ 24.0
	Sub-Total Detail			$ 207.8
	Contingency	20.0%		$ 41.6
	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	CWater	7,669,747

Table 2 Timed Budget 2025-2035

Top-Line Timed Budget for Project

Expenditures	$ 11M	$50M	$ 50M	$ 60M	$ 45M	$ 34M
Cumulative	*$ 11M*	*$ 61M*	*$ 111M*	*$ 171M*	*$ 216M*	*$ 250M*
					Net with IRA Funds	~ $ 175M

Ref: 24 03 06 MACA Campus Decarb Intro Doc and Bus Plan

Hardware and Installation: Based on information from MIT Operations, 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 residential.

Cost for purchase and installation of heat pumps was assumed to be $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

Enhancement 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 agreement has been reached. MIT's support for the proposal would increase the likelihood of success.

While more analysis is needed, we believe the heat transfer system would have a gross cost of about $15 million ($9 with IRA funds) and could help reduce annual OpEx for electricity.

Enhancement Option #2. Even if the link to Cambridge Water exceeds anticipated needs, we believe MIT should consider installing some shallow-depth thermal batteries (<100' below the surface).

Like Cambridge Water, the batteries are linked to the ambient water loop. Installation can be coordinated with or separate from the heat pumps. This thermal battery has not been used widely; test results have been positive.

The $15.0 M cost is a best guess based on discussions with an executive of the drilling operations of a major oil-and-gas exploration and service company familiar with the geological formation and backfill overburden of MIT's campus.

Options #3 & #4 – costs to be determined with additional analysis. Neither option is included in the project cost estimate.

Engineering and Other Overhead were each estimated at 15.0% of all Capital Expenditures, including engineering optional enhancements #1, #2. The estimates are probably on the high side.

Contingency: while we tried to be conservative in estimating all costs, we also believe it prudent to include a line item for contingencies. 20% is applied to all costs.

IRA FUNDING POTENTIAL: The opportunity with the IRA is 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 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 3 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.

Calculating Expected Savings in OpEx.
We have reviewed other projects using WSHPs to get some idea of possible savings in operating a distributed HVAC system. Industry experience shows that WSHPs coupled with a geothermal heat exchange system reduced annual OpEx enough to result in a payback of 5-10 years. Payback would be less with IRA funds.

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 50% less than a proposal based on a centralized system.

The estimate needs to be refined and reviewed in more detail with Operations Management 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 reinstallation time and cost. Furthermore, the risk of interruption to campus activities will be reduced by a decentralized system.

AVAILABILITY OF ELECTRICITY.

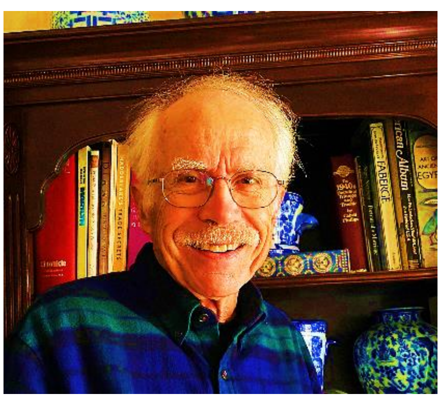
Many unknowns remain about potential disruptions to electrical supply from solar and wind. We agree MIT should consider a back-up system to ensure uninterrupted service, particularly to critical labs. The type and location of such a system does not affect analysis of which approach to decarbonize campus is the most effective.

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.

Rick Clemenzi ’81, Computer Engineering
Judy Siglin, MACA Affiliate.

Rick Clemenzi is a Systems Engineer specializing in Advanced Thermal Systems. He is the principal engineer at Geothermal Design Center a licensed geothermal specialty engineering firm, and co-founder of Net Zero Foundation along with Judy Siglin who has backed their undertaking in this non-profit development. Geothermal Design Center is focused on 5th and 6th Generation Advanced Geothermal Heat Pump applications, and Net Zero Foundation is working for the fastest overall path to energy decarbonization. See also https://www.linkedin.com/in/rickclemenzi/. As the Net Zero Foundation, they won the 2016 MIT Climate CoLab MIT Campus Decarbonization competition presenting a geothermal district heating and cooling (GDHC) solution specifically targeted to MIT's campus. Rick is also a Certified GeoExchange Designer (CGD) and sits on the C-448 ANSI/CSA Bi-National Ground Source Heat Pump Design and Installation Standard's Technical Committee. Rick and Judy are members of MIT Alumni for Climate Action. Rick Clemenzi rickclemenzi@gmail.com]; Judy Siglin judysiglin@gmail.com



John R. Dabels SM ’79 Sloan

A major portion of career split between: (i) helping guide the development and launch of a range of capital-intensive products, mostly automotive related but also military aircraft. Environmental-related products include electric vehicles (GM EV1), electric motorcycles, electric bicycles, hybrid-electric buses; (ii) conducting financial analysis or operating as CFO/CEO in several larger and smaller companies. Also, investor in several start-ups.
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Susan Murcott ’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 Lecturer at D-Lab/ (D-Lab “advances collaborative approaches and practical solutions to global poverty” as well as engaging students in project-based learning as it relates to design, development and dissemination of innovations).

Beginning in 2020, student teams from D-Lab have created the MIT Climate Clock. See: https://web.mit.edu/CLIMATECLOCK/#future This spring 2024 will be the 9th year Susan co-teaches D-Lab “Climate Change and Planetary Health” (EC.719/EC.789). One focus of climate action is the emphasize on rapid decarbonization of MIT’s campus, targeting 2035 as a do-able goal. Susan has significant experience mentoring students in design and innovation. See videos: http://globalwater.mit.edu/videosvv Susan Murcott murcott@mit.edu

Shiladitya DasSarma, ‘84, Biochemistry

Shiladitya DasSarma, PhD ‘84, Biochemistry. After his PhD from MIT with Nobel laureate HG Khorana and postdoc at the Massachusetts General Hospital, Harvard Medical School, Dr. DasSarma has served on the faculty of the University of Massachusetts Amherst and the University System of Maryland for nearly 40 years. As a Professor at the University of Maryland School of Medicine, he developed an interprofessional course entitled “Climate Change, Health, and Society” for medical and law students. His research lab at the Institute of Marine and Environmental Technology in Baltimore concerns the impacts of climate change on society, life in extreme environments and the mechanisms of cell survival after environmental stress. He is Founder and President of the MIT Alumni for Climate Action (see: https://maca.earth) and was awarded the Margaret McVicar Award for his leadership on climate action by MIT. See his recent interview with the New York Times on impacts of climate change in Hawaii (https://www.nytimes.com/2023/11/11/us/hawaii-kaelia-pond-pink.html

David T. Williams MIT '82, Mechanical Engineering Dept. Principal, Senior Mechanical Engineering, Sustainability Specialist, LHB Corporation

David attended MIT from 1977-1982 pursuing a course in Mechanical Engineering with a strong interest in building systems. At the time courses of this nature were few in number and collaboratively taught with the School of Architecture, to such an extent he did an IIA option to take more architectural courses. He took a memorable course in HVAC taught by an architect, Harvey Bryan, where he studied heat pump systems design. (Harvey Bryan also taught the solar energy design course that David took). Additionally, David did his bachelor's thesis with Dr. Tom Bligh where he did some testing to support energy modeling of underground buildings heat loss to the ground (DOE2 software). All these experiences led to a keen interest in energy efficient building design, which he has done for most of his 40+ year professional career 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. Some of the highlights of David's career include developed a concept for K-12 schools in northern climates to use Thermal Displacement Ventilation along with distributed air handling equipment and low temperature (140-100F) hot water serving radiant floors to improve thermal comfort and reduce heating energy use by over 50% from business-as-usual. Additionally, he was involved in developing ground source heat pump loop field concepts that the MN Department of Health agreed were not under their jurisdiction, allowing more flexibility in installation in large commercial systems. toshio@alum.mit.edu

Herb Zien '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. The business was sold to Veolia Energy for $800 million and Herb is now Vice Chair of LiquidCool Solutions, which holds 63 patents on rack-based immersion data center cooling technology. In addition, recognizing that District Energy Systems that sell steam and hot water are inefficient and incompatible with decarbonization initiatives, he is developing geothermal heating and cooling systems for commercial buildings and micro districts. hbzien@gmail.com

<u>Tunca Alikaya,</u> ’24 E-MBA, Sloan

A Geo@MIT team member and MACA partner. Employee Nov. 2011 – present of Schlumberger/Celsius Energy, 1 Hampshire Street, Cambridge MA *“The world’s leading technology provider for reservoir characterization, drilling, production, and processing to the oil and gas industry.”*

Director of Drilling Operations and Business Development
Cambridge MA, USA | October 2021 – Present
Commercial Traction & Drilling Operations Management

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. Working with a prestigious East Coast University while contributing to the global decarbonization. Steering shallow geothermal drilling operations to its next level in US.

<u>Geo@MIT Student Team</u> worked tirelessly with Susan Murcott and MACA team members, particularly Rick Clemenzi and Judy Siglin to develop a comprehensive campus decarbonization plan for submission to a competition sponsored by US Department of Energy. Many elements of that submission are incorporated in the MACA decarbonization plan. We sincerely thank the GEO Team for all their efforts. They are a credit to MIT.

- Megan Lim, MIT, Undergraduate, Sloan School of Management
- Jason Chen, MIT Undergraduate, Mechanical Engineering
- Olivia Chen, MIT Undergraduate, Mechanical Engineering

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 multi-faceted and requires a systems approach	Other plans being considered so we can provide objective comparison and/or help w/ analysis
Pilot program and staged implementation reduce risk and uncertainty	OpEx savings – projected 50% reduction needs to be confirmed with more current data from Operations Group
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	
Water-source heat pumps are: ▪ Highly efficient ▪ Highly reliable ▪ Durable – over 20-year life	
Converting chilled water loop to ambient reduces capital expenditures and increases overall efficiency	
Optional enhancements reduce OpEx for electricity	
MACA team has extensive HVAC project design and implementation experience	

Glossary of Terms/Short Answers

- 4th and 6th Generation District Heating and Cooling – 4th Generation implies a highly Central Plant focused approach with a 4-pipe Hot Water and Chilled Water distribution system to buildings. 6th Generation implies a highly distributed approach, possibly with some central plant capabilities, including multiple energy use, recovery, and storage capabilities, and with a system management approach which focuses on resilience and operational cost reduction.
- 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 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. Capital expenditures currently 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. For the MIT proposal, expenses for designing, 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 criteria 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.