

An aerial photograph of a city skyline at sunset. The sky is filled with orange and yellow clouds. In the foreground, there are several buildings, including a large brick building with many windows and a smaller building with a green roof. In the background, a tall clock tower is visible. The overall scene is a mix of urban architecture and natural light.

SUMMARY REPORT

UNIVERSITY OF MICHIGAN

Carbon Neutral Power & Heat Infrastructure Study

Prepared by Integral Group

750 17th Street, NW | Suite 200
Washington, DC 20006

200 Granville St – Suite 180
Vancouver, BC Canada V6C 1S4

54 W 40th St
New York, NY 10018 United States

November 2020

Copyright © 2021 by the Regents of the University of Michigan
Some rights reserved



This work is licensed under the Creative Commons Attribution-NonCommercial-NoDerivatives 4.0 International License. To view a copy of this license, visit <http://creativecommons.org/licenses/by-nc-nd/4.0/> or send a letter to Creative Commons, PO Box 1866, Mountain View, California, 94042, USA.

Published in the United States of America by
Michigan Publishing

DOI: <http://doi.org/10.3998/mpub.12106210>

ISBN 978-1-60785-692-4 (open access)

This publication is a result of work sponsored by the University of Michigan (U-M) President's Commission on Carbon Neutrality (PCCN) to inform the PCCN's final recommendations to U-M President Mark Schlissel. This publication does not reflect Commission-level recommendations, and should not be interpreted as being recommendations of the PCCN nor carrying its endorsement.

PROJECT SCOPE

Integral Group's scope for this project, which reported to the U-M President's Commission on Carbon Neutrality (PCCN), was broken down into two basic phases. Phase 1: Establish energy baselines and explore the range of carbon neutral options. Phase 2: Refine these options, model outcomes, and design solutions at the conceptual level.

For the purposes of this study, U-M's Ann Arbor campus was characterized by four sub-campus. Medical Center was considered part of Central Campus; NCRC was considered part of North Campus. U-M Dearborn and U-M Flint were also included in the scope of this project.

ACKNOWLEDGMENTS

Integral would like to especially acknowledge Andrew Berki, Andrew Horning, Kevin Morgan, Jim Adams, Malcolm Bambling, and Lydia Whitbeck for their ongoing and robust collaboration, guidance, and feedback during the development of this study.

AUTHORSHIP

This report was prepared by the following members of Integral Group:

Sam Brooks, Principal

Vladimir Mikler, M.Sc., P.Eng., LEED AP, Principal

Natalie Vadeboncoeur, M.Sc., P.Eng., Associate

James Perakis, Associate

Jennie Kim, Mechanical Designer

Eric Van Nus, Mechanical Designer

LIMITING CONDITIONS

This report is intended solely for the University of Michigan. The recommendations presented in this report represent the professional opinions of Integral Group in light of the terms of reference, the scope of work, and any limiting conditions noted herein. Any use of the report, reliance on the report, or decisions based upon the report, by a third party, are the responsibility of those third parties unless authorized in writing by Integral Group. The University of Michigan has copyright permission for the reproduction and distribution of this report.

TABLE OF CONTENTS

PAGE	CONTENT
1	PROJECT & REPORT OVERVIEW
1	STRATEGIC OVERVIEW
3	ASSUMPTIONS
3	RISKS & UNKNOWN S
5	PROPOSED SOLUTION S
10	SOLUTION MATRIX
11	CAMPUS-BY-CAMPUS SPECIFIC S
15	PHASING & IMPLEMENTATION
18	CONCLUSION
19	WEB-BASED PROJECT PLATFORM

PROJECT & REPORT OVERVIEW

The University of Michigan, through the President's Commission on Carbon Neutrality (PCCN), has undertaken a comprehensive initiative to explore options and develop strategies to achieve carbon neutrality. To address its power and heat infrastructure — a key component of this path towards zero emissions — U-M engaged Integral Group to (i) assess the feasibility of carbon neutrality; and (ii) develop a vision, plan, and timeline for significant reductions in greenhouse gas (GHG) emissions.

This Summary Report is a companion document to Integral Group's full report, "Carbon Neutral Power & Heat Infrastructure Study." Integral Group has also created a web-based project platform that allows users to visualize and interact with the project's findings. This website can be accessed via the following URL: <https://www.elementa.nyc/projects/michigan/interactive/>

STRATEGIC OVERVIEW

*A transition to carbon neutral energy systems will require **foundational** changes to U-M's built environment.*

The University's energy systems are the product of generations of investments and planning. This infrastructure works well: lights turn and stay on; buildings are comfortable; hospitals' thermal needs are met. Any effort to transform this system faces inherent inertia towards a status quo that has served its purpose — until now.

The power and heat infrastructure that serves U-M's 37 million square feet of real estate has a carbon footprint equivalent to roughly 80,000 homes. Nearly 1 million acres of US forests would be required to sequester the annual CO₂ emissions from the U-M built environment.

While unwinding, recalibrating, and replacing this infrastructure will not be easy, the risks of a warming world demand change. Leaders and innovators must step forward — to meet this challenge and create a more sustainable built environment.

CHALLENGES

At its core, this study and its proposed solutions have two primary goals, in order of importance: (i) eliminate or reduce natural gas consumption; (ii) decarbonize electricity supply, with U-M's available levers. The nature of the campus also presents particular challenges.

Cold Weather + Energy Intensive Facilities. Reducing emissions is difficult in cold weather climates. Traditionally, the combustion of natural gas and oil has been a relatively easy means of generating enough thermal energy to heat buildings; using electricity to create sufficient heat is much more difficult. Thus, all else being equal, decarbonization in Ann Arbor, MI is more challenging than it is in more temperate climates.

Apart from the weather, the University of Michigan also faces significant challenges to meet the thermal needs of its many health-care and research facilities. Due to the differences in user needs and services provided, for instance, inpatient health care facilities tend to require much more energy capacity than general office buildings or classroom facilities.

Natural Gas. Natural gas, a fossil fuel that emits heat-trapping GHGs, provides the majority of U-M's energy (including the majority of its thermal energy). It is a reliable and cheap fuel that is often tied to significant previous capital investments. Eliminating or reducing natural gas consumption will be difficult.

Electricity. Electricity for campus consumption is also carbon intensive. Within U-M's grid, nearly two-thirds of power generation comes from coal- and natural gas-fired plants. Yet, electricity is fundamentally different than natural gas: now-mature technologies can produce electricity without GHG emissions.

At the same time, on-campus options for eliminating GHG emissions from electricity are relatively limited. Rooftops and parking lots provide opportunities for solar panel installations, but even in the most optimistic scenarios, onsite solar provides a moderate portion (likely less than 15%) of the University's power needs.

Credits and Offsets. Renewable Energy Credits (REC) are sometimes used to claim "100% renewable" power, but the impact of REC purchasing is dubious. As many observers note, RECs often play a negligible role in the deployment of solar and wind resources. Further, offsite renewables only work on a "net" basis; the generation profiles of intermittent renewable resources do not match the real-world demand profiles of buildings and campuses.

Biofuels. Replacing carbon-intensive natural gas with arguably "carbon free" gas is a technically viable option. In Michigan, this most commonly takes place by switching from natural gas to Renewable Natural Gas (RNG), which typically sources gas from landfills and prairie farms (i.e. Concentrated Animal Feeding Operations, or "CAFO"). As a part of this project, Integral performed due diligence on the local market and potential vendors.

Biofuels are unlikely to meet the University's needs and goals for at least three reasons: (i) RNG is currently very expensive, sometimes 5x(+) more costly than natural gas; (ii) Landfills and prairie farms are a relatively limited resource for bio-gas production; given this fact, RNG presents both reliability (i.e. lack of fuel availability) and financial (i.e. rising prices because of limited supply) risks; (iii) Utilization of onsite materials (e.g. food waste for conversion to gas) cannot meaningfully address U-M's total energy needs. For these reasons and more, biofuels are at odds with the PCCN mandate to develop solutions that can scale and transfer to other institutions and communities.

Carbon capture. While technology to capture and store carbon emissions exists, the market remains nascent and does not offer a realistic solution. During several site visits to prospective pilot projects — ranging from algae-based carbon capture to negative cement — the project team was left with two strong impressions: (i) the technology shows some promise; (ii) the technology is not yet ready to scale to meet the needs of an institution like U-M. If and when the technology effectively commercializes (i.e. becomes technologically and financially feasible), carbon capture faces a final hurdle to achieve true carbon neutrality: continued reliance on natural gas (i.e. if U-M were to keep its natural gas infrastructure) can negatively impact the climate, given the considerable impact of extraction and so-called ‘fugitive’ GHG emissions.

ASSUMPTIONS

The costs and impact of the proposed solutions for the University of Michigan must be understood in the context of two basic strategic assumptions, both essentially first principals in the arena of carbon neutrality:

1. Climate change poses an existential risk to humanity
2. The arc of human progress and ingenuity points toward the mitigation of this risk

The leap of faith with this latter assumption — that governments, behaviors, and economies will ultimately address climate challenge — is essential to embark down the path of carbon mitigation, in the first place. If reducing emissions and stabilizing heat-trapping GHGs were viewed as aspirational but unrealistic global goals, rational actors would instead focus their resources on adapting to the consequences of catastrophic global warming.

STRATEGIC ASSUMPTIONS - IMPLICATIONS

These two core assumptions suggest that a restructuring of the financial, policy, and regulatory landscape is inevitable. Fundamental changes in these areas could range from carbon taxes to outright fossil fuel bans. (Such bans are already happening in some jurisdictions in CA, where natural gas infrastructure is banned for new buildings.) Assuming that the world does, in fact, see regulatory and market restructuring, the technological and financial implications could be extraordinary.

RISKS & UNKNOWNNS

The proposed project would represent the largest energy transformation of this kind — likely ever, anywhere in the world. The inherent challenges of such an endeavor are truly extraordinary. And because there is no playbook for a project of this kind, the true range of risks and unknownns is impossible to predict.

LIMITATIONS OF TRADITIONAL FINANCIAL ANALYSES

Difficulty predicting future commodity prices. Always a difficult process, forecasting future energy costs (e.g. natural gas, electricity) during a time of potential upheaval in energy markets (i.e. due to COVID-19) is particularly difficult.

Importance of widening the lens on potential risks. Acknowledging the profound qualitative financial risks with traditional energy infrastructure — specifically, the risk for U-M to continue with Business-as-Usual (BAU) and purchase fossil-fuel-based energy — is central to understanding this report’s proposed solutions and their financial prudence.

Asymmetric future price risk. Integral posits that the distribution of outcomes for future energy prices should look asymmetric. Rather than a bell-curve-like profile, it is more likely that outcomes of skyrocketing energy prices are more likely than the other end of possible outcomes, where prices may simply stay the same or go modestly lower.

Unfortunately and unsurprisingly, though, widely-accepted forecasting for energy markets does not capture the aforementioned macro risks. As is common with reports of this nature, Integral’s Life-Cycle Cost Analysis (LCCA) for this project rests on conventional forecasts, including the US Energy Information Administration’s (EIA) Annual Energy Outlook (AEO).

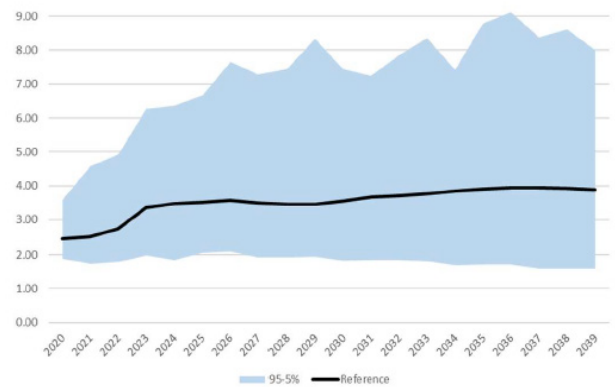


Chart above: stochastic modeling for possible future natural gas prices — showing an asymmetric view of possible gas price outcomes, with greater risk of much higher prices. [Siemens, 2020]

The 2020 AEO’s “high price scenario,” used in this project’s LCCA, projects just 3% annual growth in energy costs over the next 30 years. Given the market-changing risks identified above, this band of probable outcomes could be far too narrow. It is not hard to imagine scenarios in which fossil fuel-based energy prices double, or even much more, over the course of a decade.

TECHNOLOGICAL ADVANCES

The next energy revolution. Moving forward, energy technology breakthroughs could surface in myriad areas. Ultra-high density storage could change the nature of intermittent solar and wind; new building materials could enable game-changing efficiency retrofits; hydrogen power could transform energy generation. Step-change progress in any of these areas could have a massive impact on the ability to decarbonize energy supply. As noted below, the energy world has a history of changing quickly and dramatically.

*"In short, we need
an energy miracle
[for climate change].
When I say 'miracle,' I
don't mean something
that's impossible. I've
seen miracles happen
before."*

- Bill Gates, Annual Letter, 2016

Energy markets are incredible difficult to predict: an example. Through the mid 2000s, fracking was virtually unheard of. Natural gas import terminals were under construction — because most experts warned of natural gas scarcity. In June 2005, natural gas cost \$7/MMBtu. By June 2008, with continuing concerns about natural gas supply, prices spiked to \$13/MMBtu. Around that time, energy companies discovered that a perfect mix of injected fluid and horizontal drilling extracted fuels from underground “shale” formations. The energy world was shocked. Oil and gas were not supposed to come out of dense rock, but they did. Commodity markets turned upside down. The US is now an exporter of natural gas, with excess supply plummeting prices. As of June 2020, natural gas is \$1.75/MMBtu.

Will clean energy have fracking-like revolutions? Some observers reasonably argue such transformations — ranging from storage to hydrogen — are inevitable.

PROPOSED SOLUTIONS

SOLUTIONS

Electrification. At present, the most technically and commercially viable option for Michigan to decarbonize its infrastructure for heat and power: renewable electricity, combined with geo-exchange to efficiently support thermal needs. Successful campus electrification will require foundational physical changes and the procurement of renewables, but this is an achievable solution that delivers the PCCN’s mandates.

Electrification also ‘future proofs’ U-M for technological advances in coming years. New forms of renewable power generation and storage could enable increased onsite renewable power generation, in addition to easing the regional grid’s transition to renewables.

The electrification of the campus — the optimal low-exergy path to carbon neutrality — is feasible for two primary reasons: (i) campuses have reasonably balanced demand for heating and cooling throughout the year; (ii) campuses have large plots of land for geothermal heat exchange (GHX).

Geo-Exchange. Integral recommends a low-exergy option that involves GHX with heat recovery chiller technology (GHX/HRCH). This option requires an eventual campus-wide conversion from steam distribution to medium temperature hot water (MTHW) distribution, as well as the construction of new cooling distribution networks. This also requires the conversion of high temperature building heating systems to accommodate MTHW.

Each campus or district will require a new centralized GHX/HRCH plant (or nodal plants) that ties into a new geo-field, with the scale of boreholes and piping driven by the size of the campus and its thermal load. In total, Integral estimates nearly

20,000 boreholes, with most going below ground by roughly 600 feet. During the winter, the GHX/HRCH plants will use electricity to extract heat from the Earth to heat the campus. During the summer, the plants will recharge the Earth with waste heat generated from cooling the campus. The Earth effectively acts as a battery that stores heat, helping buffer against mismatched heating and cooling loads over the course of a year.

The scale of the proposed geo-exchange project is notable. Ball State University's geothermal district system is the largest operational geothermal district system in the US; that campus has 3,600 boreholes. A notable project at the American University in Madaba, thought to be the largest in the Middle East, boasts 420 boreholes. The plant at Vancouver International Airport, likely the largest in Canada, has 841 boreholes.

*"Emissions reductions are driven by a clear tempering of energy demand and a **strong electrification of the buildings sector**... Electrification contributes to the reduction of direct CO₂ emissions by replacing carbon-intensive fuels."*

- Intergovernmental Panel on Climate Change (IPCC); "Mitigation Pathways Compatible with 1.5°" (2019)

Improved energy system efficiency. The transition to GHX/HRCH also dramatically increases the campuses' thermal efficiency. The analyses estimated a ~65% reduction in overall thermal energy use, driven by two main factors: (i) Higher thermal efficiency: heat recovery chillers are ~300% efficient, while combustion is ~80% efficient; (ii) This type of plant moves heat around a campus efficiently — optimizing the movement of thermal energy from where it is generated to where it is needed.

Considering both thermal and non-thermal energy use, the proposed solutions would decrease energy consumption by 47%. In the Business as Usual (BAU) case, all campuses use the equivalent of 1.98M MWh/year in steam, natural gas, and electricity; with proposed solutions, U-M would use 1.06M MWh/year.

Reduced utility costs. The improved system efficiency and its resulting reduction in energy demand has one clear and straightforward benefit: reduced utility costs. Even with electricity costs high relative to natural gas (5x + on a \$/BTU basis), the total reduction in energy demand is so high that overall utility costs will decrease.

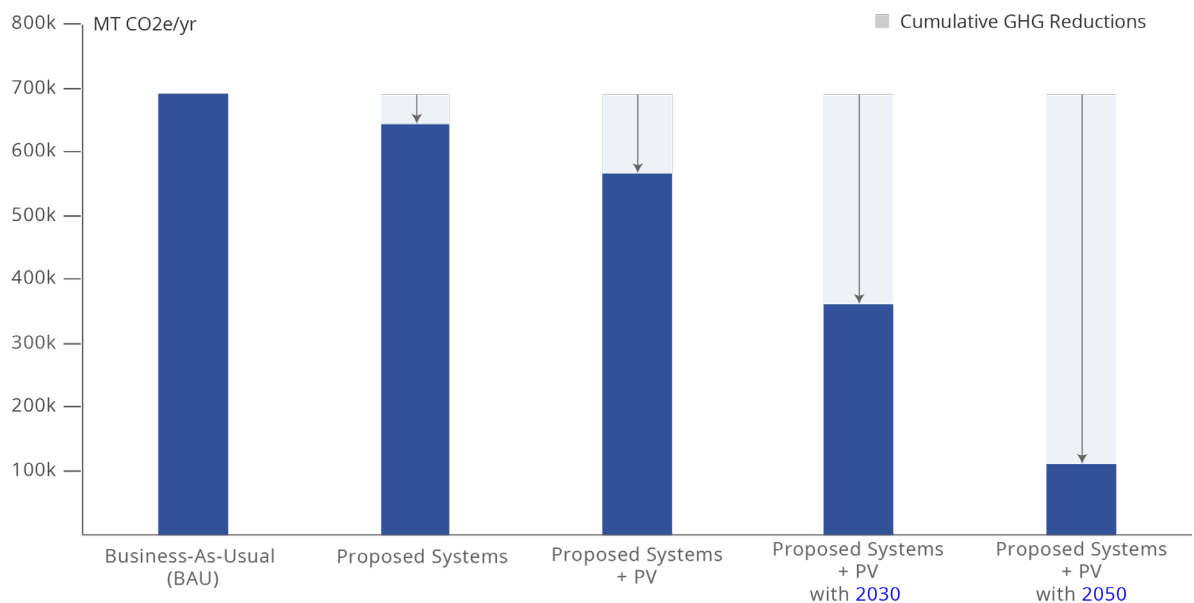
Using traditional commodity price assumptions, U-M is estimated to save \$1.6B in operating costs (due to utility expenditures) over the first three decades. With a hypothetical carbon tax of \$150/ton, the savings could more than double (assuming the decarbonization of DTE electricity achieves its intended goals).

GHG EMISSIONS

Due mostly to these three core components — electrification, geo-exchange, and improved system efficiency — the proposed solutions would put U-M on a path towards carbon neutrality with its power and heat infrastructure.

Due in large part to the tremendous gains in overall thermal efficiency, the proposed solutions would have a big impact. Despite the increase in electricity use, the transition away from on site co-generation, and the fact that the 2020 DTE grid is 50% more carbon intensive than on site co-gen, the proposed solution still results in a present-day 30% reduction in building GHG emissions.

TOTAL BUILDING GHG EMISSIONS REDUCTIONS



CAPITAL COSTS

While the scope of the report falls short of detailed cost estimates that would accompany the next phases of engineering (e.g. design development (DD)), Integral developed initial estimates based on market intelligence and experience with similar projects.

Integral's estimated cost for the entire proposed project (in 2020 dollars): \$3.5 billion. Estimated capital costs of new energy infrastructure across U-M can be seen on the following page.

(dollar figures in millions)

Campus	Central	Athletic	East Med	North	Dearborn	Flint
Thermal systems	\$925	\$254	\$37	\$523	\$76	\$58
Solar PV	\$24	\$31	\$18	\$79	\$49	\$27
Bldg conversion	\$312	\$47	n/a	\$94	\$16	\$94
Contingency	\$378	\$101	\$19	\$208	\$43	\$54
TOTAL <i>With Contingency</i>	\$1,639	\$433	\$74	\$904	\$184	\$233

Note: electric infrastructure costs omitted. While outside of the scope of this initial study, Integral recognizes there could be considerable costs associated with the campus' proposed electrification. Future collaboration with Ann Arbor's local electric utility, DTE, is necessary to better understand and identify the necessary improvements and costs

RETURN ON INVESTMENT

While the proposed energy system transformation would result in lower utility costs for each campus (as noted, above), the upfront capital costs of the prospective transaction are massive. Seen through a traditional lens with standard assumptions, the payback is long. Using traditional analysis, the nominal payback period would be 61 years; the 30-year NPV is (\$2.01B). A typical lens, however, may not fully describe the potential financial implications of this project — or, said differently, of maintaining the status quo.

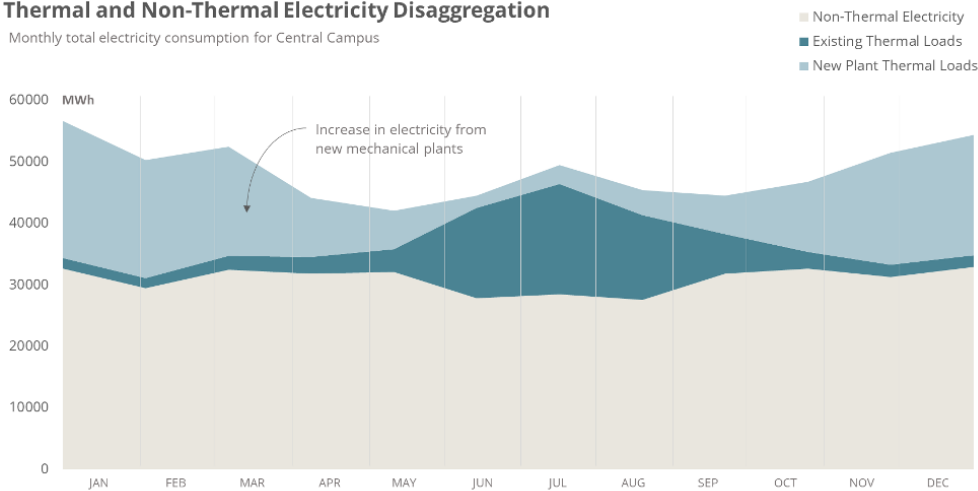
Impact of strategic assumptions and other factors. A number of external forces could significantly impact the financial performance of the proposed project. Several of the key assumptions driving the financial analysis could swing considerably — potentially to U-M's benefit if a carbon neutral path is pursued — as pressure to act on climate change drives foundational changes in technologies, markets, and public policies and regulations.

- *Capital costs.* The Life-Cycle Cost Analysis (LCCA), naturally impacted by proposed capital costs, is conservative in this area in two key ways:
 1. *Conservative bias to assumed capital costs.* Some of the big component costs — such as building conversion and borehole drilling — could swing considerably after (a) further detailed engineering study, which could identify new challenges or opportunities; and/or (b) a competitive procurement process that could drive lower prices; and/or (c) markets fundamentally change with new entrants and innovation.
 2. *No assumed technological advances.* Clean energy technologies and techniques continue to improve and, in general, reduce capital costs.

- *Carbon tax.* A hypothetical carbon tax (e.g. resulting from future legislation or regulation) would have a significant impact. A \$50/ton fee reduces the simple payback period to 49 years; \$200/ton cuts it to 31 years.
- *Natural gas prices.* If prices were to escalate to the 95% percentile of Siemens 2020 stochastic modeling (see chart on page 4), the payback period would shrink by 14 years. (Note that a carbon fee can serve as a good proxy for potential natural gas price movements.)
- *Cost of capital.* A change in the assumed discount rate has an impact, although modest, on the proposed project's economics. At 4%, the total project NPV is (\$2.01B); at 6%, the NPV falls to (\$2.26B).

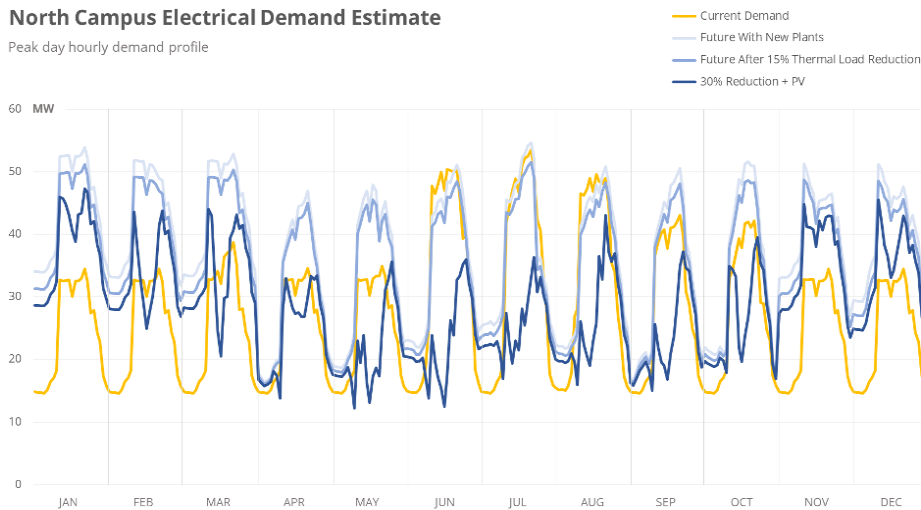
Thermal and Non-Thermal Electricity Disaggregation

Monthly total electricity consumption for Central Campus



North Campus Electrical Demand Estimate

Peak day hourly demand profile



DISTRIBUTION GRID IMPACT

The all-electric geo-exchange solution will naturally increase electricity demand and, to some extent, peak electricity consumption. The latter is particularly important with respect to the local and regional grid, as electrical infrastructure is often built in accordance with peak levels.

Interestingly, given the enormous overall energy system efficiency improvements — driven by the move to geo-exchange and low-temperature thermal — the impact on *peak* load is relatively muted. As seen in these charts, wintertime electricity use increases considerably with the proposed GHX solution, but, on most campuses, these peaks are only modestly higher than current summertime peaks.

The ultimate impact on the grid will be determined by the extent to which U-M generates this electricity on campus (via existing plants or onsite solar or future tech) or DTE provides it via traditional plants on the centralized grid. In neither scenario, though, will the campus require significantly increased generation capacity.

DECARBONIZATION - SOLUTION MATRIX

Option	Benefits	Limitations / Risks	Long-Term Outlook
Electrification	<ul style="list-style-type: none"> Mature technologies (e.g. solar, wind) can produce zero-carbon and increasingly cost-effective electricity Most climate scientists, including those involved with the Intergovernmental Panel on Climate Change (IPCC), believe electrification of the building sector is a vital component of a pathway to <2° global warming 	<ul style="list-style-type: none"> Intermittency of renewable power poses a big challenge: wind doesn't always blow and sun doesn't always shine when buildings need power While energy storage holds promise, batteries remain expensive Reliance on the centralized electric grid, with its bulk power generation and long transmission lines, can be less reliant than onsite Combined Heat & Power (CHP) 	<ul style="list-style-type: none"> While still the source of significant debate, an increasing number of energy modelers find credible pathways to 80%+ renewable energy Battery storage costs are falling; costs may drop below \$100/kWh by 2024 (from \$1,100 in 2010) A breakthrough in electricity generation, such as hydrogen or nuclear, would help catapult the penetration of zero-carbon resources
Biofuels / Biomass / “Renewable Natural Gas” (RNG)	<ul style="list-style-type: none"> Transition from natural gas to biofuels — such as RNG generated from landfills and farms — can leverage existing infrastructure; a “fuel switch” can achieve quick carbon reductions Biofuels often provide improved reliability relative to solar or wind generation 	<ul style="list-style-type: none"> Biofuel feedstock, including landfill gas and wood, is relatively limited; experts predict biofuels could only scale so far, satisfying just 10-15% of US thermal demand Biofuels face criticism about whether they are “zero carbon” in practice (e.g. wood “waste” has at times included forest clear-cutting) 	<ul style="list-style-type: none"> Because of inherently limited supply, increased demand in the biofuels market could work against itself: increased demand for biofuels would, almost definitionally, increase prices Biofuels suppliers, particularly those involving wood “waste,” may continue to seek loopholes in market requirements, minimizing carbon impact
Carbon Offsets	<ul style="list-style-type: none"> Carbon offsets — ranging from Renewable Energy Credits (RECs) to tree planting — provide a quick and often cheap path to decarbonization 	<ul style="list-style-type: none"> Real-world experience with carbon offsets is poor, often falling well short of decarbonization goals Many widely-accepted carbon accounting practices devalue or reject the use of offsets 	<ul style="list-style-type: none"> While directly reducing emissions — i.e. reducing onsite building emissions — will be a superior option, offsets could play a meaningful role in carbon mitigation if accounting standards tighten
Geo-Exchange (GHX)	<ul style="list-style-type: none"> Leveraging the earth's constant temperature vastly improves efficiency of electric HVAC equipment (e.g. heat pumps) 	<ul style="list-style-type: none"> Land constraints can limit viability Increased first-cost relative to other all-electric solutions (e.g. air-source heat pumps) 	<ul style="list-style-type: none"> Reduction in total life-cycle costs will continue to make geo-exchange attractive when land constraints not an issue
Onsite Solar PV	<ul style="list-style-type: none"> Mature technology Costs have fallen dramatically over the last decade (\$10/W to below \$2/W for commercial sector) 	<ul style="list-style-type: none"> Onsite solar is limited in its ability to generate high % of demand; even if every U-M roof and parking lot were covered with solar, unlikely to generate more than 20% of electric needs 	<ul style="list-style-type: none"> Increased panel efficiency may be as important as cost reductions — as efficiency improves, onsite solar can provide greater portion of energy demand
Solar Thermal	<ul style="list-style-type: none"> Tech, which heats water, has better efficiency than solar PV Improves GHX efficiency by reheating ground in winter 	<ul style="list-style-type: none"> Solar thermal is unable to meet significant portion of thermal demands on its own 	<ul style="list-style-type: none"> While more of a complementary (rather than primary) solution, solar thermal can play a meaningful role in key applications
Carbon Capture	<ul style="list-style-type: none"> Onsite carbon capture (e.g. using flue gas from onsite CHP) can provide carbon mitigation with minimal disruption to business-as-usual 	<ul style="list-style-type: none"> The carbon capture industry has seen little more than pilot projects thus far; critics argue carbon capture has long over-promised and under-delivered 	<ul style="list-style-type: none"> While an infusion of government R&D could change the dynamics, the carbon capture industry is far from proving commercial viability
Nuclear (Modular)	<ul style="list-style-type: none"> In theory, modular nuclear could provide extremely reliable onsite power generation 	<ul style="list-style-type: none"> Even at utility scale, nuclear remains very expensive; at modular scale, it's even more expensive at present Concerns remain about nuclear waste and safety 	<ul style="list-style-type: none"> While industry has a budget-busting history, it continues to see very significant R&D — with some investors confident costs will come down
Hydrogen	<ul style="list-style-type: none"> Hydrogen can be stored and transported, a big advantage over traditional renewables Converting hydrogen to heat and electricity produces no GHGs 	<ul style="list-style-type: none"> At present, most hydrogen production is natural-gas driven Costs remain very expensive relative to alternatives 	<ul style="list-style-type: none"> Some observers see a future in which hydrogen is generated at scale by solar (vs. natural gas) While industry needs breakthroughs, may hold most promise of “long shot” tech incl carbon capture, nuclear

CAMPUS-BY-CAMPUS PLANS

CENTRAL CAMPUS

Central, the largest U-M campus with respect to building square footage and energy use, poses inherent challenges with the tension between the density of infrastructure and limited land availability. However, the campus' diverse blend of building types — hospitals, laboratories, residences, and libraries — also present an opportunity: there are ample opportunities for heat recovery between buildings.

The baseline case for Central proposes a GHX/HRCH solution that uses Mitchell Field and the neighboring treed area marked for geothermal (8,900 boreholes total). This option involves the conversion from steam to medium temperature heating water (MTHW) of the campus distribution network and individual buildings. It also involves the creation of a new chilled water main distribution network. A new central plant will house a fleet of HRCHs that will provide both heating and cooling to the campus.

While Integral used Mitchell Field as a base case, another option exists, at least in theory: using city-owned land to the north of the campus, within and around Fuller Park. Such an arrangement would provide significant space for GHX fields, but several key challenges would need to be addressed: (i) the city, not U-M, owns the land; (ii) piping from the geo-fields would need to go underneath a railroad and a river to reach Central Campus' thermal distribution network. Piping systems of this kind are rare and the risks are relatively hard to predict.

ROSS ATHLETIC CAMPUS

The Ross Athletic Campus consists of almost 70 buildings divided between the areas north and south of the U-M golf course. The campus consists primarily of sports training facilities, including the football and basketball stadiums, aquatic center, ice arena, and indoor track facility, as well as administration buildings. While only the basketball stadium and indoor track facility have major chiller equipment, many of the remaining campus buildings have limited cooling provided by packaged rooftop units. As a result, the campus is heavily heating dominant. Fortunately, this campus has a large cooling load at the Yost Ice Arena that can help balance the campus's thermal demand and lend itself to a GHX/HRCH solution.

The proposed solution includes constructing a new central plant building near the Hoover Plant with GHX/HRCH, supplementary boilers, a new MTHW and CHW network, and a connection to Yost Ice Arena; additionally, supplementary solar thermal heating could be used to recharge and balance the geo-field.

The existing outdoor playing fields provide excellent spaces for geothermal. With the south end of campus is separated by almost a mile of golf course, Integral recommends that a dedicated nodal plant serve the southern group of buildings. The report assumed that most campus buildings will require mechanical system conversions to utilize the medium temperature water generated at the plant.

The proposed solution also includes the addition of solar PV. Solar canopies can be installed over parking lots and structures, providing enough capacity to offset 34% of the electricity demand of the new proposed system.

EAST MEDICAL CAMPUS

East Medical Campus in Ann Arbor consists of six core buildings, three healthcare and three data center type buildings, all currently served by standalone dedicated heating and cooling systems and purchased DTE electricity. The campus is bisected by Plymouth Road; the data center buildings are on one side of the highway, while the hospital buildings are on the other. The large data center cooling load, relative to the hospital's heating load, makes East Medical the only cooling dominant campus.

The proposed solution includes two nodal GHX/HRCH plants on either side of Plymouth Road that are thermally linked via a common geo-field. The large green space between the hospital parking lot and Plymouth Road can be used for geothermal. As the campus is heavily cooling dominant, supplementary heat rejection equipment will be required to balance the load on the geo-field. Building upgrades will be required to accommodate a new MTHW and CHW distribution network.

East Medical's ample parking lot area lends itself well to a large solar PV canopy installation. In total, solar canopies could provide offset 33% of the electricity demand of the new proposed systems. The flat roofs of the buildings are also ideal for rooftop solar, which could increase the percentage of load served by solar even more.

NORTH CAMPUS

Like Central Campus, North Campus is a good candidate for the GHX/HRCH option because (i) there is a viable plot of land that can be used for GHX; and (ii) the campus has a variety of building types and a diverse demand profile. These factors enable efficient heat recovery and a balanced GHX system. North Campus is unique, however, as it covers a relatively large land area that is less densely developed than Central Campus. A semi-distributed, or "nodal," plant approach is recommended for North Campus.

North Campus is also unique because it has a large centralized chilled water plant (NCCP) with an extensive distribution network that serves most of the academic

core buildings. Integral recommends that NCCP upgrade to a GHX/HRCH plant, tie into the existing CHW network, and pair with a medium temperature hot water distribution network alongside the CHW. The same approach is anticipated at NCRC. Both NCCP and NCRC plants will tie into the same neighboring geo-fields, while each of the residential neighborhoods will require their own small geo-field and newly constructed nodal plant.

Solar PV has the potential to offset 14% of North Campus' projected new electricity consumption. There are several buildings that would be ideal for rooftop solar, such as the Duderstadt Center.

U-M DEARBORN

Unlike the Ann Arbor campuses, U-M Dearborn has limited energy intensive lab buildings, and no major athletics buildings, hospitals, or major data centers. The campus consists mostly of libraries, classrooms, and offices; these building types result in a heating-dominant campus.

Despite its imbalanced thermal profile, GHX/HRCH remains a good option if solar thermal collectors are utilized to recharge the field when the sun is shining. Integral recommends a central plant at the main campus, plus a nodal plant with dedicated geo-field at the Fairlane Center.

U-M Dearborn is unique from all other U-M campuses: its onsite solar potential — with vast parking lots, parking structures, and rooftops — provides the opportunity to achieve net zero emissions with its electricity supply. Given the scale, the campus would likely potential solar generation, it would be likely generation from Dearborn

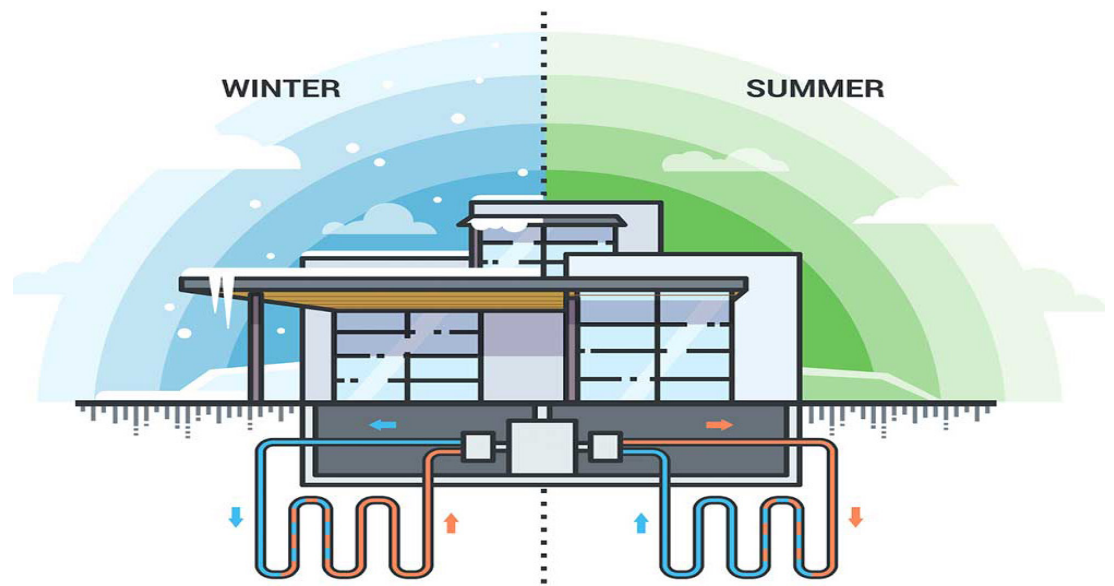
U-M FLINT

The Flint campus lies on Flint River waterfront property and consists of approximately 20 buildings with an area totaling over 2.2 million square feet. Like U-M Dearborn, U-M Flint lacks the large cooling-intensive labs, hospitals, recreation centers, and data centers. While heating dominant, Flint it is more balanced than Dearborn.

The proposed solution includes the construction of a new central GHX/HRCH plant on the main part of campus (south of the river) and a nodal plant north of the river. Both new plants would have new MTHW and CHW distribution networks, in addition to supplementary boilers. It was assumed that most buildings will require mechanical system conversions to utilize the medium temperature water generated at the plant.

U-M Flint's extensive parking lot area lends itself well to large solar PV installations that can offset a large portion of the proposed system's electricity use. Installing solar canopies on parking lots alone provide enough capacity to offset 31% of electricity. With solar PV installed on rooftops as well, the offset increases to 40%.

Campus	Proposed Systems	Energy Use Impact (GWh)
Central 140 bldgs; 19.1M sqft <i>Moderately heating dominant</i>	<ul style="list-style-type: none"> Central GHX/HRCH plant Supplementary boilers to meet peak heating load 46 acres geo-field with 8,900 boreholes New MTHW and CHW distribution piping networks Building conversion from steam to MTHW Eventual phase-out of co-generation plant ~ 914,000 ft2 of solar PV on parking lots and structures 	Business As Usual (BAU) 651 - Steam 53 - Natural Gas 442 - Electric Proposed New Systems 65 - Natural Gas 580 - Electric Total Energy Use Decline: 44% Total Emissions Decline: 84%
North 375 bldgs; 10.7M sqft <i>Mildly heating dominant</i>	<ul style="list-style-type: none"> Convert NCCP and NCRC existing plants to GHX/HRCH Supplementary boilers to optimize field New nodal GHX/HRCH residential systems 23 acres total geo-field with 4,600 boreholes New MTHW distribution network. Reuse existing CHW distribution piping. Building conversion from steam to MTHW ~2,988,500 ft2 of solar PV on parking lots and structures 	Business As Usual (BAU) 128 - Steam 262 - Natural Gas 213 - Electric Proposed New Systems 5 - Natural Gas 271 - Electric Total Energy Use Decline: 54% Total Emissions Decline: 75%
Ross Athletic 184 bldgs; 9.8M sqft <i>Moderately heating dominant</i>	<ul style="list-style-type: none"> Central HRCH plant at north end of campus with supplementary boilers Connect Yost Arena heat rejection to plant to help balance thermal loads 67,000 ft2 of rooftop / parking lot canopy solar thermal collectors to help balance thermal loads New nodal GHX/HRCH system at south end of campus 19 acres total geo-field with 2,700 boreholes New MTHW and CHW distribution piping networks Building conversion from steam/HTHW to MTHW ~1,203,000 ft2 of solar PV on parking lots and structures 	Business As Usual (BAU) 23 - Steam 53 - Natural Gas 29 - Electric Proposed New Systems 1 - Natural Gas 46 - Electric Total Energy Use Decline: 55% Total Emissions Decline: 69%
East Medical 15 bldgs; 1.2M sqft <i>Moderately cooling dominant</i>	<ul style="list-style-type: none"> Nodal GHX/HRCH plants on north and south sides of highway Supplementary heat rejection equipment to meet peak heat rejection load Shared 2 acres geo-field with 400 boreholes New MTHW and CHW distribution piping networks Building conversion from HTHW to MTHW ~712,000 ft2 of solar PV on parking lots and structures 	Business As Usual (BAU) 0 - Steam 8 - Natural Gas 26 - Electric Proposed New Systems 0 - Natural Gas 28 - Electric Total Energy Use Decline: 20% Total Emissions Decline: 53%
U-M Dearborn 37 bldgs; 2.2M sqft <i>Extremely heating dominant</i>	<ul style="list-style-type: none"> Central HRCH plant at main campus with supplementary boilers 67,000 ft2 of parking lot canopy solar thermal collectors to help balance thermal loads Nodal GHX/HRCH system at Fairlane campus, across highway 4 acres total geo-field with 700 boreholes New MTHW and CHW distribution piping networks Building conversion from steam/HTHW to MTHW ~1,201,500 ft2 of solar PV on parking lots and rooftops 	Business As Usual (BAU) 1 - Steam 34 - Natural Gas 14 - Electric Proposed New Systems 6 - Natural Gas 20 - Electric Total Energy Use Decline: 47% Total Emissions Decline: 66%
U-M Flint 16 bldgs; 3.7M sqft <i>Moderately heating dominant</i>	<ul style="list-style-type: none"> 4 acres total geo-field with 700 boreholes New MTHW and CHW distribution piping networks Building conversion from steam/HTHW to MTHW ~600,000 ft2 of solar PV on parking lots and rooftops 	Business As Usual (BAU) 10 - Steam 9 - Natural Gas 25 - Electric Proposed New Systems 6 - Natural Gas 20 - Electric Total Energy Use Decline: 25% Total Emissions Decline: 86%



Geo-exchange leverages the earth's constant temperature to improve the efficiency of thermal energy systems. In the winter, the , sometimes referred to as ground-source heat pumps, transfer heat from the ground into buildings; ii the summer, the system transfers heat out of buildings into the ground.

PHASING & IMPLEMENTATION

Implementing a project of this magnitude is an extraordinary endeavor. Even a 30-year time-frame, the base assumption for this report's life cycle analyses, will involve an urgent call to action and concurrent phasing of multiple campuses.

CAMPUS DISRUPTION & RISKS

Thermal. One clear area of potential disruption: heating services during the migration to new carbon neutral infrastructure. One example: CPP will need to continue to operate during the transition, providing steam to buildings that have not yet been connected to the new MTHW system. That will be challenging.

Even if construction on heating systems takes place during the summer when heating demand is lower, heating is still needed for summer dehumidification, which is vital for critical health care activities. 24/7 buildings such as hospitals, labs, and library archives may experience more disruption than scheduled buildings.

Roads. Integral assumes that new piping distribution infrastructure will be directly buried generally under existing roads. This will require road shutdowns, disrupting campus accessibility by car, bus, and bicycle.

Buildings. Various degrees of upgrades are required to convert existing buildings from steam/HTHW (high-temp hot water) to MTHW (medium-temp hot water).

Disruptions to these buildings will depend on the extent of these upgrades. If a building requires new windows and upgraded wall insulation, the disruption may be significant; a building that needs a new air handling unit coil replacement may notice little or nothing.

Playing fields, lawns, and parking lots - for GHX. Portion of playing fields, parking lots, and lawns — all identified on various campuses for future geo-fields — would be unavailable during borehole drilling and pipe installation. (Note, however, that these fields, lots, and lawns would be restored to their prior use after GHX installation.)

Solar-related risks. Integral has identified a potentially massive deployment of solar across the six campus — mostly on parking lots but also on selected rooftops. While feasible, however, Integral recognizes that such a large-scale solar deployment may be logistically infeasible. Concerns with parking lots could include vehicle clearance, while rooftops could have structural issues. Solar on rooftops also often competes with alternative uses, from mechanical equipment to amenity space.

On the Dearborn campus, there may be challenges with interconnection. While annual solar generation could equal annual energy consumption — a massive feat that would involve an historically large behind-the-meter installation — on an intra-day basis, the panels would often over-generate relative to load. This could create difficulties for the local distribution infrastructure, which may need upgrades in order to accommodate the proposed project's interconnection to the grid.

TRANSITION PERIOD

Integral counsels that compressing the timeline of energy system transformation across U-M's six campuses would be exceedingly difficult. Phasing is dependent on a range of factors: campus disruption; availability of capital; the University's project management capacity; design/procurement/construction timelines; and existing equipment or building replacement timelines. Shortening the timeline to transition to carbon neutral infrastructure would require almost perfect alignment across these key factors. Integral's proposals are based on more traditional and likely scenarios of outcomes.

Given these physical realities, in order to achieve carbon neutrality quickly, U-M will likely need to pursue credit or offset purchasing. While this approach is sub-optimal, as noted above (p2), it is important to note that not all offsets are created equally. U-M could reasonably seek to further explore and evaluate specific offset options to achieve a rapid course to carbon neutrality. At the same time, however, U-M should not to lose sight of the vital mission to address its own infrastructure, on its own land, to most directly decarbonize its campuses.

NORTH CAMPUS ACADEMIC CORE & U-M DEARBORN

Integral recommends that implementation begin with opportunities for significant impact with relatively low risk. In this context, the best option is likely the North Campus academic core, which encompasses the North Campus Chiller Plant district. This project would avoid the complexities of other campuses. There are no energy-intensive hospitals, nor any rivers or railroads to navigate. The proposed geo-exchange network would also leverage the central chiller plant and an extensive CHW (chilled water) distribution network.

U-M Dearborn is also a good candidate to sequence early on. While there would be potential challenges with solar interconnection — given the potentially massive scale on parking lots and rooftops — the campus has the potential to achieve carbon neutrality with onsite solar PV installations. With the proposed GHX/HRCH plant, system efficiency would be improved to the point where annual onsite solar generation could equal or exceed annual energy consumption.

SAMPLE CAMPUS UPGRADE PHASING

The following table lists a sample of potential sequencing that seeks to minimize concurrent campus projects. As there is no interdependency between campuses related to thermal infrastructure, the campuses can be sequenced in any order that works best for U-M.

Campus	Timeline	Comments
North Campus	Years 1 - 15 (15 yrs)	Initial implementation project: North Campus Academic Core
U-M Dearborn	Years 1 - 10 (10 yrs)	Can achieve onsite net zero emissions with parking lots and rooftop solar PV
Central Campus	Years 5 - 25 (20 yrs)	Gradual phase-out of CPP as new systems are built out
Ross Athletic	Years 10 - 20 (10 yrs)	Quick timeline difficult, given sensitivity to onsite disruptions (e.g. parking for football games)
East Medical	Years 15 to 20 (5 yrs)	Small campus, short timeline, starting in year 15 after North Campus is completed
U-M Flint	Years 15 - 25 (10 yrs)	10 yrs likely required because of demands from three concurrent projects from years 15-20

CONCLUSION

The proposed energy system transformation would likely be the largest electrification and decarbonization infrastructure project ever. Even one phase, such as the North Campus project, would represent a landmark effort.

CHALLENGES

The challenges with this proposed project are significant and difficult to predict, particularly at this conceptual stage. This would put pressure on U-M resources, from borrowing capacity to internal project management; some new energy system components would demand regulatory approval, such as solar interconnection and potential pressure on local electric distribution; costs for future scenarios — capital and utility costs for Business as Usual (AU) and the proposed energy systems — could swing significantly from initial estimates.

STATUS QUO

The potential costs of doing nothing are massive. From a financial perspective, continued reliance on carbon-based energy has clear financial risks; carbon taxes, for example, could increase the cost of natural gas, which anchors much of U-M's energy infrastructure. From an environmental perspective, inaction on climate change, well defined by the PCCN, will have profound negative consequences.

OTHER OPTIONS

Other pathways to carbon neutrality may exist, but Integral counsels that these options are inferior. Biofuels, for instance, are often attractive because of perceived simplicity: changing from traditional gas to “renewable” gas can be done quickly and with minimal retrofits. But this hardens reliance on combustion — an often inefficient technology (e.g. heating steam or water to unnecessarily high temperatures) at odds with the scientific community's general thesis to pursue electrification when possible — and subject U-M to a market with definitionally limited fuel availability and high price risk. Other options, such as carbon capture or nuclear, may appear attractive in theory, but the real-world track-record indicates environmental risks and often prohibitive price tags.

SOLUTION

With geo-exchange fields that leverage the earth's constant temperature to provide efficient thermal energy, the University would turn to electricity as its main source of heat and power. The benefits and upside are plain: mature technologies exist to generate electricity from renewable resources — and technological advances promise to reduce costs and improve scalability of solar and wind. With onsite and offsite renewables energy supply, U-M's path to carbon neutrality would be clear and sustainable.

WEB-BASED PROJECT PLATFORM

The full scope of this analysis is difficult to communicate because of the scale of the University and the complexity of the systems proposed. To address these communication challenges, Integral has developed an online platform that includes building and campus maps, overlaid with schematic drawings for thermal energy distribution networks, geo-exchange fields, and renewable energy.

See below for a guide to the platform that corresponds with website screenshots on the following page.

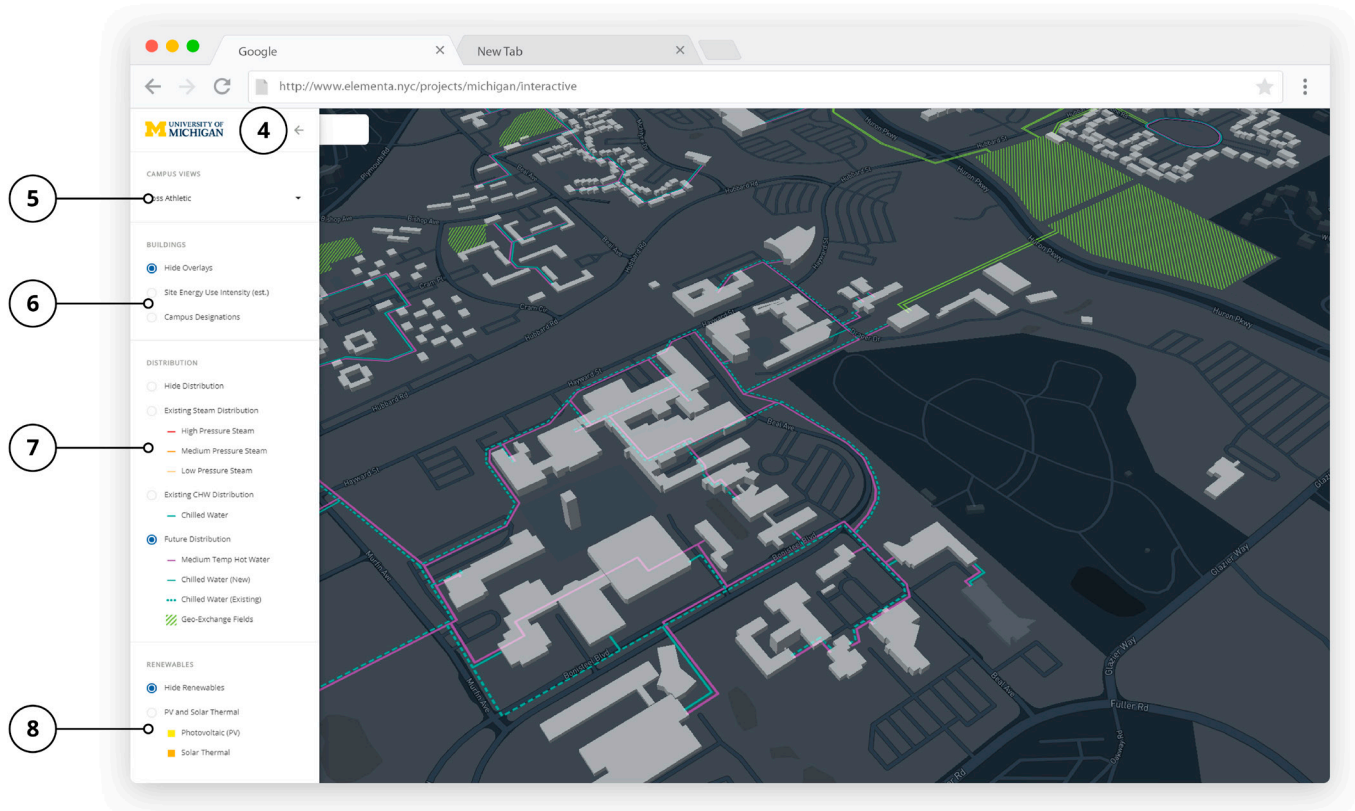
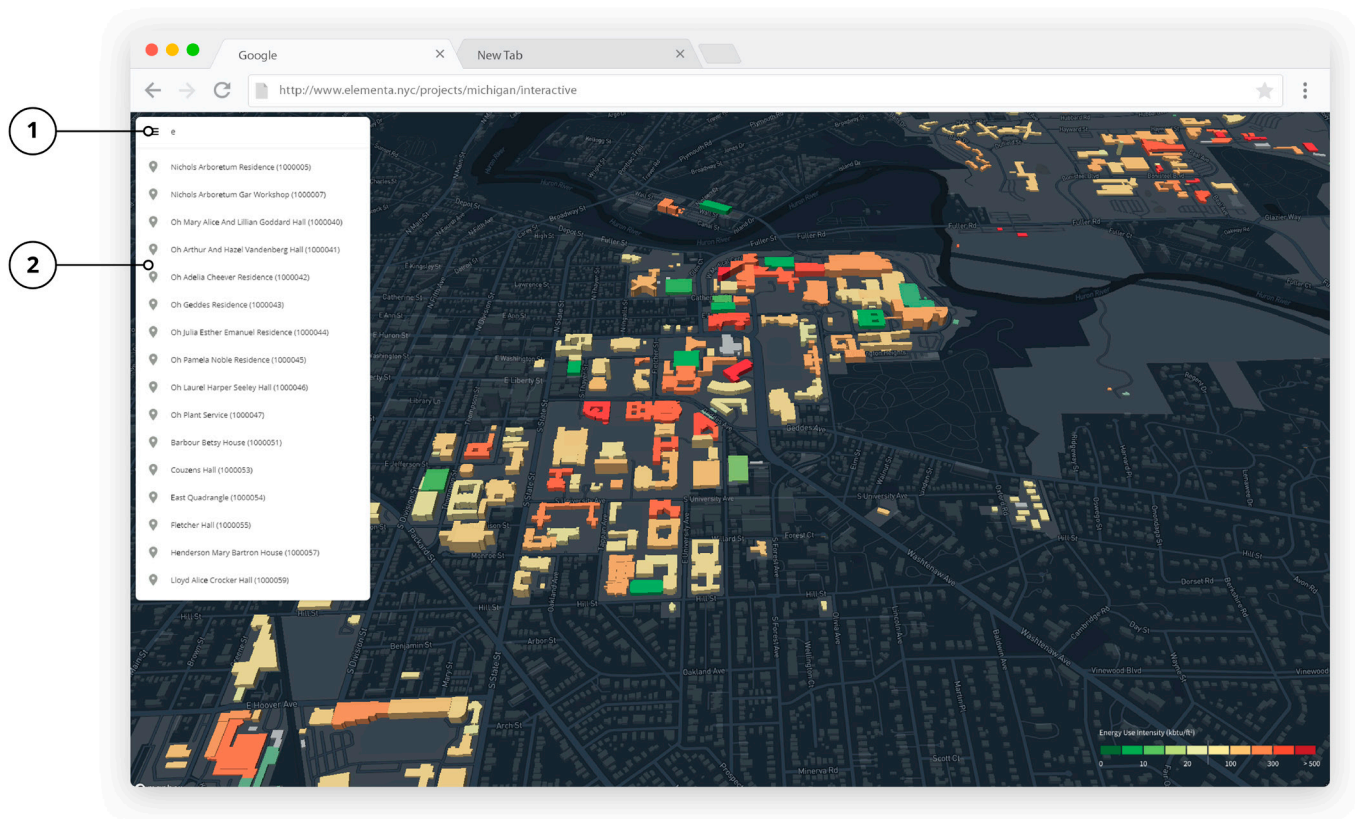
PLATFORM GUIDE

<https://www.elementa.nyc/projects/michigan/interactive/>

The image on the following page shows some of the primary features and controls:

- 1. **Main Menu:** Use this button to access the side panel, where you can control what information to include in the map and select different campus views.*
- 2. **Search Bar:** The search bar is used to search for individual buildings. You can search by building name or by building number and the top 16 matches will appear in a dropdown. Clicking on a result will take you to the building. You can also use the arrow keys to move through the list and the enter key to zoom to a building.*
- 3. **Map:** On a desktop, the map is controlled with a mouse (or touchpad). The left mouse button pans, the right mouse button rotates, and the scroll wheel will control the zoom. On mobile devices, pinch-and-zoom gestures work well.*
- 4. **Close Button:** Use this button to close the side panel.*
- 5. **View Select:** When you select a campus, the map will zoom to that location.*
- 6. **Overlays:** This information will appear as overlays on the building geometry. The energy use intensity overlays are based on 2018 monthly energy consumption data from the University of Michigan. The campus designations are also based on data provided by the University.*
- 7. **Distribution Overlays:** The existing system distribution geometry is based on data provided by the University of Michigan. The proposed distribution networks and geo-exchange fields are based on Integral's recommended solutions.*
- 8. **Renewable Energy Systems:** Solar PV and solar thermal are included in this analysis.*

SCREENSHOTS & GUIDE: WEB-BASED PROJECT PLATFORM



<https://www.elementa.nyc/projects/michigan/interactive/>