Northern Arizona University

2021 Climate Action **Plan Analysis**

Figure 1. (NAU to provide needed caption explaining image)

NORTHERN
ARIZONA
UNIVERSITY

Figure 2. NAU Flagstaff Mountain Campus is well-served by Mountain Line, the region's transit system.

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Dear Lumberjacks,

At Northern Arizona University (NAU), we value forward-thinking, knowledge, innovation, and stewardship of place and resources. Sustainability and climate action have always been associated with both academic and operational excellence at our institution. NAU carries out advanced climate and environmental-based research, offers innovative sustainability academic programs, and a history of campus wide sustainability initiatives. We are also proud to have a student body that wants to see NAU take meaningful sustainability and climate-based action. With significant contribution from the student led NAU Green Fund, NAU contracted Affiliate Engineers Inc. to help develop this Climate Action Analysis to support and inform our ongoing efforts.

This document is nearly two years in the making. It was developed through engagement with university administration, faculty, staff, operations, researchers, students, and community representatives. A Climate Action Plan (CAP) Steering Committee provided guidance, input, and recommendations on how to best move forward. Specific working groups addressed campus energy utilization, landscape and water use, waste management, transportation, and resilience.

This analysis outlines the potential strategies for the NAU Flagstaff Mountain Campus to achieve carbon neutrality in the next ten to thirty years. It also outlines how NAU will utilize our campus as a living laboratory while aligning and collaborating with the City of Flagstaff to achieve mutual goals in mitigation and resiliency. It incorporates the social cost of carbon and provides details that will support our decision-making process moving forward. However, our work only starts here. There is much to evaluate, process, and do. To become leaders in sustainability and climate action, we will need to be bold, decisive, and creative. We will come together as a community and learn together, draw upon one another's expertise, and inspire each other. We will collaborate with partners and work through challenges and obstacles through the NAU spirit of accountability, innovation, and service. We will lead the way and demonstrate that we can achieve anything when we set our minds and hearts to the task!

Abraham Henn
Manager, NAU Office of Sustainability

Andrew Iacona
Project Manager

NAU

Figure 3. Northern Arizona University sits at the base of the San Francisco Peaks, on homelands sacred to Native Americans throughout the region. We honor their past, present, and future generations, who have lived here for millennia and will forever call this place home.

Executive Summary

This document was developed by a network of university faculty, staff and students and members of the larger community representing city, state, utilities, and non-profits. They were organized into committees and advisory groups on key topics. These stakeholders articulated goals for the study. The first two speak to action with specific outcomes:

- NAU Flagstaff Mountain Campus will realize carbon neutrality in the next ten to thirty years.
- The NAU 2021 CAP will position NAU Flagstaff Mountain Campus to commit to Second Nature's Climate Commitment[1].

And, two speak to reinforcing of the university's culture:

- NAU Flagstaff Mountain Campus will be a campus community whose academics, research and operations collaborate to address climate change adaptation and mitigation.
- NAU Flagstaff Mountain Campus will align and collaborate with the City of Flagstaff to realize shared university and city climate goals and objectives.

NAU's commitment to sustainability is long standing and this document follows other plans for carbon reduction. It reinforces and perpetuates some elements:

- It aligns with previous documents in addressing both carbon reduction and a broad consideration of sustainability.
- It reflects the university's culture as a living laboratory[2], expecting that this structure will be significant to the plan's implementation.
- It perpetuates a planning approach that engages a large and richly diverse university constituent group in the plan creation.

It also offers some noteworthy departures:

- It changes the university's previous climate action plans' named date for carbon neutrality. Instead, this plan's ambitions focus on eliminating greenhouse gas emissions from on-site fuel use at the Flagstaff Mountain Campus within ten years and takes a comprehensive approach and steadfast pace towards eliminating other C02e emissions for the Flagstaff Mountain Campus within thirty years.
- It reframes the recent campus interest in biomass by proposing an alternative next generation system: electrification achieved through conversion from steam to low temperature heating hot water and central heat pumps.
- It introduces resilience as a component of realizing carbon neutrality.
- It introduces use of the social cost of carbon.
- It provides a structure and definition to future greenhouse gas accounting efforts for the university, both the Flagstaff Mountain Campus and extension campuses.
- It includes an implementation schedule.

Figure 4. (NAU to provide Image and caption)

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[1] See: https://secondnature.org/signatory-handbook/the-commitments/

[2] NAU defines living laboratory to mean a "research concept, defined as a user-centered, open-innovation ecosystem, often operating in a territorial context, integrating concurrent research and innovation processes within a public-private-people partnership." (source: CAP request for proposal, dated February 27, 2020).

Introduction

Figure 5. Dr. Jose´ Luiz Cruz Rivera, NAU's 17th president, began his tenure on June 14th, 2021 with immediate concern to engage with university students.

Introduction

Established in 1899, today Northern Arizona University (NAU) educates nearly 30,000 students. More than two-thirds are enrolled in the Flagstaff Mountain Campus and the remainder in a series of more than twenty extension campuses. Today, NAU's seven colleges offer 130 accredited degree programs through in-person and online learning.

The university's history reveals its resilience. The school grew in its first two decades to specialize in education and became the Northern Arizona State Teachers College and then the Arizona State Teachers College at Flagstaff. During World War II it was host to a Navy training program. With the surge of veteran attendance after the war, educational programs were expanded in the arts and sciences and the school became the Arizona State College at Flagstaff. The 1950's brought a new name – Arizona State College – and incorporation of a forestry program. In 1966, the university established its current name.

Flagstaff is home to the university's largest campus. Its 829 acres are centrally located in the City of Flagstaff, a community of 75,000 residents and the largest city in the northern region of the state. Residents enjoy a semi-arid climate with sun nearly every day of the year and more than 100 inches of snow in typical years.


Figure 6. The NAU Flagstaff Mountain Campus in a snow storm.

NAU traces its sustainability identity to the environmental science degree program, established in 1973 and one of the first such programs nationally, and creation of the Institute for Tribal Environmental Professionals (1992). In 2007, the university became a charter signatory to the American College and University Presidents' Climate Commitment[3]. In 2010, the university issued its first climate action plan (CAP). Its aim was for the Flagstaff Mountain Campus to be climate neutral by 2020. The plan addresses incorporating sustainability in curriculum, research and the campus experience, and establishes milestone dates[4] for emissions reductions which are broadly described to include those associated with purchasing, operations, transportation, water use, recycling and waste management.

The first NAU CAP is aspirational in its goal and practical in details: it identifies the university's responsible parties and financing strategy to support progress towards a 2020 deadline for carbon neutrality. NAU's 2015 update to its 2010 CAP was developed to ensure the first plan's relevance and vitality. Three years after the update, the university continued its exploration of climate action by exploring means of using biomass as the Flagstaff Mountain Campus' primary fuel source.

The university has reported on its Scope 1 and Scope 2 greenhouse gas emissions for most of the past thirteen years and uses the Sustainability Indicator Management & Analysis Platform (SIMAP) format[5].

Through that period, it has invested in building energy demand management, operational innovations to reduce greenhouse gas emissions and has purchased offsets.

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3 | This pledge was renamed as the Carbon Leadership Commitment.

4 | The plan establishes that by 2014, the carbon footprint is to equal the 2000 levels. By 2018, the carbon footprint is to equal1990 levels. By 2020, the carbon footprint is to be net zero.

5 | SIMAP is based on the World Resources Institute "Corporate accounting and Reporting Standard" which states that sources that add up to less than 5% of the entity's total emissions should be acknowledged, but need not be inventoried. Instead, the university is to establish a high bound value (estimate) and use that.

Figure 7. NAU Central Plant

The NAU 2021 CAP satisfies the university's four goals for this study.

1. **NAU Flagstaff Mountain Campus will realize carbon neutrality in the next ten to thirty years.** This analysis presents ambitious and achievable means for the university to become carbon neutral for the Flagstaff Mountain Campus as it relates to its Scope 1 and Scope 2 emissions[6] and to realize this goal with an end date that is framed by 2030 to 2050. This assessment presents two pathways, each tested for three end dates, for carbon neutrality. At least one scenario describes needed plans and capital investments to realize the goal by 2030.

   The university recognizes that addressing Scope 3 emissions[7] is necessary for complete carbon neutrality and will develop a plan to address these emissions. However, at present, the university lacks an accounting infrastructure for these emissions. Additionally, many of the units or departments whose activities generate these emissions have not, heretofore, been aware of or valued emissions reductions through their activities. Therefore, this assessment makes the practical, yet ambitious commitment that within five years after development of the CAP, the university will generate reliable data on its Scope 3 emissions and commit to means for neutralizing Scope 3 emissions towards a stated end date.

2. **NAU Flagstaff Mountain Campus will be a campus community whose academics, research and operations collaborate to address climate change adaptation and mitigation.** This plan's development engages university administration, faculty, operations, and students to identify the best means of expanding university climate adaptation and mitigation activities and programs. Committees of topic-specific interest – energy, landscape, transportation, waste and resilience – contribute their expertise to this momentum. A majority of on-going sustainability initiatives are student driven through the Office of Sustainability, the Green Fund, and the Environmental Caucus, along with staff and faculty work in the Sustainable Campus Ecosystem Initiative and the Coordinating Committee for Sustainability. This plan uses current information to establish consensus support for programs and initiatives and an administrative structure to further guide the transition of campus culture in support of climate change adaptation and mitigation by activating the living laboratory concept.

3. **NAU Flagstaff Mountain Campus will align and collaborate with the City of Flagstaff to meet university and city climate goals and objectives.** In the Climate Action and Adaptation Plan (2018), the city states its vision for 80% carbon reduction by 2050 through climate change mitigation and adaptation actions The plan commits to three goals and to strategies across seven sectors and considers equity through the city's lens of nine equity considerations and questions. The city's stated climate emergency prompted revision to the 2018 city CAAP to shift the net zero carbon emissions date to 2030 and prompted revisions to the city CAAP. NAU is participating in this update and the NAU CAP will work to find alignment with city goals and activities as articulated in its 2018 plan and subsequent updates and plans.

4. The NAU 2021 CAP will position NAU Flagstaff Mountain Campus to commit to Second Nature's Climate Commitment. Through this plan, the university will complete the needed steps to achieve the Presidents' Climate Leadership Commitment, which includes resilience planning as well as steps towards carbon reductions, as defined by Second Nature's Climate Leadership Network.

The NAU 2021 CAP development process engaged representatives of the City of Flagstaff and individuals representing community groups, non-profit organizations, other levels of government and businesses in the Flagstaff community. It makes explicit the relationships of the city and university campus in each reaching their goals for carbon neutrality and community resilience.

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[6] | Scope 1 emissions are understood to be greenhouse gas emissions from sources that are owned or controlled by the reporting entity. Scope 2 emissions are understood to be greenhouse gas emissions resulting from the generation of electricity heat, or steam purchased by a reporting entity. (Source: US EPA)

[7] | Scope 3 emissions are understood to be greenhouse gas emissions from sources not owned or directly controlled by a reporting entity, but related to the reporting entity's activities. (Source: US EPA)

Figure 8. Campus Outdoor Classroom

This assessment was developed through committees. The Steering Committee guided decision-making, articulated project goals, endorsed the work of the other NAU 2021 CAP committees, considered changes in university operations experienced during the COVID-19 pandemic that will likely be perpetuated afterwards, engaged the Sustainable Campus Ecosystem Initiatives and endorsed the draft plan. It was constituted by university administration, faculty, operations, researchers, students and community representatives. Topic specific committees addressed campus energy, landscape and water use, waste management, transportation and resilience. Specific to its focus, each topic-specific committee established objectives, articulated the operational impact of COVID-19 on campus operations and proposed activity to realize the plan's carbon reduction goals.

- The Energy Committee addressed energy supply, distribution, and building demand and water use in buildings and campus utilities. It was constituted by university faculty, researchers, and operations staff and representatives of the city, and APS (electric utility).
- The Landscape Committee addressed campus landscape design and management and water use in the landscape. It was constituted by university faculty, researchers, operations staff and students and representatives of the city, county, non-profit community and the region's hydrologists.
- The Resilience Committee articulated and addressed Flagstaff Mountain Campus resilience needs and means of attending to these in coordination with the city's resilience efforts. It was constituted by university faculty, researchers, operations staff and students and representatives of the city and its neighborhood advocacy community.
- The Transportation Committee addressed campus transportation (planning and use) and fleet management. It was constituted by university faculty, operations staff and students and representatives of the city and its transportation advocacy community.
- The Waste Committee addressed Flagstaff Mountain Campus waste generation and management and related procurement practices. It was constituted by university operations staff (including the university's food service contractor), students and representatives of the city.

As priorities for the plan took form, three additional groups were formed to inform the committees. They answered specific questions of what value should the university employ as the social cost of carbon, how should this plan envision the university's future as a forest manager, and what should the university apply as its organizational boundaries and operational control to bring greater rigor and consistency to its future greenhouse gas emissions inventories.

University Greenhouse Gas Emissions

Figure 9. Solar Panels on the Energy & Computational Models Lab

University Greenhouse Gas Emissions

University Emissions Reduction Investment Strategy

This assessment broadly considers opportunities to promote sustainability in combination with the traditional scope of higher education climate action plans: planning for greenhouse gas emissions reduction for Scope 1 and Scope 2 emissions.

NAU's Flagstaff Mountain Campus has issued greenhouse gas emission inventories on a nearly annual basis since 2007. During this time, the Flagstaff Mountain Campus occupied space grew by more than 1 million gross square feet. Countering the increase in energy and greenhouse gas emissions that would be expected to occur with this growth, the university credits its investments in reducing building energy demand and improving efficiencies of its plants and distribution systems as having mitigated the energy and emissions impacted that would be expected with campus growth.

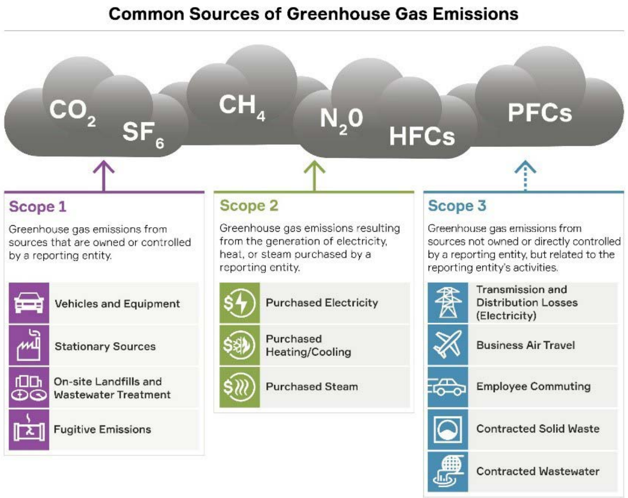
The majority of the Flagstaff Mountain Campus' Scope 1 and 2 greenhouse gas emissions are associated with natural gas combustion for heating (Scope 1) and purchased electricity (Scope 2).

This assessment investigated readily available and emerging technologies for campus heating and power, evaluating their compatibility with existing infrastructure and geographic site, and estimating future economic conditions. The NAU 2021 CAP commits to a next generation campus energy system and to immediate development of two concepts with selection to be made late in 2021 and the system to be in place within a decade. One option is woody biomass as a primary heating source. Biomass fuels are considered carbon neutral if they would have otherwise contributed to methane release to the atmosphere. For example, wood feedstock that is removed via sustainable forest management avoids the emissions associated with wildfires caused by not managing the forest or open burning or composting of wood that is removed. However, wood waste streams may be regulated in the future as carbon emitting sources[8]. As an alternative, the NAU 2021 CAP considers electrification to be achieved through low temperature heating water conversion with central heat pumps.

Scope	Source	2016 (MTCO2e)	2017 (MTCO2e)	2018 (MTCO2e)	2019 (MTCO2e)
2	Purchased electricity	35,668	35,819	28,539	30,264
1	On-site fuel	20,093	22,060	19,696	22,199
	Fleet	2,067	2,067	1,732	1,728
3	T&D loss	No data	No data	1,460	1,549
	Commuting	4,524	4,524	No data	No data
	Air travel	2,565	2,565	No data	No data
	Solid waste	8,719	No data	No data	No data
	Gross emissions	73,636	67,035	51,427	55,740

Figure 10. Summary of NAU's GHG Emissions Inventories

Assuming that the existing electrical grid serving the Flagstaff Mountain Campus is adequate for expected capacity and reliable, then it is likely to be most cost effective for NAU to procure the majority of its need for renewable electricity from off-site sources. This power can be procured through the existing electric utility company or via a virtual power purchase agreement(s). A virtual power purchase agreement is a contract with an agreed upon price and it provides the purchaser with a renewable energy credit to establish that the energy that procured through the agreement represents additionality to total production. The economies of scale and access to additional resources off-site enables NAU


Common Sources of Greenhouse Gas Emissions

Scope 1: Greenhouse gas emissions from sources that are owned or controlled by a reporting entity.

Scope 2: Greenhouse gas emissions resulting from the generation of electricity, heat, or steam purchased by a reporting entity.

Scope 3: Greenhouse gas emissions from sources not owned or directly controlled by a reporting entity, but related to the reporting entity's activities.

Figure 11. Source: US EPA

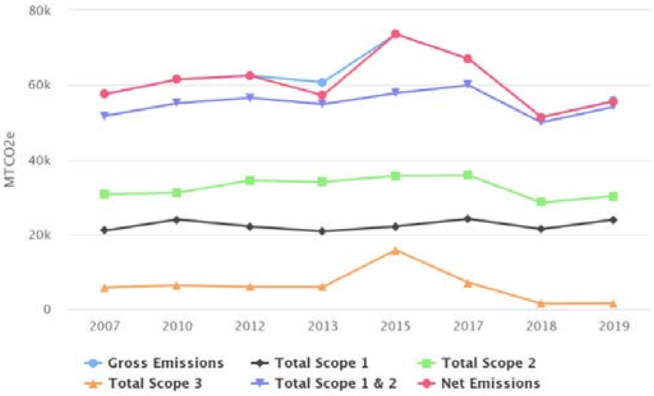


Figure 12. Graphic Presentation of NAU's GHG Emissions

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[8] For an introduction to the controversy within the U.S., see: https://www.scientificamerican.com/article/congress-says-biomass-is-carbon-neutral-but-scientists-disagree/ and for a deeper understanding of the science, see: https://www.ipcc.ch/site/assets/uploads/2018/03/Chapter-2-Bioenergy-1.pdf.

to purchase renewable power generation produced through geothermal systems, hydro and tidal systems, nuclear facilities (this fuel is carbon neutral but not renewable), renewable natural gas, biomass, other biofuels, solar PV and solar thermal, and wind.

Reducing building energy demand is best accomplished in design of new construction. For the Flagstaff Mountain Campus, NAU projects very modest new construction or major renovations in the next decade. Thus, this report focuses on opportunities to reduce demand in the existing building stock.

The NAU 2021 CAP prioritizes other campus sustainability activities identified as likely generating the most generate greenhouse gas emissions:[9]

- Expand on-campus composting of food and yard wastes. It is difficult to generate reliable emissions values associated with waste composting, but it is clearly preferable to landfilling and combustion from an emissions perspective. The university will rely on SIMAP guidance for waste composting[10], which suggests that the emissions value should be that associated with transportation of waste to the compost facility.
- Manage campus roads and landscapes with reduced use of fertilizers and chemicals, including those used for winter ice conditions. Here, too, the university will again rely on SIMAP guidance which classifies this as de minimis.
- Expand transportation demand management.
- Electrify the campus vehicle fleet.

Emissions Accounting and Methodology

The process of developing this plan revealed the need to institutionalize a standard approach to greenhouse gas emissions accounting and to collecting and interpreting data. In generating the NAU 2021 CAP, the university established the following standards for future greenhouse gas emissions inventories:

- Control approach. The university will employ an operational control approach. Here, the entity accounts for 100% of greenhouse gas emissions from operations that it controls. It considers control to rest with its full power to introduce and execute operating policies and procedures.

  This best addresses the complexity of NAU ownership and space use. NAU operates in 21 locations and its space use as lessor and as lessee accounts for over 3 million square feet[11]. The majority of NAU's space use at its extended campuses is under ownership and control of other entities. Formal arrangements are in place for spaces as small as an ATM and as limited as a few hours a week.

  Using this approach, some of NAU's Scope 1 and Scope 2 greenhouse gas emissions will be accounted for as Scope 3 emissions by associated entities. For example, at the Flagstaff Mountain Campus, the ACC (housing for which the utility use is a combination of university supplied and other and varies by building), food service operations and the on-campus hotel should report their use of NAU's utilities as Scope 3 emissions.
- Temporal considerations. NAU will make all reasonable effort to track its greenhouse gas emissions employing temporal adjustments to the greenhouse gas emissions rates associated with university activity as they are available.

The transition to improved accounting involves many NAU departments and units, The effort will be guided by the Office of Sustainability with support from NAU's Information Technology Services.

	Flagstaff Mountain Campus	Extension Campuses with Most Leased Space[12]	Extension Campuses with Limited Space Leased[13]
FY21	Improve Scope 1 and Scope 2 accounting	Suspend accounting efforts	Suspend accounting efforts
FY 22	Complete improving Scope 1 and Scope 2 accounting and decide which Scope 3 emissions to count	Suspend accounting efforts	Suspend accounting efforts
FY23	Improve Scope 3 accounting and institutionalize improved Scope 1 and Scope 2 accounting	Improve Scope 1 and Scope 2 accounting	Suspend accounting efforts
FY24	Complete improving Scope 3 accounting	Institutionalize improved Scope1 and Scope 2 accounting	Estimate Scope 1 and Scope 2 emissions based on other extension campuses' data
FY25	Institutionalize improved Scope 3 accounting		Improve Scope 1 and Scope 2 accounting
FY26			Institutionalize improved Scope1 and Scope 2 accounting

Figure 13. NAU's Schedule to Improve its Greenhouse Gas Emissions Accounting

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[9] | Outside of data on utility use, university data to generate greenhouse gas emissions is incomplete.

[10] | SIMAP User's Guide Version DRAFT 6.2 2018

[11] | Reference: NAU 2021-2023 Capital Plan

[12] | Phoenix Biomedical Campus, the North Valley Campus and the Yuma- AWC Campuses (these have been shown to be superior at greenhouse gas emissions accounting)

[13] | Remaining extension campuses

[14] | Priority Scope 3 emissions are: faculty, student and staff commuting to/from NAU campus; NAU travel (faculty, staff and students official travel – that done to represent the university or otherwise assigned by the university); transmission and distribution losses associated with electricity and power, solid waste generation (to include waste diversion); embedded energy in supply water to the campus and wastewater generation, and; those associated with the investments that constitute NAU's endowment.

In 2020, NAU executed a Scope 1 and Scope 2 greenhouse gas emissions inventory of all of its properties and carefully documented its assumptions and experiences. The NAU 2021 CAP development process reviewed these with the following recommendations for future greenhouse gas emissions inventories:

1. **Continue to use the SIMAP to develop NAU greenhouse gas emissions inventories.**
2. **Assume that all emissions associated with electrical utilities are produced using the same electrical generation profiles found in the EPA Power Profiler.**
3. **Use natural gas emission factors from the Climate Registry.**
4. **For NAU as lessee:**
    a. **When supplied from the owner/lease holder, apply utility use/sf.**
    b. **When utility use/sf is not supplied, calculate greenhouse gas Scope 1 and Scope 2 emissions as an adjusted square footage compared to the (assignable) space described in its lease. The adjustment will calculate the portion of the NAU leased space as compared to total building gross square footage.**
    c. **Calculate NAU's portion of emissions by applying the per square foot emissions for the metered areas to the NAU leased and used spaces.**
    d. **Assume variable square footage (sq. footage outside of lease. agreement) reported by entities to be in permanent (year-round) use for the year in question.**
    e. **Calculate all spaces assuming commercial and residential use types.**
    f. **Modify the standard lease agreements to compel the owner and lessee to share their respective assumptions and calculation for NAU space use.**

For space that NAU owns and/or controls and leases to others[15], NAU will count the Scope 1 and Scope 2 emissions associated with this space as with all space that the university owns and controls. Further, NAU will offer its lessees current Scope 1 and Scope 2 greenhouse gas emissions inventory information for their space as a standard component of the lease agreement.

Figure 14. Solar panels installed to take advantage of Flagstaff's 266 days per annum of sunny skies.

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[15] Such as Drury Inn and Suites Hotel and American Campus Communities housing.

Figure 15. NAU's University Union.

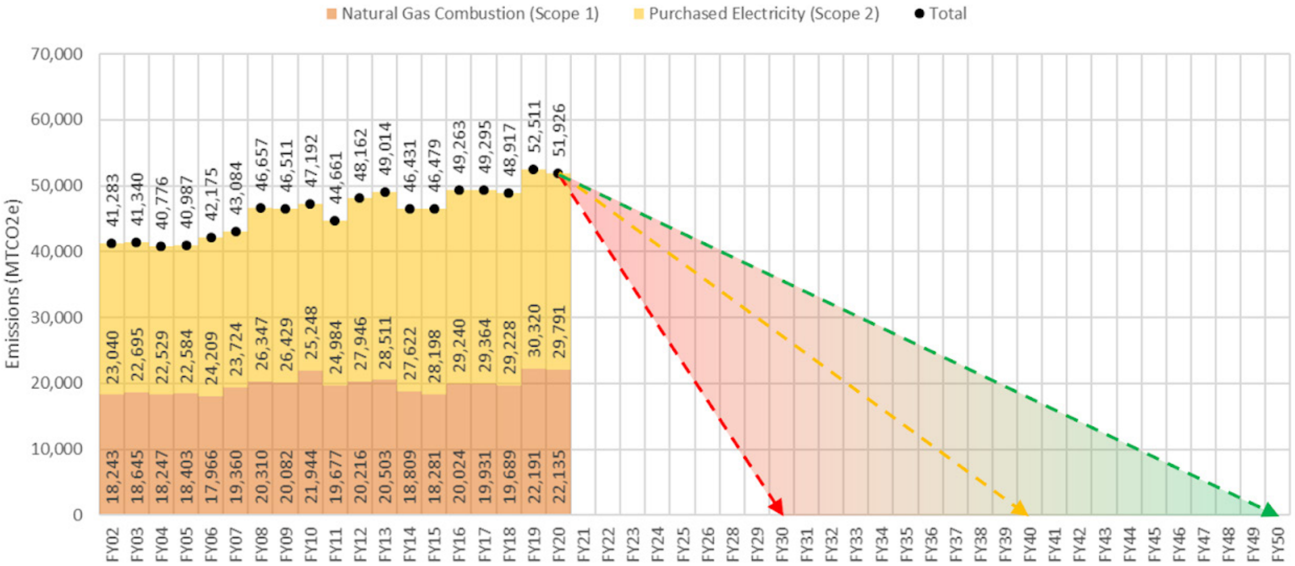
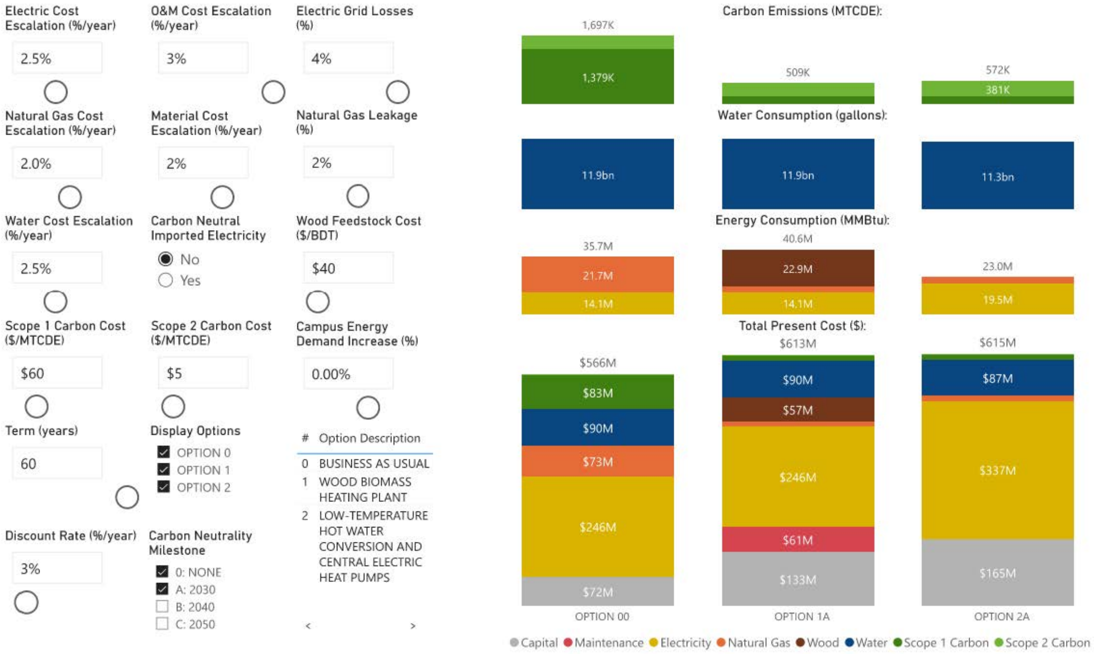


Figure 16. GHG Emissions Associated with Natural Gas Combustion for Heating & Purchased Electricity



Electric Cost Escalation (%/year): 2.5%

O&M Cost Escalation (%/year): 3%

Electric Grid Losses (%): 4%

Natural Gas Cost Escalation (%/year): 2.0%

Material Cost Escalation (%/year): 2%

Natural Gas Leakage (%): 2%

Water Cost Escalation (%/year): 2.5%

Carbon Neutral Imported Electricity
● No
○ Yes

Wood Feedstock Cost ($/BDT): $40

Scope 1 Carbon Cost ($/MTCDE): $60

Scope 2 Carbon Cost ($/MTCDE): $5

Campus Energy Demand Increase (%): 0.00%

Term (years): 60

Display Options
☑ OPTION 0
☑ OPTION 1
☑ OPTION 2

#	Option Description
0	BUSINESS AS USUAL
1	WOOD BIOMASS HEATING PLANT
2	LOW-TEMPERATURE HOT WATER CONVERSION AND CENTRAL ELECTRIC HEAT PUMPS

Discount Rate (%/year): 3%

Carbon Neutrality Milestone
☑ 0: NONE
☑ A: 2030
☐ B: 2040
☐ C: 2050

Figure 17. Energy Action Planning Tool Dashboard

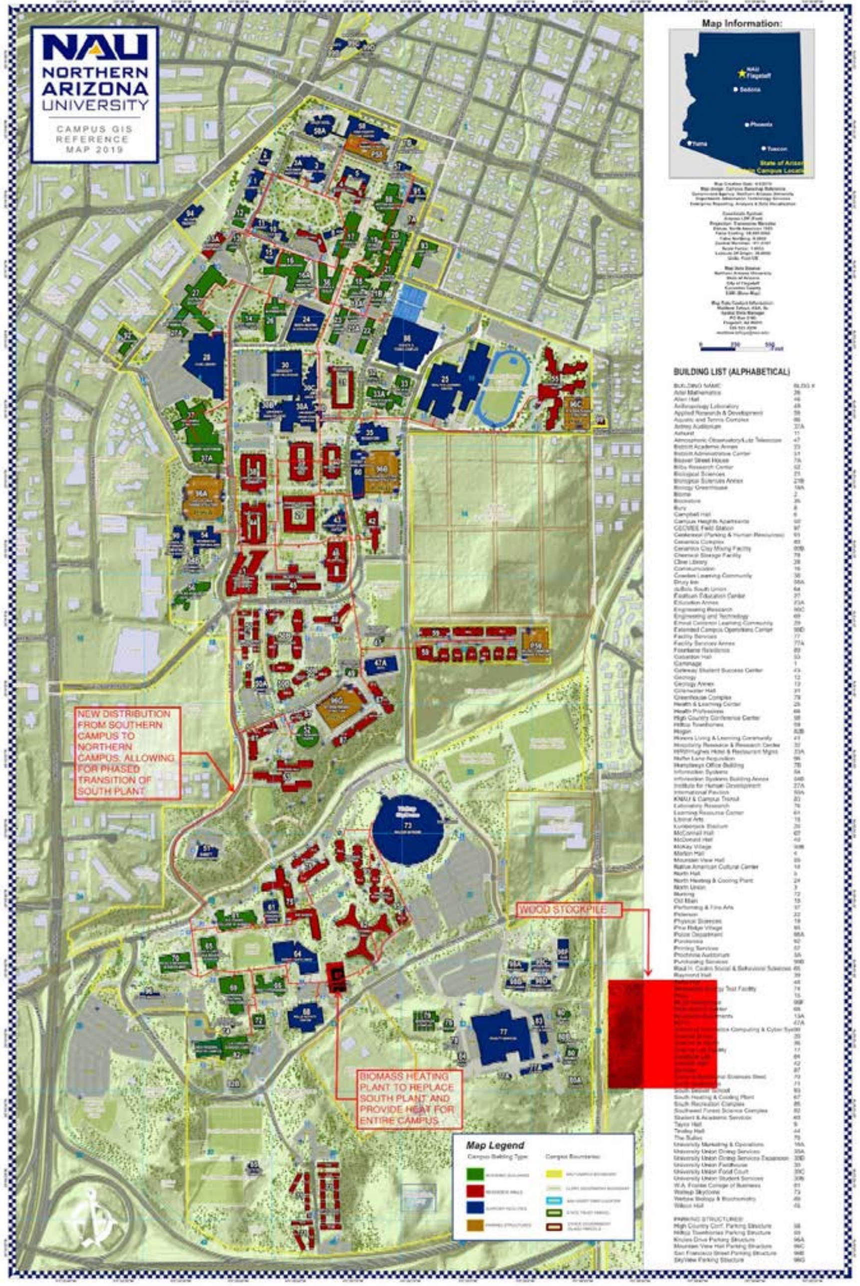


Figure 18. Concept Diagram of Wood Biomass Heating Option

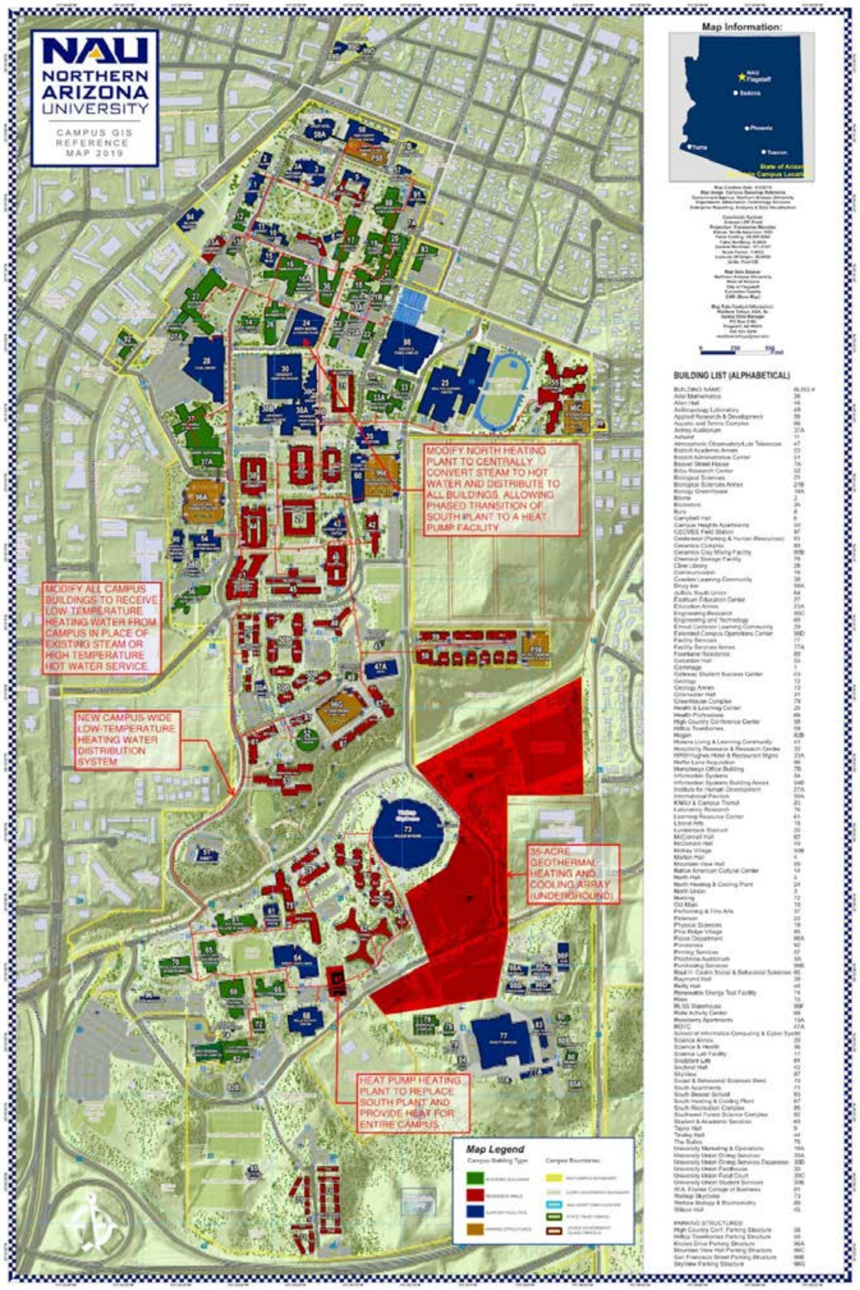


Figure 19. Concept Diagram of Low-Temperature Heating Water conversion with central Heat Plant Option

Resilience

Figure 20. NAU forestry field student experience.

Resilience

In this assessment, the challenge of incorporating social equity emerged as a broad construct. The university will develop its understanding of its resilience and its resilience needs more completely and using the construct provided by Second Nature (NAU 2021 Plan goal #4). Fundamental to this approach NAU/ City of Flagstaff collaboration.

A city is considered to be resilient when its residents, communities, institutions, business and municipal systems adapt and grow to overcome chronic stresses and adeptly respond to acute shocks. Understood broadly, chronic stresses include a full range of economic, environmental and social factors. In this context, social equity is a resilience concern. This recognizes population groups that disproportionately bear the impact of chronic stresses and acute shocks. In applying the lens of social equity, efforts are made to create new practices that are/will eliminate the possibility of uneven impacts.

In addition to ongoing needs, urban infrastructure is intended to mitigate impacts on private property and the public when acute shocks occur. Climate change is causing disaster scale events to occur more often and with increased intensity with consequence to community fabrics and as a matter of increased cost to recovery.

The City of Flagstaff addresses the broad definition of resilience in its plans and practices. It has specific focus on issues of social equity and on providing a resilient infrastructure for the whole community benefit. In this plan, NAU dedicates itself to continued partnership with the City of Flagstaff in pursuit of resilience.

The COVID-19 pandemic tested many of Flagstaff Mountain Campus systems. The pandemic forced shifts in the university workforce, allowing for a dramatic increase in numbers of employees who worked remotely. On-line classes during the pandemic affirms the viability of the university's larger shift (or expansion of offerings) in that direction. However, it appears to be too soon for many campus systems to identify if changes made during the pandemic will be extended and, therefore, the potential associated impact on reducing university greenhouse gas emissions can't yet be quantified.

Climate Change Projections

In Coconino County, public records establish that flooding dominates as the type of extreme weather event of the last three decades. This is the expectation going forward, though climate projections show a shifting location and intensity of the flood risks. Drought is the second most common climate/weather event of magnitude in the region and is forecast to continue.

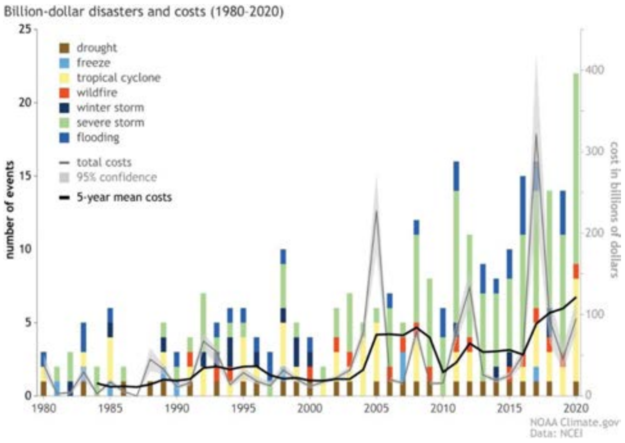


Figure 21. NOAA Accounting of Billion-Dollar Disasters and Costs

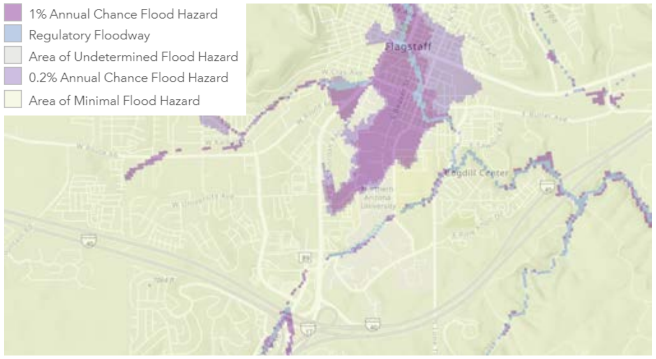


Figure 22. Current Flood Map
(Source: FEMA)

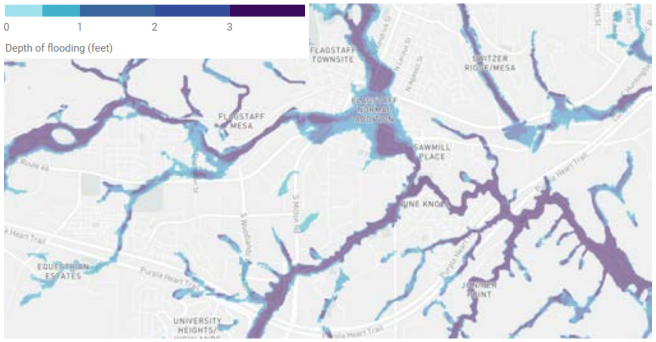


Figure 23. Projected Flood Risk for 2050
(Source: First Street Foundation)

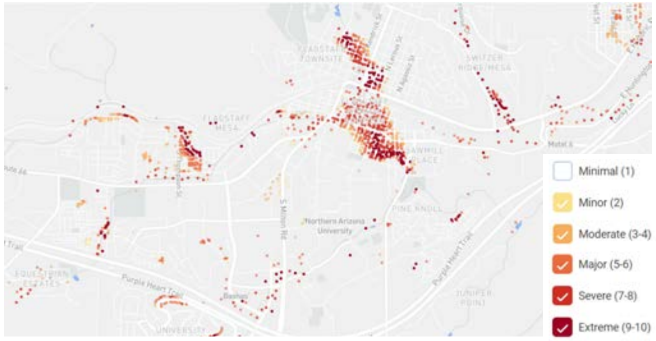


Figure 24. Projected Flood Risk Intensity for 2050 (Source: First Street Foundation)

For Coconino County, federal government climate models[16] show that the maximum daily temperature will rise, as will the number of consecutive days of extreme heat. The climate models show that the maximum days of extreme cold and number of consecutive days of extreme cold will moderate.

An Action Plan to Anticipate Climate Shocks and Stressors

The university elected to follow the Second Nature structure for identifying campus resilience needs and opportunities and for coordinating those with the university's host city. This will enable NAU to commit to the Second Nature' Climate Commitment. It entails creating a resilience plan through a formal structure of:

- Coordinating with the City of Flagstaff re: identifying the needs for and creating enhanced resilience,
- Generating a baseline of resilience activities for the campus to undertake in response to its assessment of need and capabilities to respond to them, and
- Committing details of NAU's planned resilience activities in the form of a written document.

Second Nature offers flexibility in this process. At this writing, NAU anticipates that its resilience plan will address climate change mitigation through university action to reduce Scope 1 and Scope 2 greenhouse gas emissions, steps to improve resilience es an attribute of facility and campus community functionality, through living laboratory opportunities, and as a collaborating partner to the City of Flagstaff.

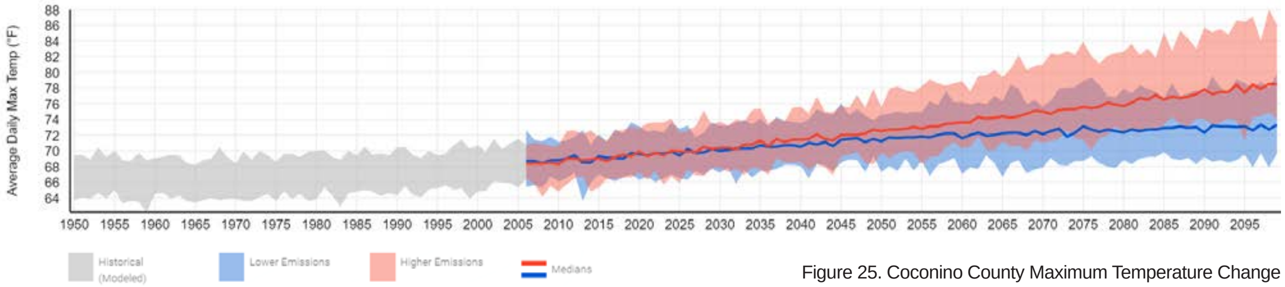


Figure 25. Coconino County Maximum Temperature Change (Source: NOAA)

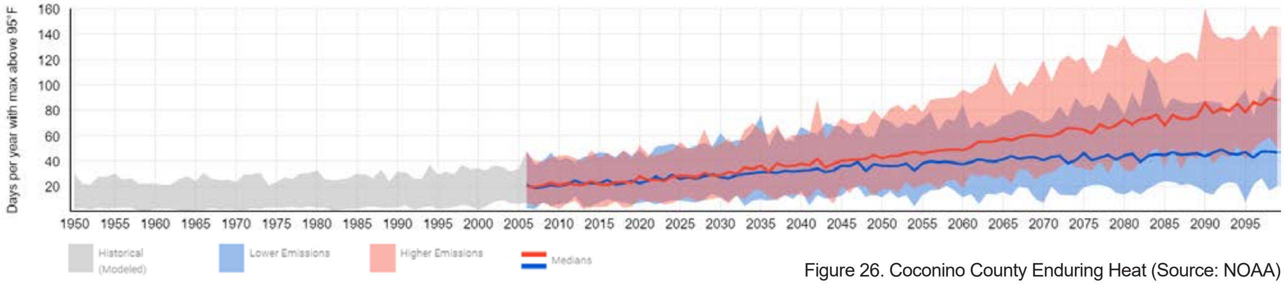


Figure 26. Coconino County Enduring Heat (Source: NOAA)

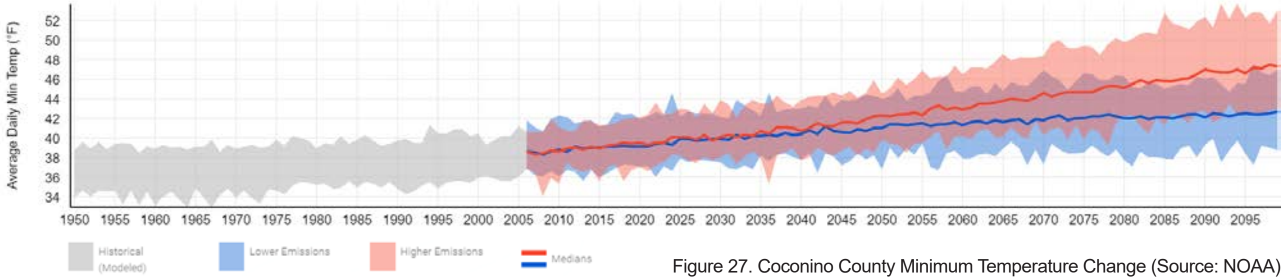


Figure 27. Coconino County Minimum Temperature Change (Source: NOAA)

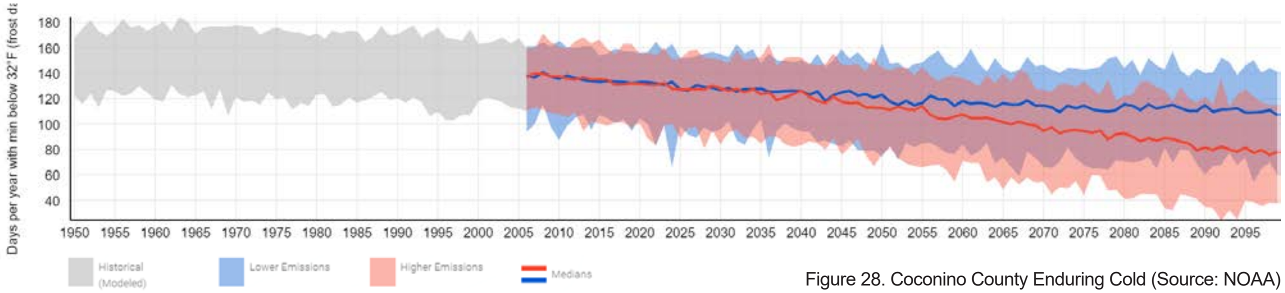


Figure 28. Coconino County Enduring Cold (Source: NOAA)

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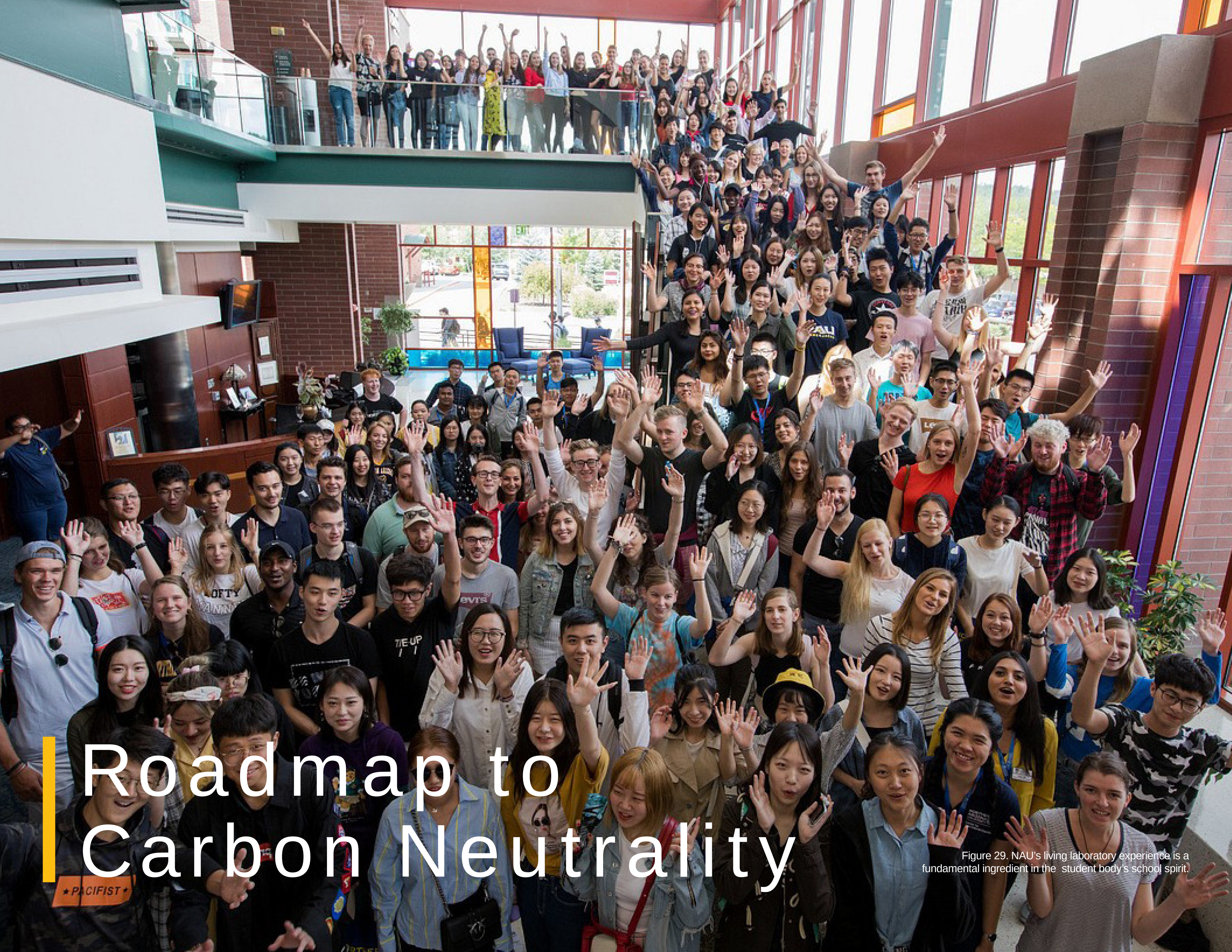
[16] Source: NOAA



Roadmap to Carbon Neutrality

Figure 29. NAU's living laboratory experience is a fundamental ingredient in the student body's school spirit.

Roadmap to Carbon Neutrality

Anticipating this assessment, the NAU Office of Sustainability executed a university-wide survey to offer the community perspective
as a start to committee efforts. The survey gave respondents the opportunity to recommend activities, some of which could be understood to reduce carbon and others that are related to broader concerns for campus sustainability. In summary, the 2019 campus survey responses for:

- Energy suggested that the Flagstaff Mountain Campus should transition from fossil fuel to 100% renewable or clean energy. The university should minimize its energy costs and anticipate changing regulations and financial risks associated with reliance on fossil fuels. Respondents asked for more activity to reduce building energy demand and further consideration of biomass as a fuel source.
- Landscape management suggested that the Flagstaff Mountain Campus should minimize water use (both potable and reclaimed) in landscape management, eliminate the use of inorganic fertilizers and pesticides (particularly those that have adverse effects on pollinators and beneficial insects), and increase space used for gardens, bioswales and naturalized habitats.
- Community resilience suggested that the Flagstaff Mountain Campus divest from fossil fuels, better address justice and equity, address food and housing insecurity on campus and ensure that CAP measures avoid disproportionate impact on vulnerable populations.
- Waste management suggested that the Flagstaff Mountain Campus should continue and expand on its waste minimization and diversion programs with the aim of realizing zero waste.
- Water management suggested that the university should adhere to a water budget so that it can contribute to the region's need to forestall the huge capital investment anticipated to expand the community's water supply.
- Transportation management suggested that the university should reduce university related travel that relies on fossil fuel vehicles.

Energy

The Flagstaff Mountain Campus expends about $4M/year in annual energy costs which equates to $0.65/SF. University standards express means of achieving energy efficiency in new construction and are silent on means of achieving efficiency in the existing building stock. Given that the university has modest expectations for new buildings, this assessment turned to the question of what opportunity is there to improve the efficiency of the existing building stock.

This assessment employed a utility meter data-driven virtual energy audit to identify the most impactful opportunities for detailed audits and gauge the potential for reductions in energy demand. The virtual energy audit of the campus considered building use, building age and the building's ability to respond to seasonal weather conditions for analysis. Through review and analysis of these attributes, the energy consumption of buildings can be ranked and prioritized by the potential for energy, water, carbon, and cost reductions. The energy use intensity (EUI) was calculated for each building with metered, monthly utility data except for 3rd party-owned residential buildings, the central utility plants and the data center. A NAU target EUI was calculated for each building representing the 75% lowest EUI among that building type on campus, similar to the EPA method for determining EnergyStar buildings. For each building, a net-zero energy target was calculated based on the AIA 2030 challenge.

Each campus building's ability to respond to seasonal weather changes was analyzed through statistical analysis of historic weather data and utility energy consumption. Then, each was assigned a climate-opportunity score representing how much energy the building uses in response to changing weather and climate conditions. An equipment opportunity score was calculated, indicating the extent of each building's energy use that is unrelated to weather and climate conditions. The highest scoring building with equipment opportunity have the most potential for energy savings. Here, the university should first consider reducing and/or replacing their energy-intensive equipment such as lighting, ventilation fans, pumps, kitchen and scientific equipment Older buildings will benefit most from repairs and technology upgrades while new building technologies may need calibration, repair or adjustment. Newer building with digital controls that have high equipment (or climate opportunity scores) are the best candidates for automated fault detection and diagnostics systems and likely already have compatible controls.

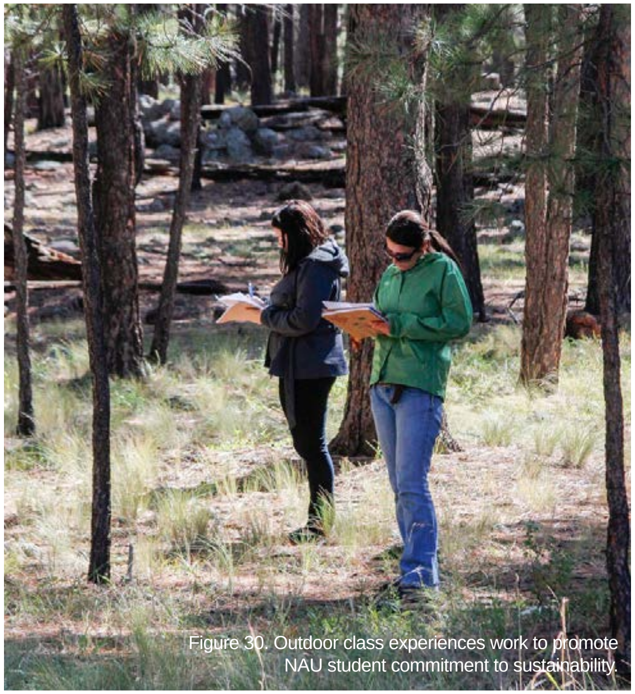


Figure 30. Outdoor class experiences work to promote NAU student commitment to sustainability.

The Information Technology Services Building (054) has a high potential for energy conservation tied to the building's data and information technology equipment but likely would not benefit from insulation or window retrofits. The assessment recommends an IT-and IT-cooling focused energy audit.

Buildings with high scores for envelope and heating systems, such as the High Country Conference Center are good candidates for full building, detailed energy audits and/or retro-commissioning. The priority candidates for energy audits, retro-commissioning and automated fault detection and diagnostics systems are the Science Laboratory, Wettaw, Performing and Fine Arts, and High Country Conference Center. If these buildings were sufficiently invested in, 42% of their energy use could be reduces (a $250,000/year savings). An investment in focused energy audits and retro-commission for these buildings followed by executing the energy savings measures recommended by the audits could yield a 5-year payback to reduce campus energy consumption by 8%. Energy persistence monitoring or automated fault detection and diagnostics should follow this investment to ensure that the energy savings are sustained. These buildings have high percentages of fresh air and high air changes rates in spaces. Rebalancing airflows rates, implementing demand control ventilation, employing aggressive temperature set-backs or resets and airside economizer validation are likely to result in significant energy savings

The university's Green Labs program should result in the Science Laboratory and Wettaw installing low-temperature freezers, more efficient equipment and fume hoods and adjusted airflow rates to meet current operational needs.

Performing and fine arts buildings are a target for lamp retrofits as their lighting demands are exceptional.

Retro-commissioning and energy retrofits can result in energy and carbon savings of 10-30%. Retrofit projects in high energy-intense buildings typically offer the best opportunity for energy cost savings and investment payback.

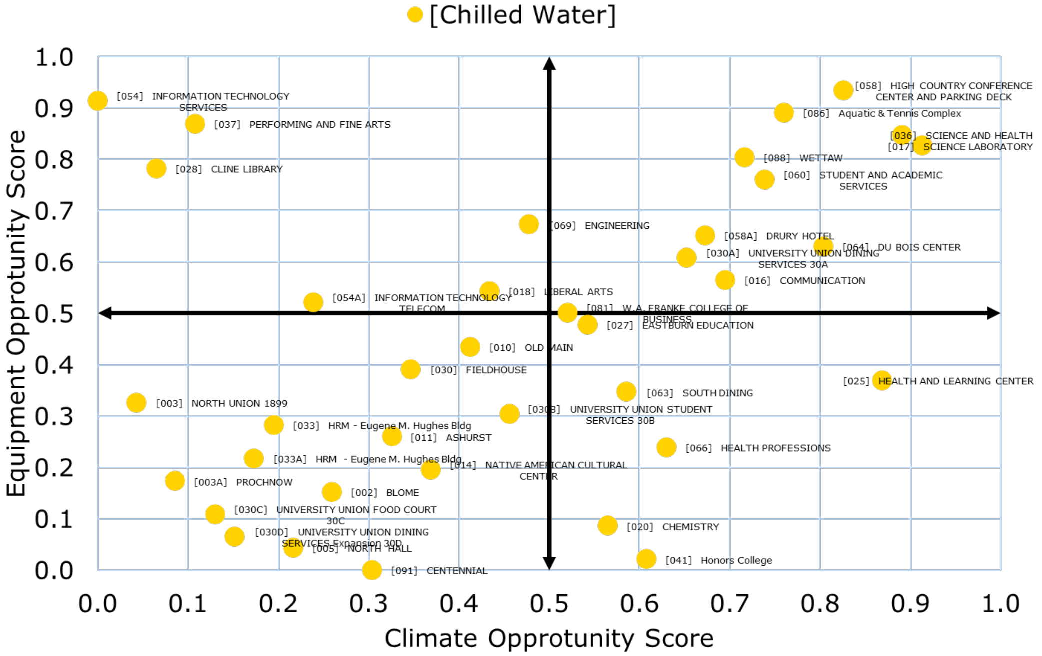


Figure 31. NAU Campus Virtual Chilled Water Energy Audit

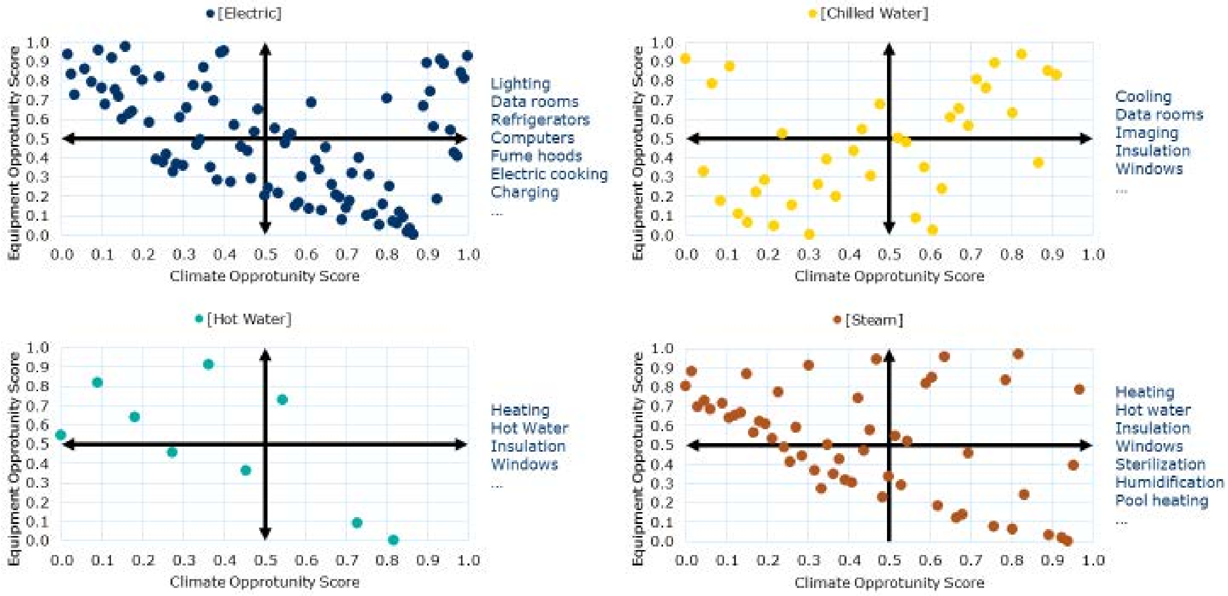


Figure 32. NAU Campus Virtual Utilities Audit

Utility	Equipment Opportunities	Climate Opportunities
Electricity	Lighting upgrades Fan and pump motor upgrades EnergyStar equipment replacements IT efficiency review Automatic receptacle controls Lab freezer audits	Fan and pump motor upgrades Fan static pressure reset Add/replace static pressure sensors Air conditioning unit replacements VAV fan retrofit
Chilled Water	Lab freezer audit Supply air temperature reset IT efficiency review Kitchen audit Dehumidifier repair/upgrade	Economizer repairs/AFDD install Chilled water pump audit/upgrade Energy valve installation/rebalance Insulation retrofits Window replacements Fenestration Weatherstripping Gravity to motorized vent replacements
Hot Water	Ventilation air balance Valve retro-commissioning Demand control ventilation install DCV calibration Energy recovery install	Insulation retrofits Window replacements Fenestration Weatherstripping Repair/replace envelope seals Gravity to motorized vent replacements
Steam	Steam system audit/inspection Steam trap/valve/accessory repairs Steam piping insulation Humidifier repairs Energy recovery install	Insulation retrofits Window replacements Fenestration weatherstripping Repair/replace envelope seals Gravity to motorized vent replacements

Figure 33. Energy Conservation Measures for Buildings 10+ Years Old

Campus buildings constructed prior to 2015 with high electric equipment opportunity scores are likely to benefit from LED lamp or fixture retrofits for common fluorescent and incandescent fixtures. LED lighting retrofits commonly have 7-15 year paybacks and are simple to implement through internal work programs or 3rd party energy service contracts.

Every campus building with high chilled water climate opportunity scores are likely to benefit from economizer diagnostics and repairs as airside economizer failures are one of the most common and energy-intensive failures. Existing ventilation systems can be retrofit with economizer controls where they do not currently exist. Economizer repairs reduce both heating and cooling demands but are most easily identified through high cooling demands.

Campus academic, administrative and residential buildings constructed prior to 1970 with high climate opportunity scores related to steam or heating hot water use are recommended to include envelope audits. Thermally bridging, slumping insulation and leaky building elements are common in pre-1970's building and contribute significantly to wasted heating.

Utility	Building	Equipment Score	Year Built
Electric	[017] Science Laboratory	0.975	2007
	[069] Engineering	0.958	1972
	[016] Communication	0.933	1960
	[082] Southwest Forest Science Complex	0.908	1992
	[088] Wettaw	0.891	2000
	[070] Social And Behavioral Sciences West	0.883	1972
	[073] Walkup Skydome	0.858	1977
	[037] Performing And Fine Arts	0.85	1969
	[053] Gabaldon Hall	0.833	1984
	[063] South Dining	0.816	1970
	[082usfs] United States Forest Service	0.808	1992
	[066] Health Professions	0.8	1970
	[062] Mcconnell Hall	0.791	1971
	[028] Cline Library	0.766	1965
	[027] Eastburn Education	0.758	1958
Steam	[020] Chemistry	0.954	1968
	[030c] University Union Food Court 30c	0.878	2009
	[003] North Union 1899	0.848	1952
	[037a] Ardrey Auditorium	0.833	1972
	[017] Science Laboratory	0.787	2007
	[003a] Prochnow	0.772	1914
Chilled Water	[058] High Country Conference Center	0.934	2008
	[037] Performing And Fine Arts	0.869	1969
	[017] Science Laboratory	0.826	2007
	[088] Wettaw	0.804	2000
	[028] Cline Library	0.782	1965
Hot Water	[081] W.A. Franke College Of Business	0.909	2005
	[072] Nursing	0.818	1978

Figure 34. NAU Equipment Audit Priority Buildings

Utility	Building	Climate Score	Year Built
Electric	[008] Bury	0.841	1908
	[019] Physical Sciences	0.958	1960
	[020] Chemistry	0.916	1968
	[021] Biological Sciences	0.891	1967
	[021b] Biological Sciences Annex	0.966	1989
	[030] Fieldhouse	0.8	1965
	[035] Bookstore	0.925	1967
	[043] Gateway Student Success Center	0.975	1967
	[058] High Country Conference Center	0.758	2008
	[070] Social And Behavioral Sciences West	0.941	1972
	[074] Renewable Energy Test Facility	0.766	1972
	[080] Ceramics Complex	0.85	1989
	[082] Southwest Forest Science Complex	0.933	1992
	[082usfs] United States Forest Service	0.991	1992
	[088] Wettaw	0.9	2000
	[089] Fountaine Apartment	0.783	1940
	[099] Seismic Observatory	0.866	1977
	[099b] Granny's Closet	0.858	1968
Steam	[001] Gammage	0.757	1930
	[017] Science Laboratory	0.969	2007
	[018] Liberal Arts	0.833	1963
	[027] Eastburn Education	0.893	1958
	[037] Performing And Fine Arts	0.924	1969
	[037a] Ardrey Auditorium	0.787	1972
	[048] Reilly Hall	0.803	1969
	[088] Wettaw	0.954	2000
Chilled Water	[017] Science Laboratory	0.913	2007
	[058] High Country Conference Center	0.826	2008
	[064] Du Bois Center	0.804	1971
Hot Water	[073] Walkup Skydome	0.818	1977

Figure 35. NAU Climate Audit Priority Buildings

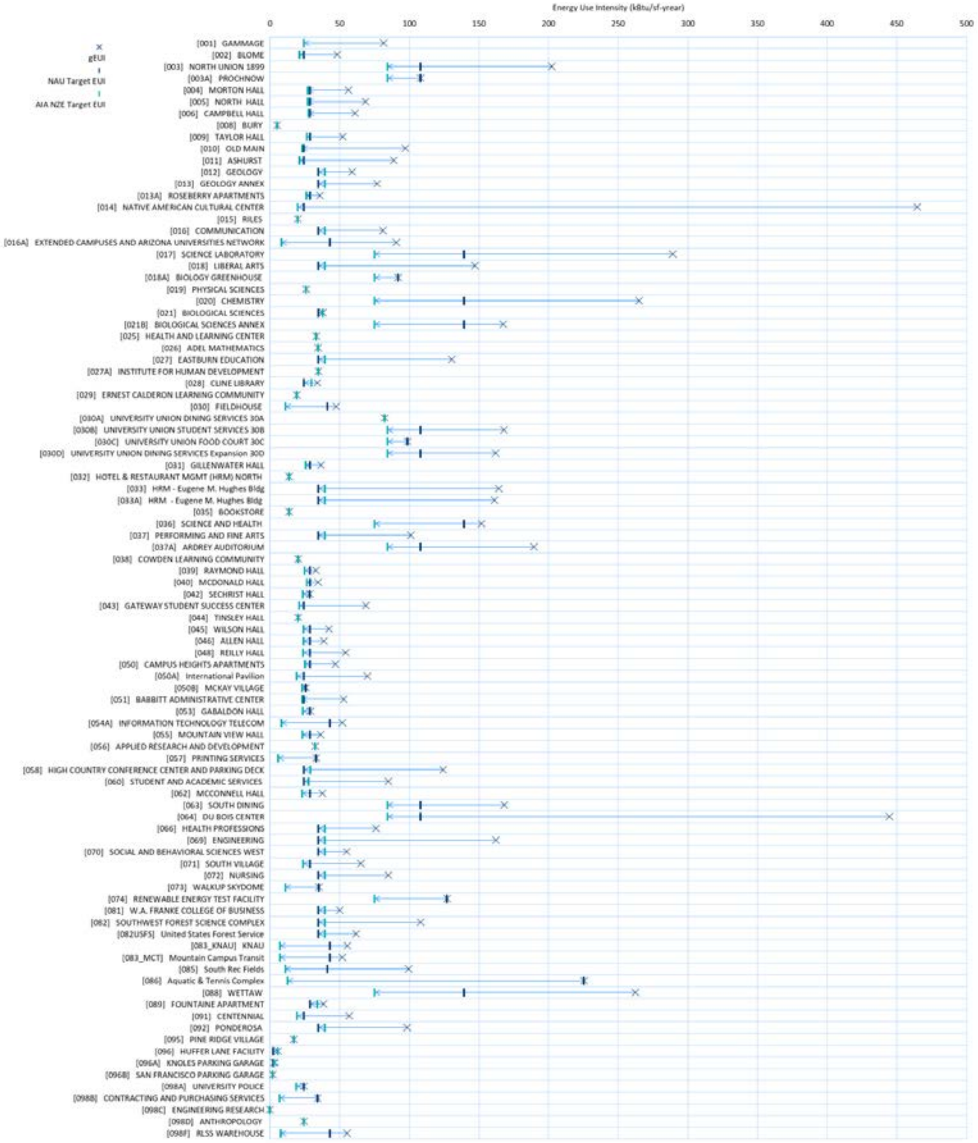
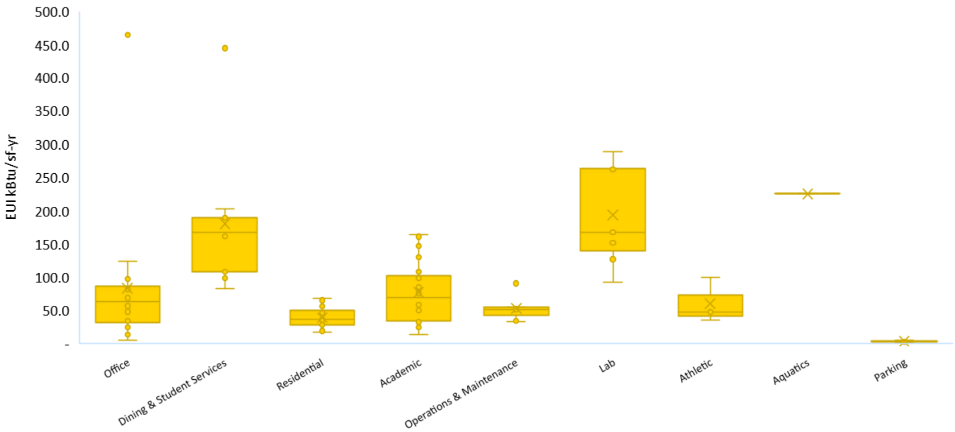


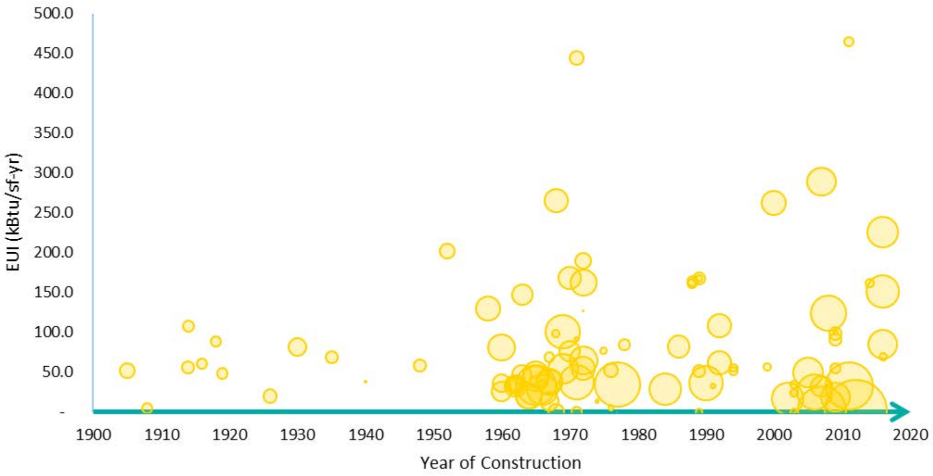
Figure 36. Energy Use Intensity of Campus Buildings

Figure 37. Energy Use Intensity of Campus Buildings by Use Types



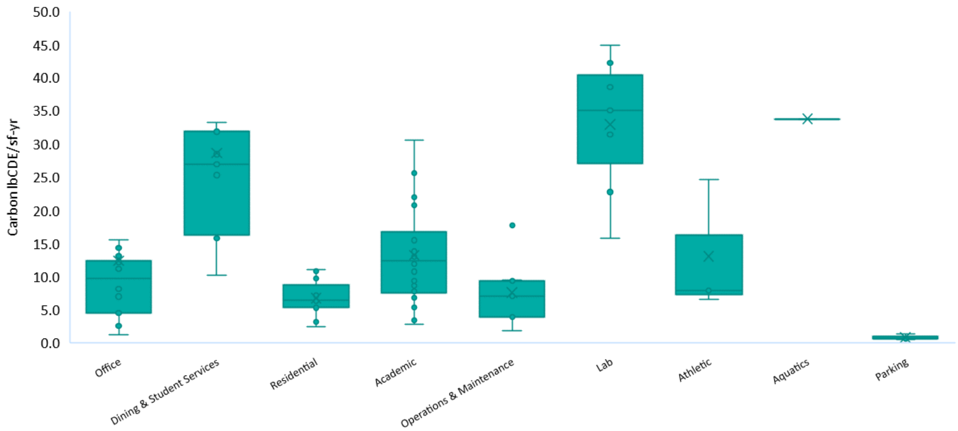
Buildings on campus were categorized into 9 building archetypes. The energy use variation for type is shown in the graphic above.

Figure 38. Building Size and Age Correlates with Energy Use Intensity



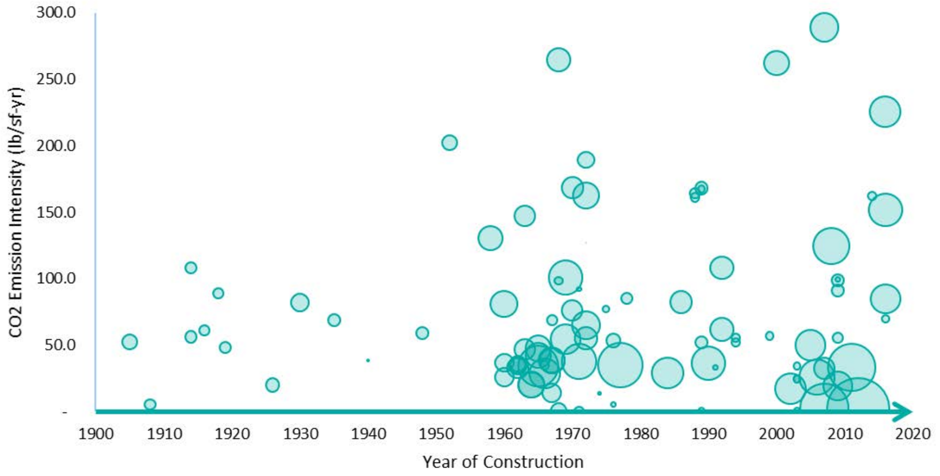
The buildings according to age, size and energy use intensity and graphed below. Notably the size and energy intensity of buildings began to increase in the 1960s.

Figure 39. High Heating Demand Correlates with Carbon Intensity



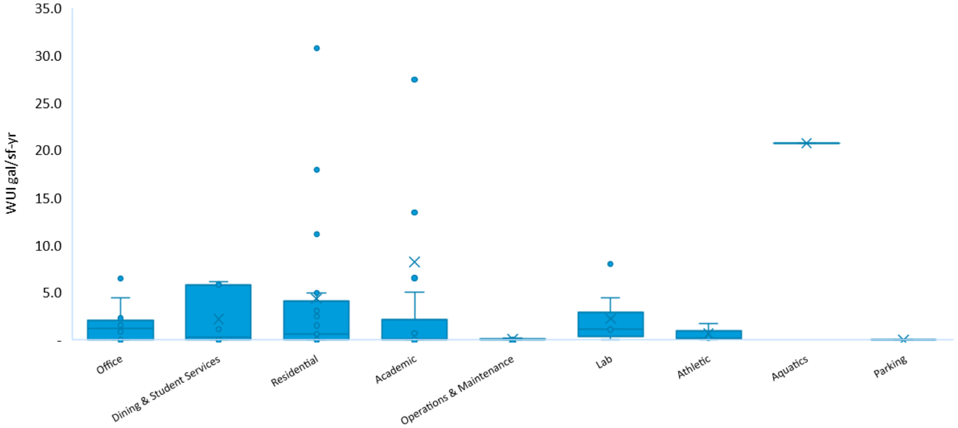
The carbon intensity of the various building types on campus is displayed in the graphic below. Notably the dining facilities, labs and aquatics center have higher carbon intensities relative to their energy use intensities as a result of high heating needs.

Figure 40. Building Age and Size Correlates with Carbon Intensity



The carbon intensity of buildings over time is shown above. Modern buildings on have higher carbon intensities, likely due to higher ventilation requirements associated with modern building codes resulting in additional heating needs.

Figure 41. Building Water Use Intensity Suggests Significant Conservation Opportunity in Outlier Scored Buildings



The water use intensity for buildings with water meters is shown above. There are numerous outliers among the residential and academic buildings. Water audits in the outlier buildings may help identify leaks or opportunities for water savings.

Figure 42. Building Age and Size Correlates with Water Use Intensity

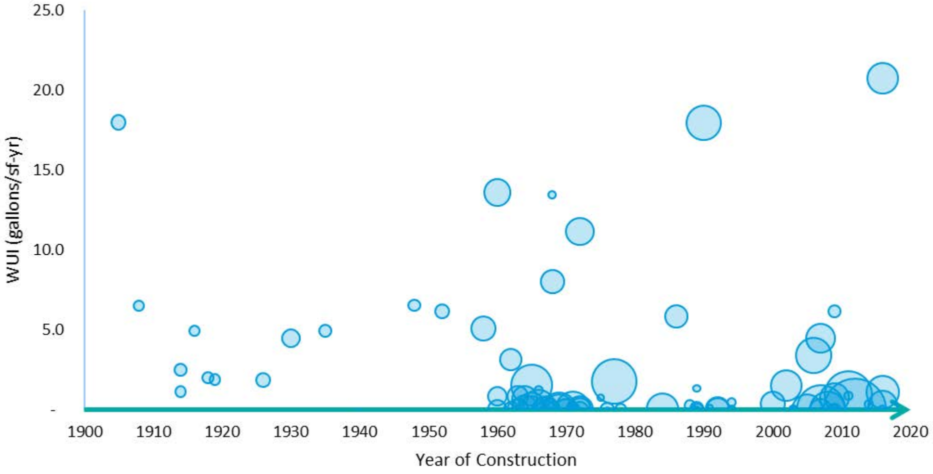
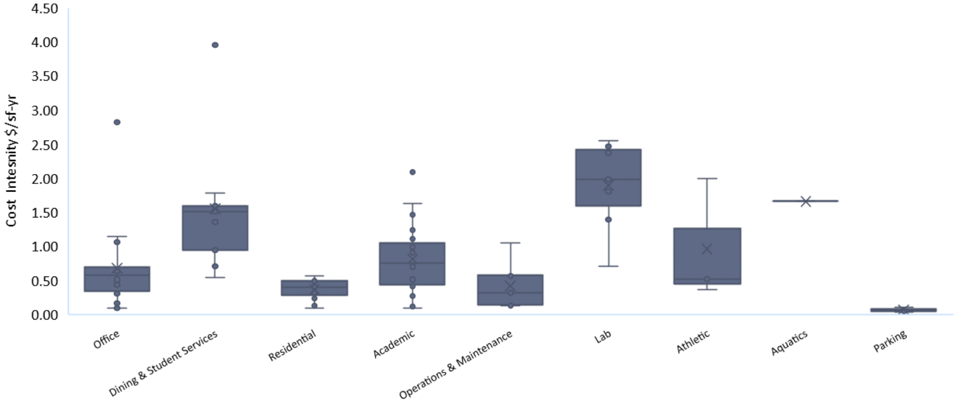
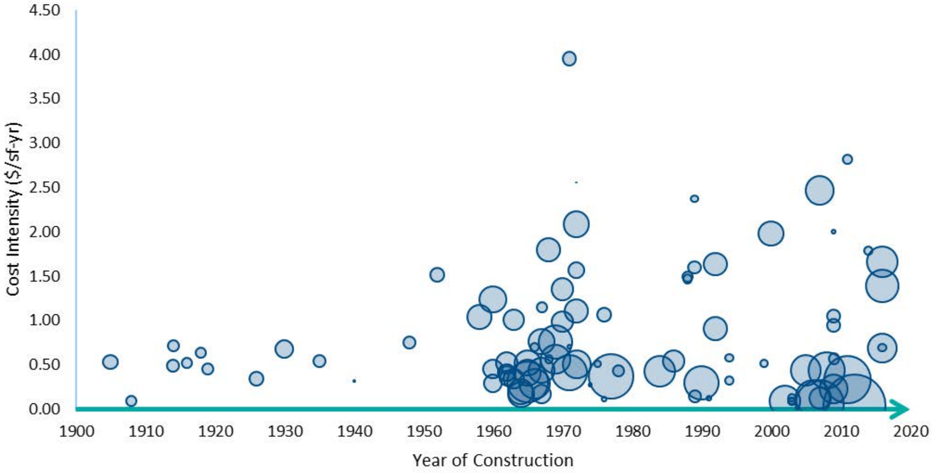


Figure 43.Building Type Correlates with Energy Cost



The energy cost index variation by building type and over time are shown above. Energy costs most closely tracks energy use intensity.

Figure 44. Higher Ventilation Rates Dictated by Code Correlate with Carbon Intensity



The two campus central heating plants are the major sources of campus natural gas combustion. North Plant produces steam for distribution to most buildings on the northern part of the Flagstaff Mountain Campus and consumes approximately 70% of the campus natural gas. The plant has three 50 kpph steam boilers (installed in 2011-2012), a 48 kpph steam boiler (installed in 1980), and a 45 kpph steam boiler (installed in 1962). The current peak load on this plant is approximately 50-60 kpph. There is sufficient capacity and redundancy to meet loads and accommodate growth even without the two older steam boilers.

South Plant produces high temperature hot water for distribution to most buildings on the southern part of the campus and consumes approximately 15% of the natural gas on the Flagstaff Mountain Campus[17]. The plant includes one 10 MMBH hot water boiler (installed in 1980), one 20 MMBH hot water boiler (installed in 1969) and one 46 MMBH hot water boiler(installed in 1974). The current peak load on this plant is approximately 14-16 MMBH. While there is sufficient capacity and redundancy to meet loads and accommodate growth, all three of these boilers are at least 40 years old.

This plan's energy committee considered a suite of options to significantly reduce or eliminate Flagstaff Mountain Campus reliance of fossil fuels. Two campus energy options proved most appealing and were selected for additional study. With both, it is recommended the campus district heating system be converted to all hot water (currently the south campus is hot water and the north campus is steam). The associated benefits are reduced heat loss, longer economic life, and lower operations and maintenance cost. An interconnect of the north and south campus systems allows for consolidation of plant equipment and reduces operational limitations.

Option 1 and Its Phasing

Option 1, woody biomass, will provide heating only, or a small amount of electricity as a by-product of heating (such as by use of a backpressure steam turbine generator). A combined heat and power facility was not included in this option because there are lower-cost options for procuring carbon-neutral electricity off-site through power purchase agreements and through the electric utility that serves the Flagstaff Mountain Campus (which plans to decarbonize the electric supply 50% by 2030 and 100% by 2050). Without impact to the emissions results, this option's heating plant could utilize gasification or direct combustion technology. The current analysis is that the existing (relatively new) steam boilers in the North Plant cannot operate on biogas from a gasification system. If that becomes feasible, it could represent capital cost reductions relative to this assessment.

The wood feedstock will be procured, delivered to campus and stockpiled. The schedule for delivery will dictate the space needed for stockpiling feedstock. For example, the on-campus stockpile would be smaller if the university arranges for more frequent deliveries during colder months (perhaps doubling the truck delivery rate). Without knowledge that a cold month delivery schedule can be arranged, the average annual delivery is assumed to be 45 trucks per week.

To limit materials handling, it is assumed that the stockpile and heating facility be proximate with underground piping to distribute the heat.

The first step to implement biomass heating is to interconnect the north and south campus heating systems (phase 1). This can be achieved by installing a high temperature hot water connection between the plants, and converting the buildings in between to utilize high temperature hot water. The building conversion designs along this path should consider that the temperature of the high temperature hot water could be lowered in the future. During an interim period, the high temperature hot water can be utilized in North Plant to generate steam in parallel to the plant's natural gas combustion steam boilers. North Plant can also utilize the natural gas combustion steam boilers to generate hot water and distribute it to the south. This allows South Plant hot water boilers to be retired at the end of their economic life (approximately 2030). When the biomass heating plant is constructed and connected to this hot water interconnect it can serve the entire campus load either by direct hot water connection or conversion of hot water to steam at North Plant. Well maintained, the North Plant natural gas combustion steam boilers can be utilized as a backup for the entire campus heating system, serving steam directly or by conversion to hot water within the plant.

Around 2040, the north campus steam and condensate piping will reach the end of its economic life and can be replaced with hot water (phase 2 and 3). North Plant natural gas combustion steam boilers can remain in use as their ability to convert steam generated into hot water has value as a backup to the biomass heating plant.

Around 2050, the south campus hot water distribution that was not replaced in Phase 1 will reach the end of its economic life and be replaced (Phase 4).

Phase 5 is a catch-all for centralization of heating systems. It is recommended these facilities be connected to the district heating system either at the end of the local heating system's economic life or as desired to eliminate the small fraction of remaining local combustion of natural gas.

The images that follow are conceptual campus phasing maps for this option.

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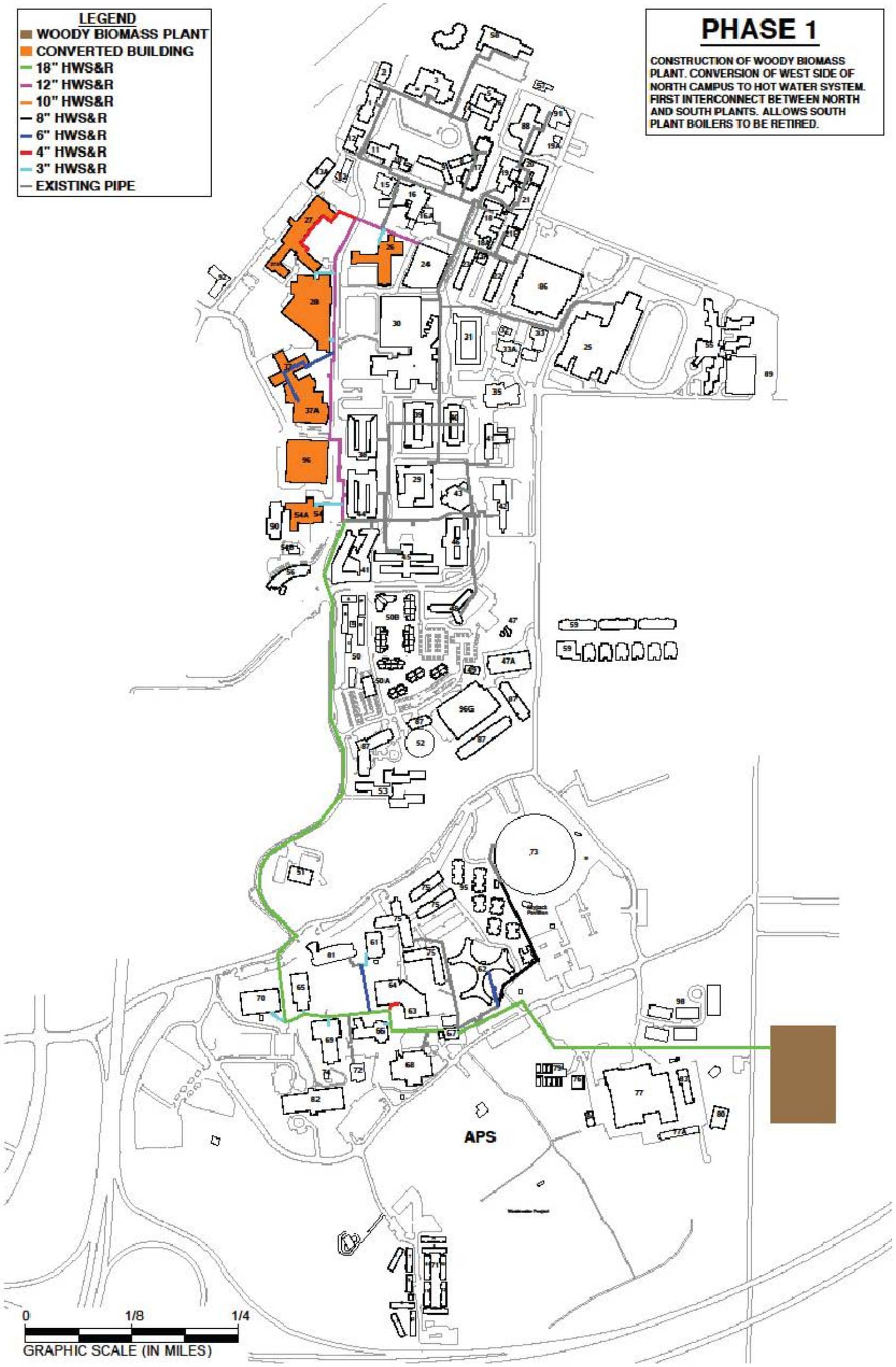
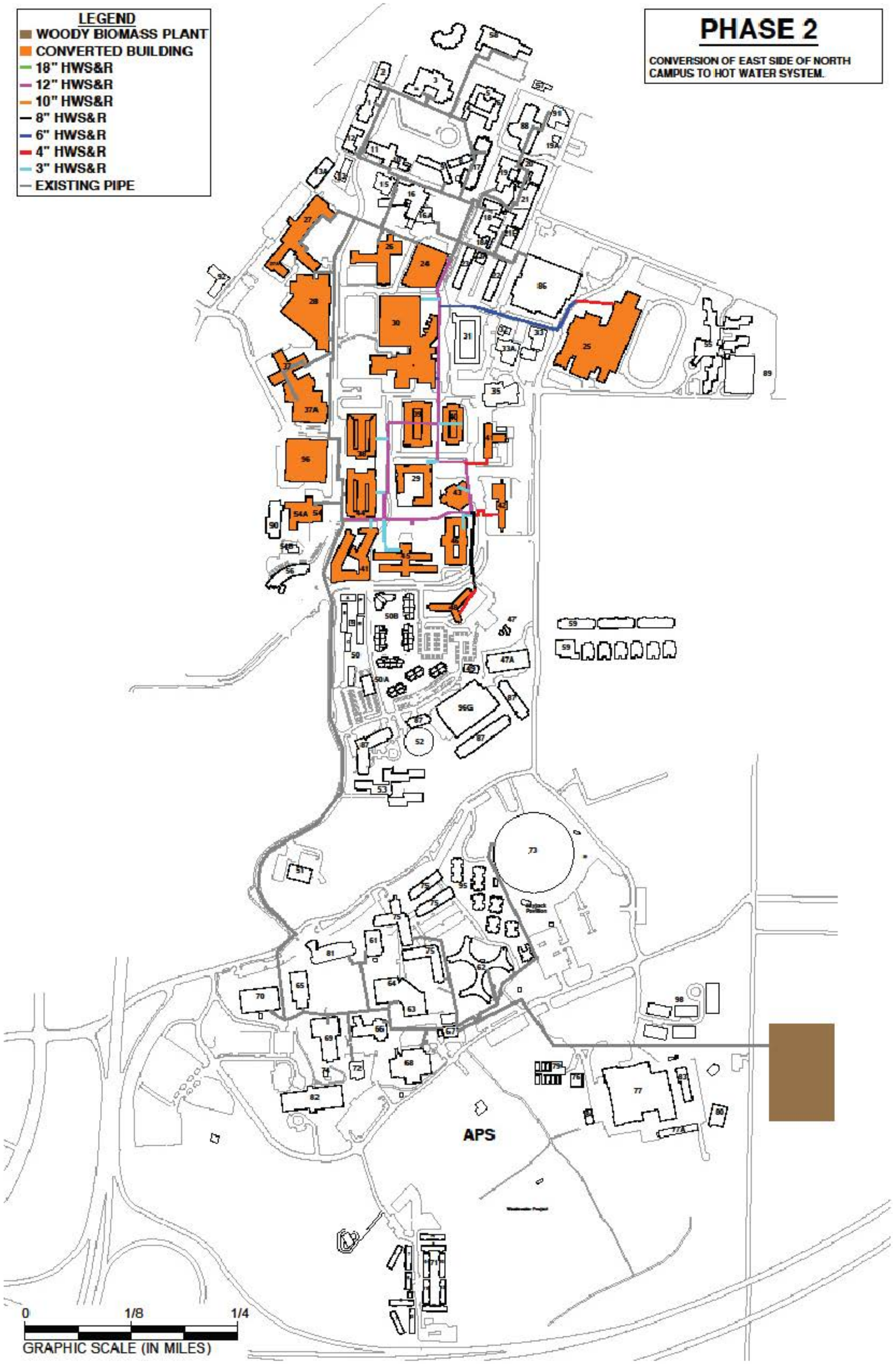
[17] | 15% of the natural gas consumed on the main Flagstaff Mountain Campus occurs directly in buildings.



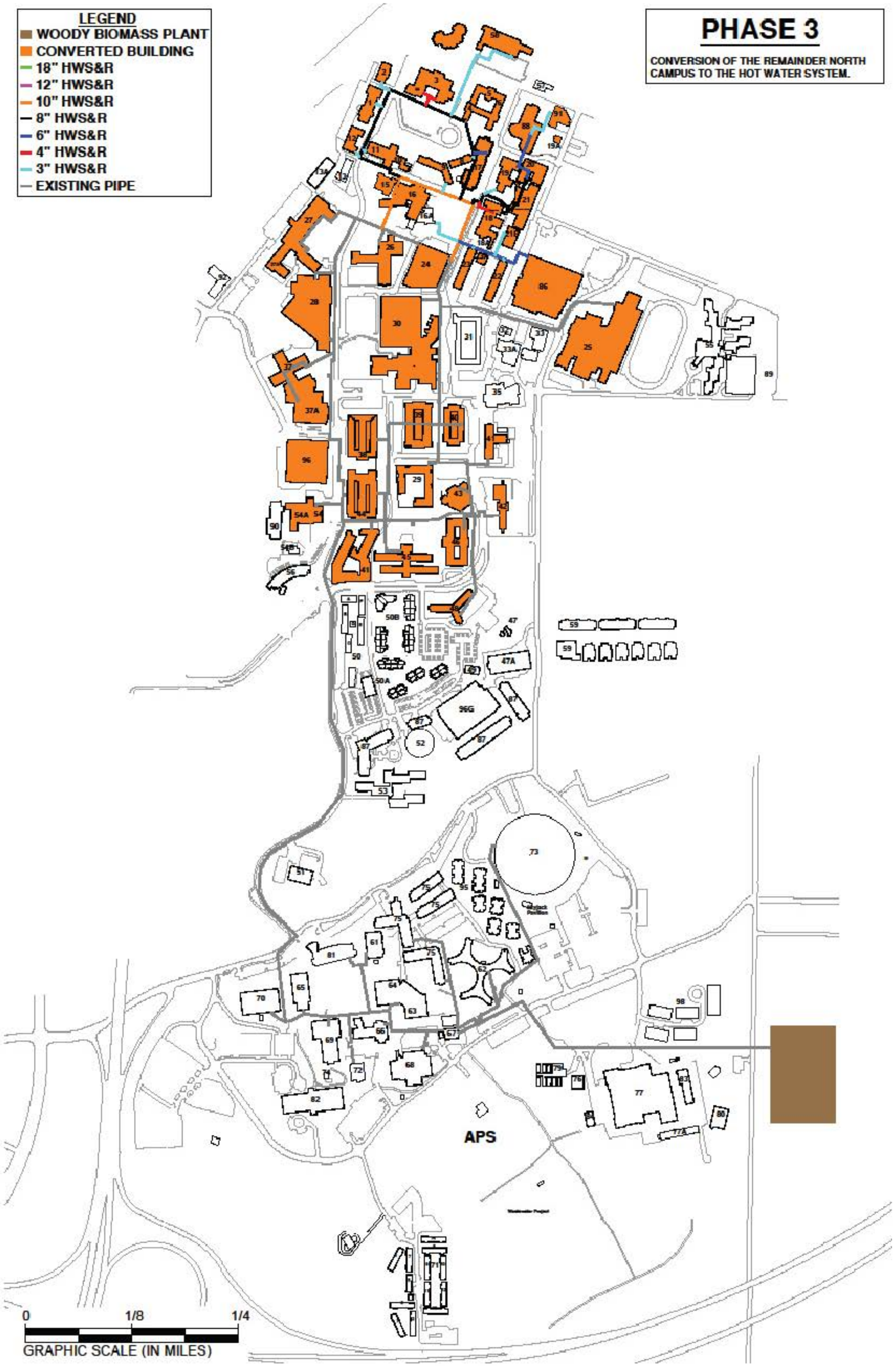
PHASE 1

CONSTRUCTION OF WOODY BIOMASS PLANT. CONVERSION OF WEST SIDE OF NORTH CAMPUS TO HOT WATER SYSTEM. FIRST INTERCONNECT BETWEEN NORTH AND SOUTH PLANTS. ALLOWS SOUTH PLANT BOILERS TO BE RETIRED.



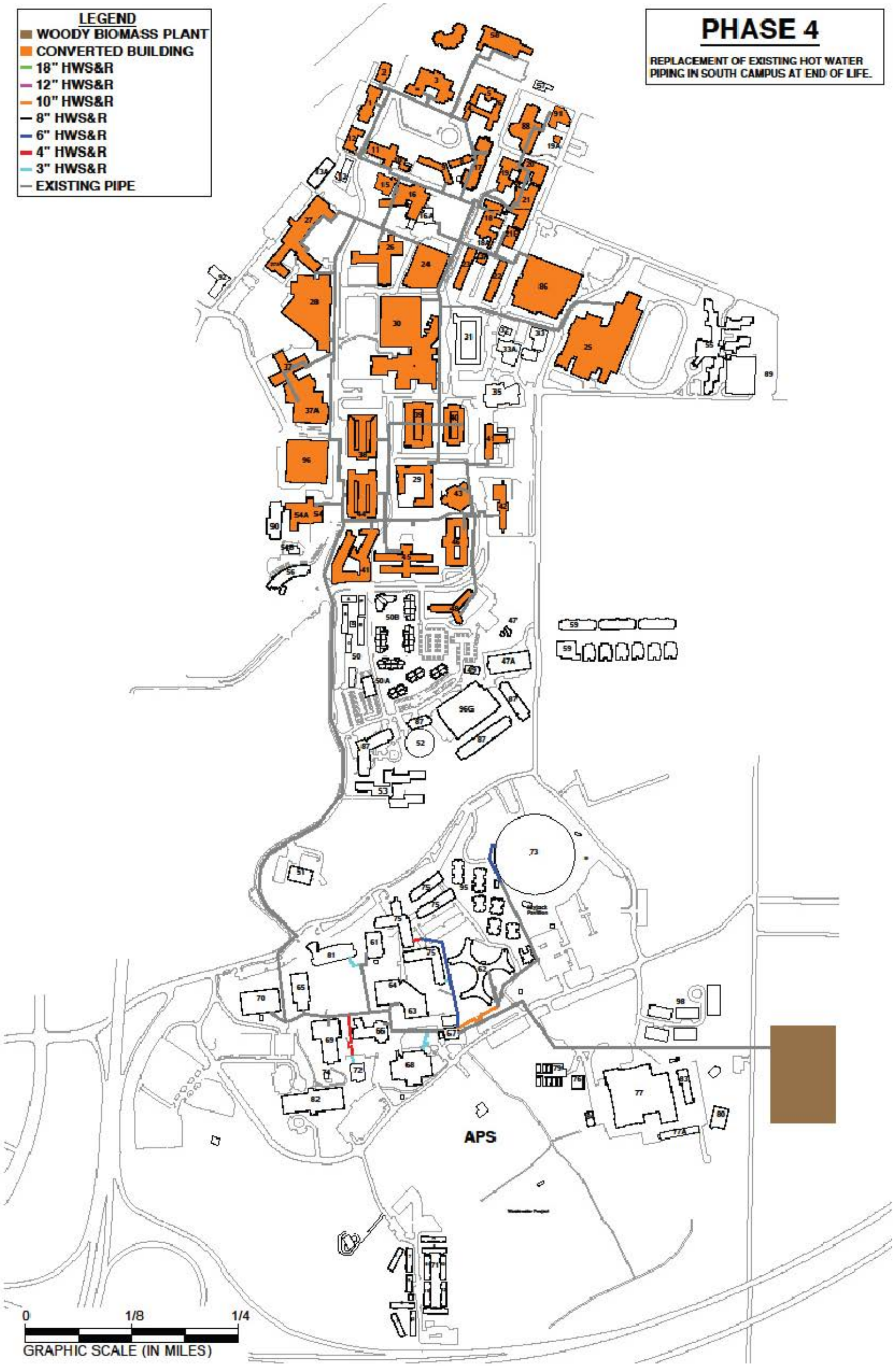
PHASE 2

CONVERSION OF EAST SIDE OF NORTH CAMPUS TO HOT WATER SYSTEM.



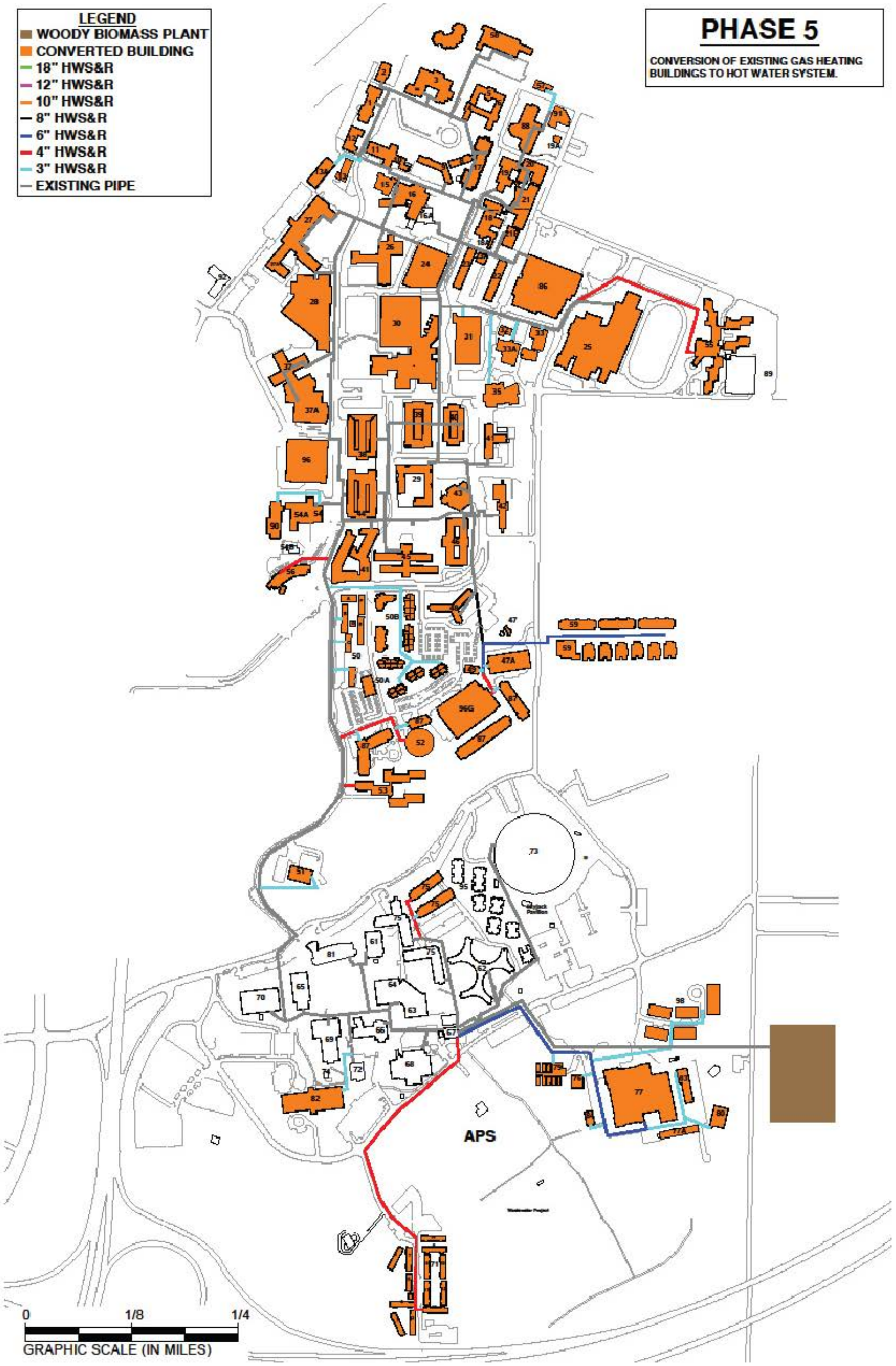
PHASE 3

CONVERSION OF THE REMAINDER NORTH CAMPUS TO THE HOT WATER SYSTEM.



PHASE 4

REPLACEMENT OF EXISTING HOT WATER PIPING IN SOUTH CAMPUS AT END OF LIFE.


LEGEND
WOODY BIOMASS PLANT
CONVERTED BUILDING
18" HWS&R
12" HWS&R
10" HWS&R
8" HWS&R
6" HWS&R
4" HWS&R
3" HWS&R
EXISTING PIPE
PHASE 5
CONVERSION OF EXISTING GAS HEATING BUILDINGS TO HOT WATER SYSTEM.
APS
73
77
0
1/8
1/4
GRAPHIC SCALE (IN MILES)

Option 2 and Its Phasing

Option 2, low temperature heating water conversion with central heat pumps, first requires replacing the campus-wide central steam and high temperature heating water distribution with a low-temperature heating water distribution. It may be advantageous to first convert steam within North Plant to low-temperature heating water and distribute it to the entire campus in a phased manner in combination with retiring and removing steam and high temperature heating water distribution. Initially, this should focus on providing a source of heat to the southern part of campus from North Plant, allowing retirement of the aged high temperature hot water boilers. This will allow South Plant to be repurposed for the heat pump facility. The heat pump facility can eventually operate in parallel to North Plant convertors, replacing the need for boiler operation at North Plant.

Phase 0 of the conversion replaces legacy south campus hot water piping (installed around 1970) and modifications necessary within south campus buildings to allow a year-round heating water supply temperature of 160°F (or less).

In phase 1, low temperature hot water is distributed north from South Plant, back feeding the steam distribution along the west side of north campus and converting those buildings to utilize 160°F hot water. Eventually, the hot water is back fed to North plant. At this point the steam-to-hot water convertors can be installed and the south campus hot water boilers can be retired. Then, South Plant will be repurposed as a heat pump plant.

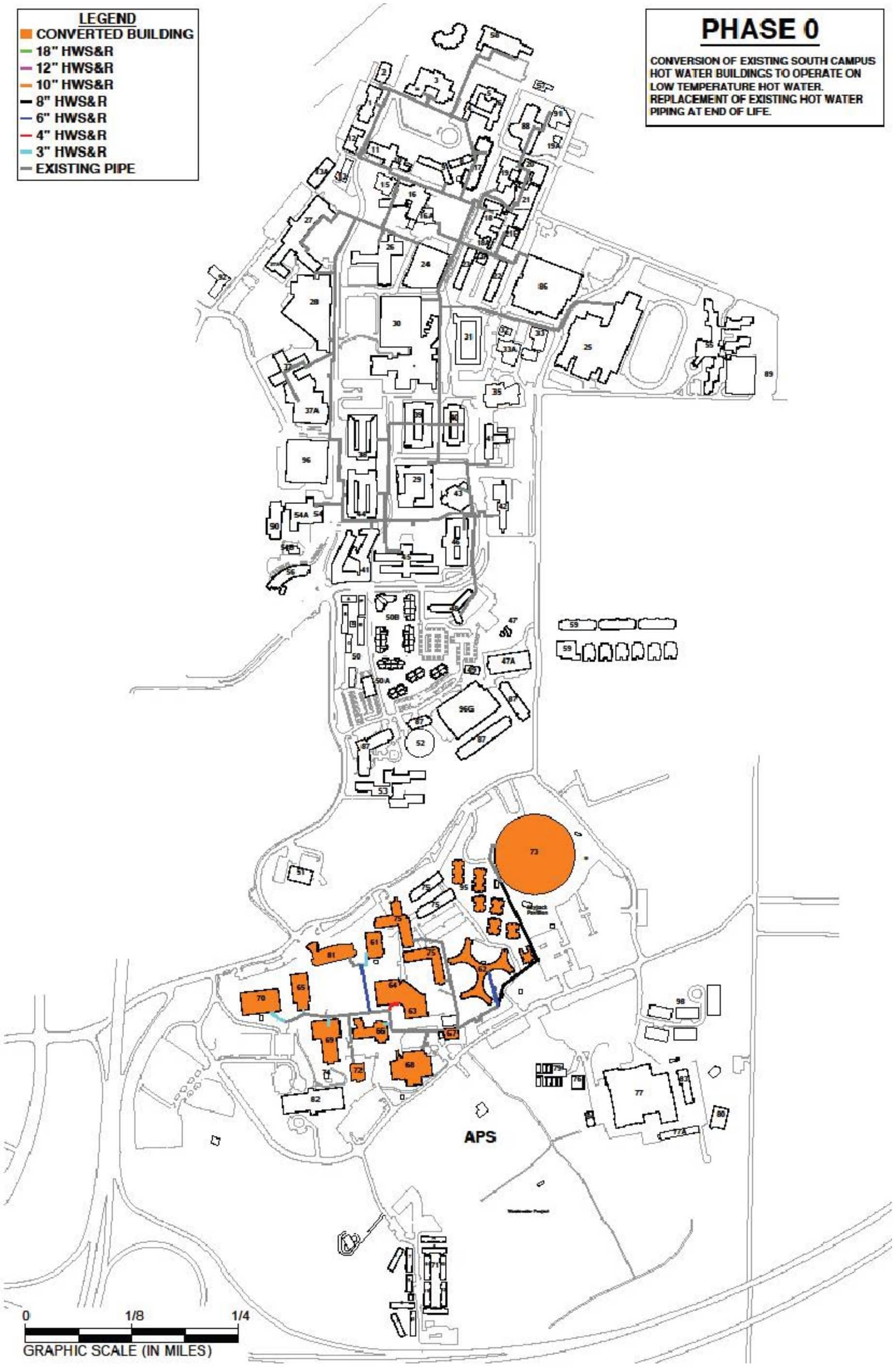
Phases 2 and 3 see the remainder of north campus steam and condensate distribution replaced with hot water distribution.

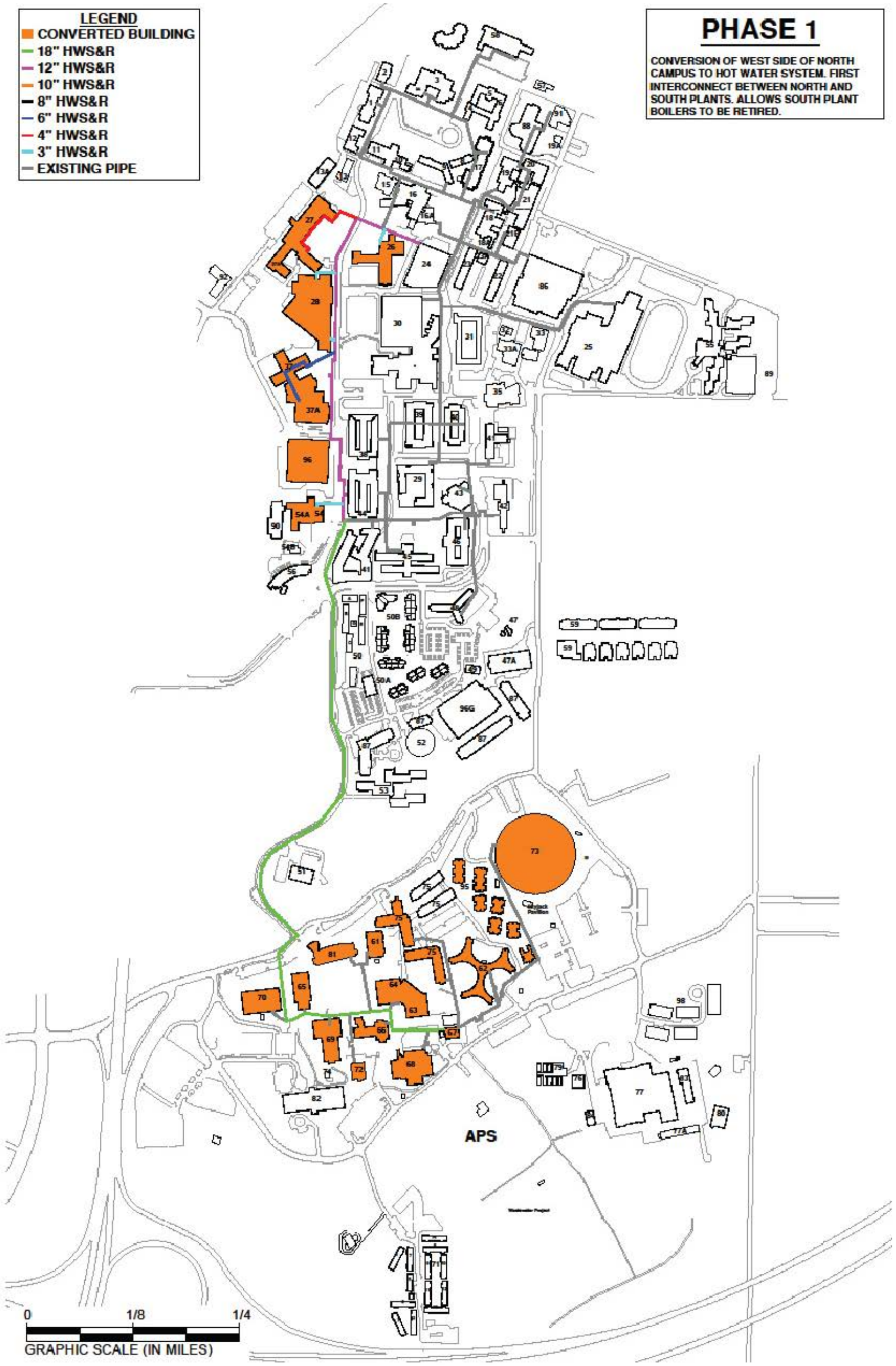
In Phase 4 the balance of the south campus hot water piping is replaced at the end of its economic life (approximately 2050).

Phase 5 is a catch-all for centralization of heating systems. It is recommended these facilities be connected to the district heating system either at the end of the local heating system's economic life or as desired to eliminate the small fraction of remaining local combustion of natural gas.

Phase 6 (which need not occur in sequence with the other phases) is installation of a low-temperature geothermal system and connection of it to the heat pump plant with north and south campus chilled water distribution systems interconnection. This enables combined heating and cooling when loads overlap. It allows the evaporators of the heat pumps to circulate closed loop cooling water through bores in the earth and extract low-grade heat that can be converted to low-temperature heating water. It is estimated that one third of the heat required annually can be recovered from existing cooling processes and two thirds will need to be extracted from the geothermal heating and cooling system. An equivalent quantity of heat will be rejected into the geothermal heating and cooling system during summer to balance the array and eliminate the need to reject heat to the environment.

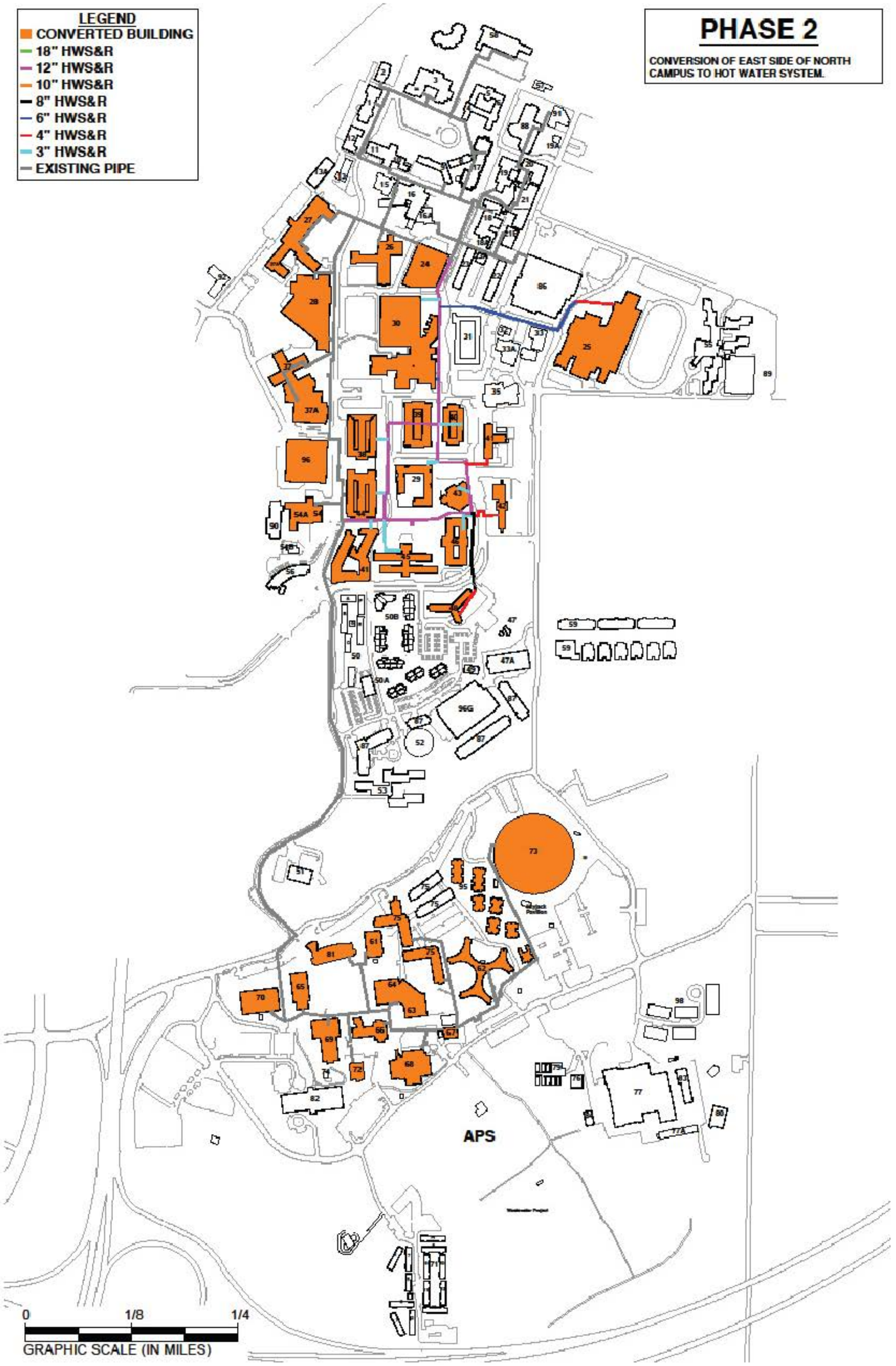
The images that follow are conceptual campus phasing maps for this option.





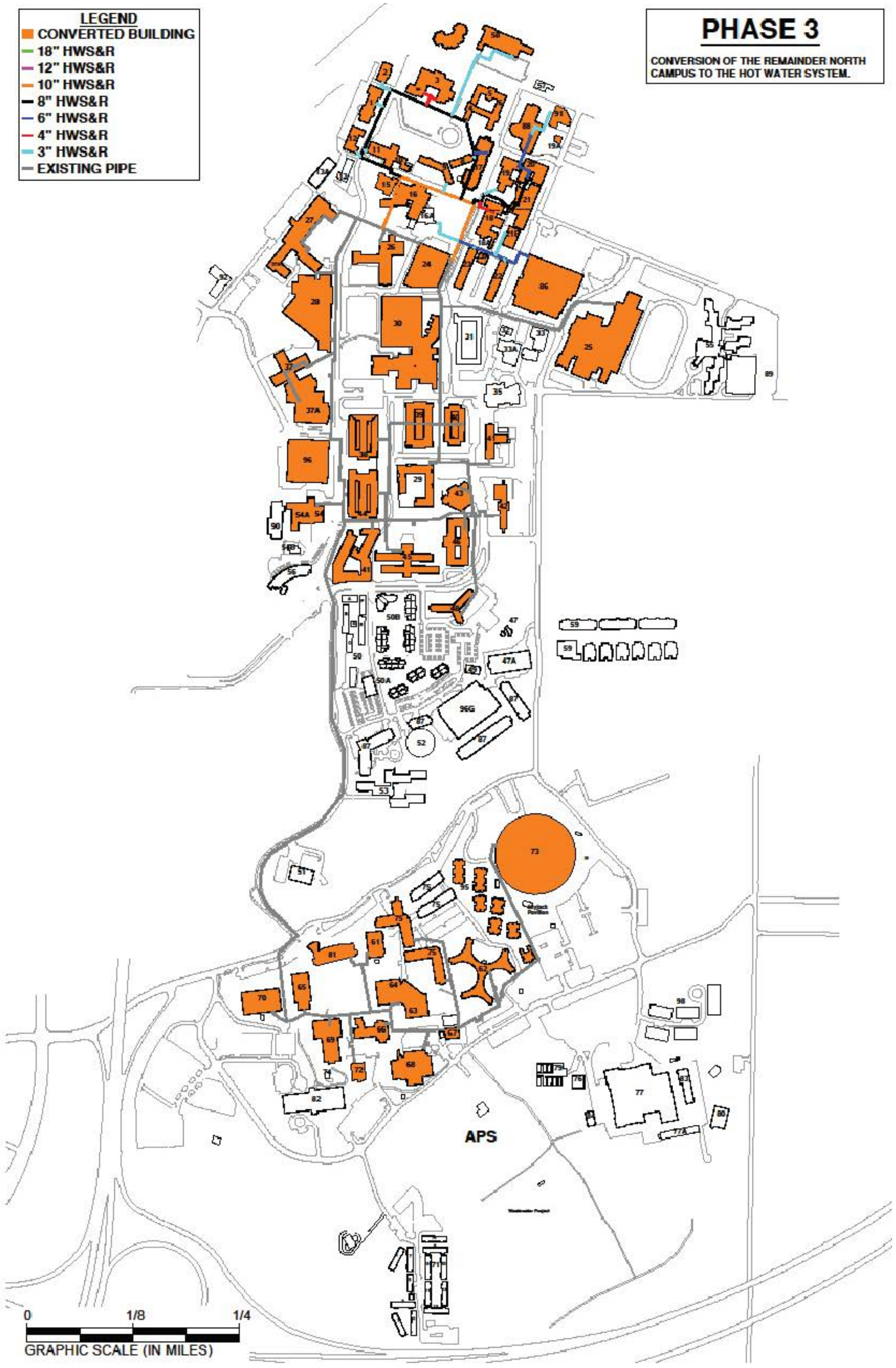
PHASE 1

CONVERSION OF WEST SIDE OF NORTH CAMPUS TO HOT WATER SYSTEM. FIRST INTERCONNECT BETWEEN NORTH AND SOUTH PLANTS. ALLOWS SOUTH PLANT BOILERS TO BE RETIRED.



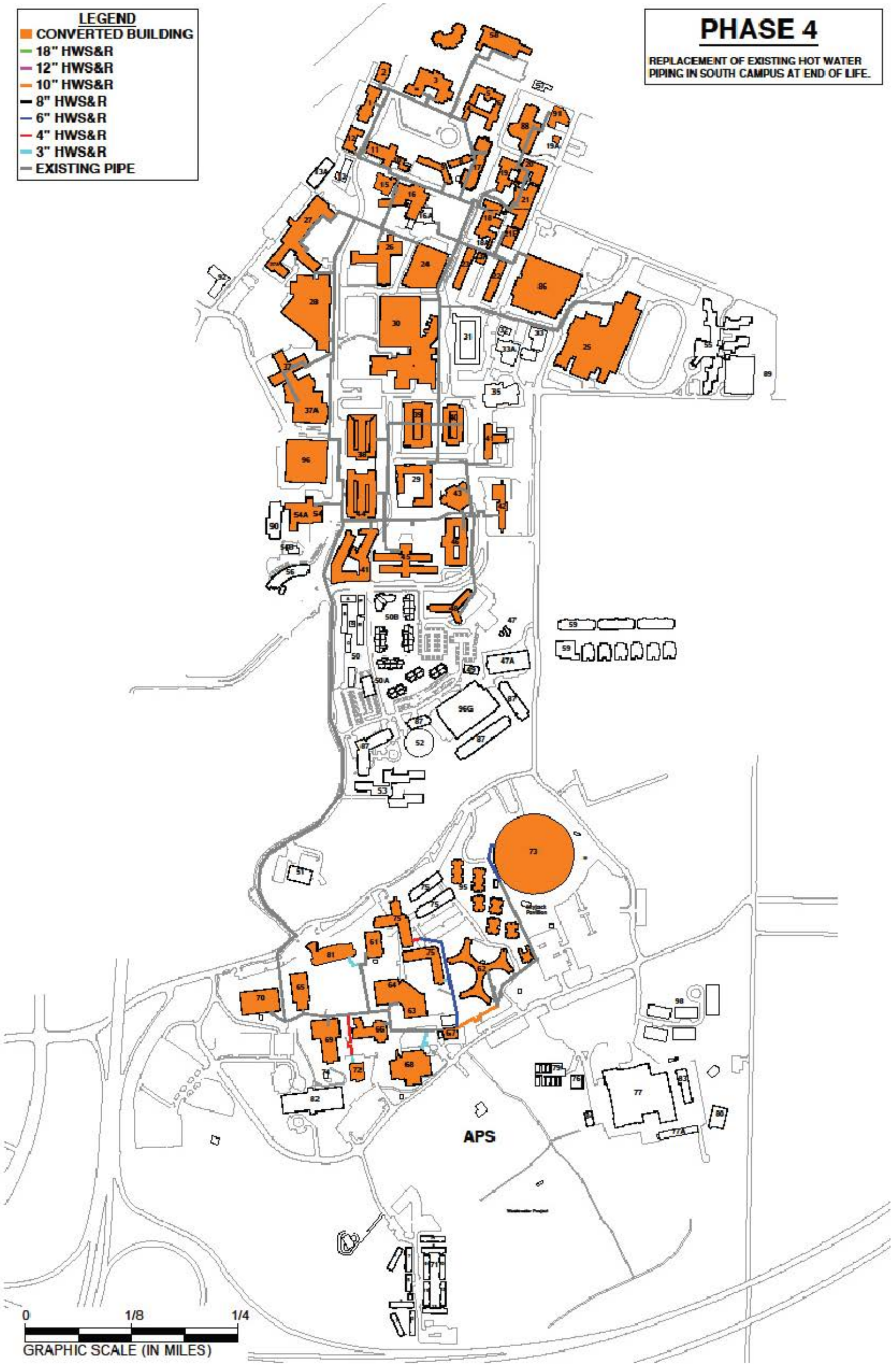
PHASE 2

CONVERSION OF EAST SIDE OF NORTH CAMPUS TO HOT WATER SYSTEM.



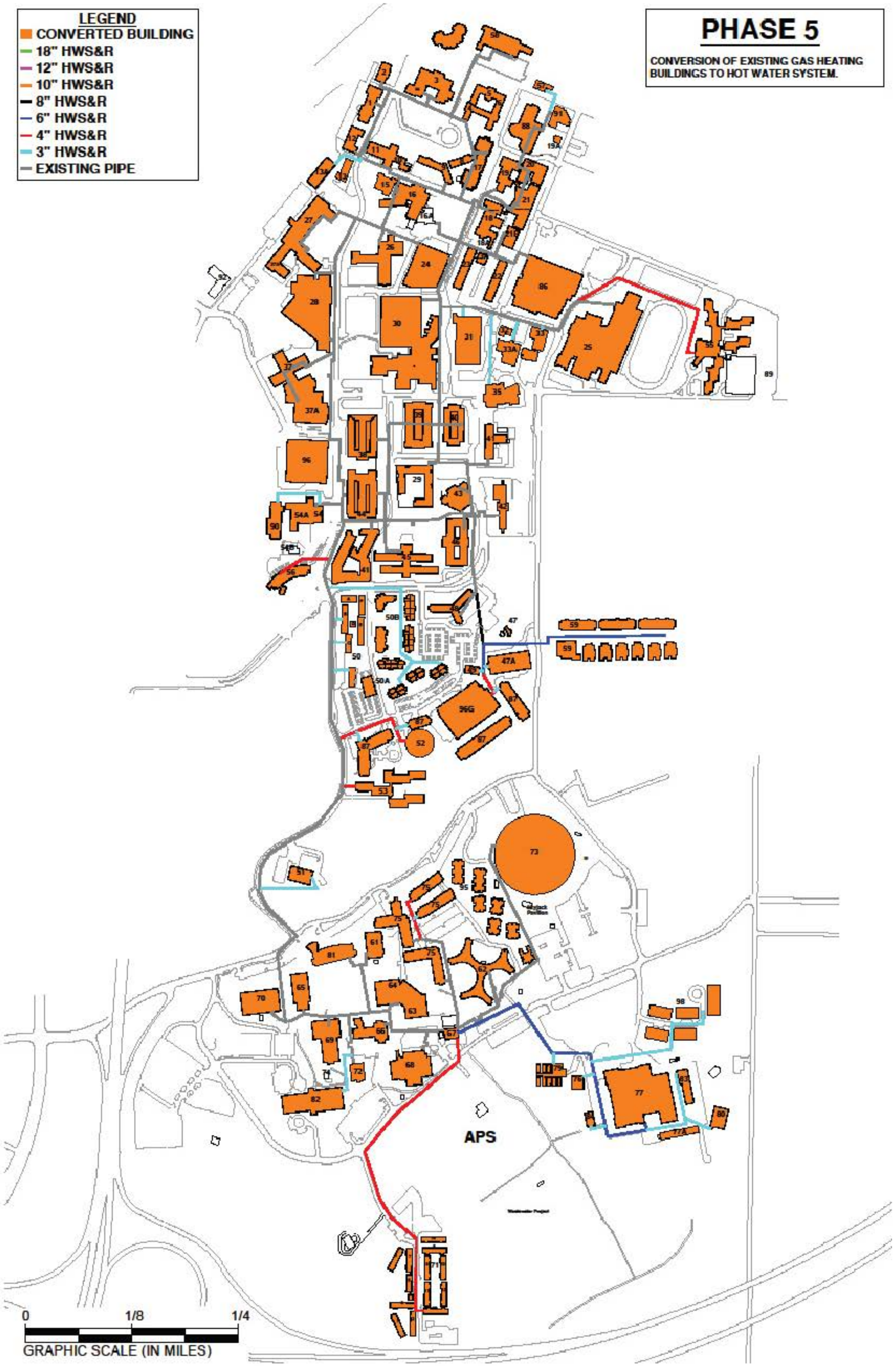
PHASE 3

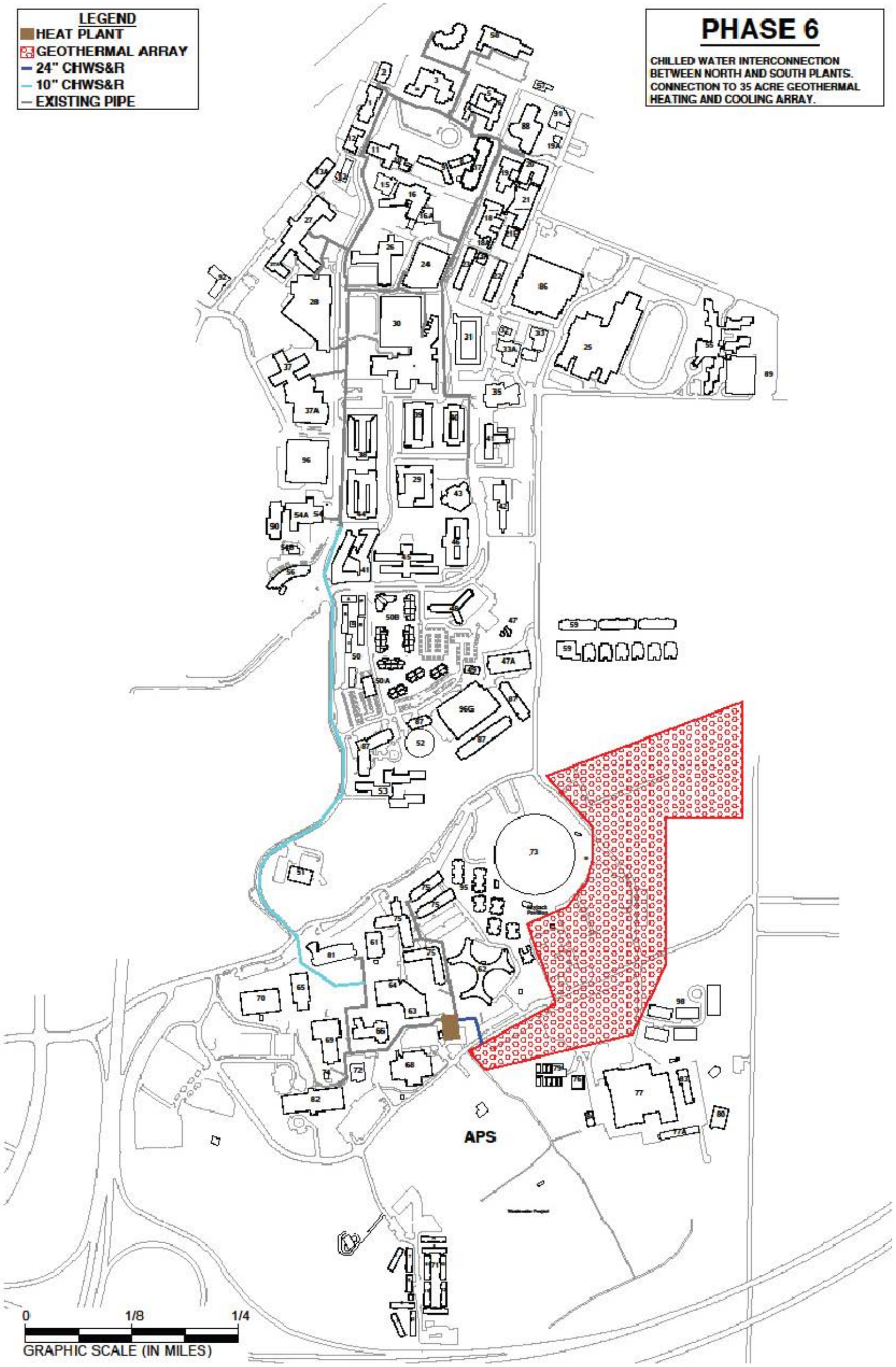
CONVERSION OF THE REMAINDER NORTH CAMPUS TO THE HOT WATER SYSTEM.

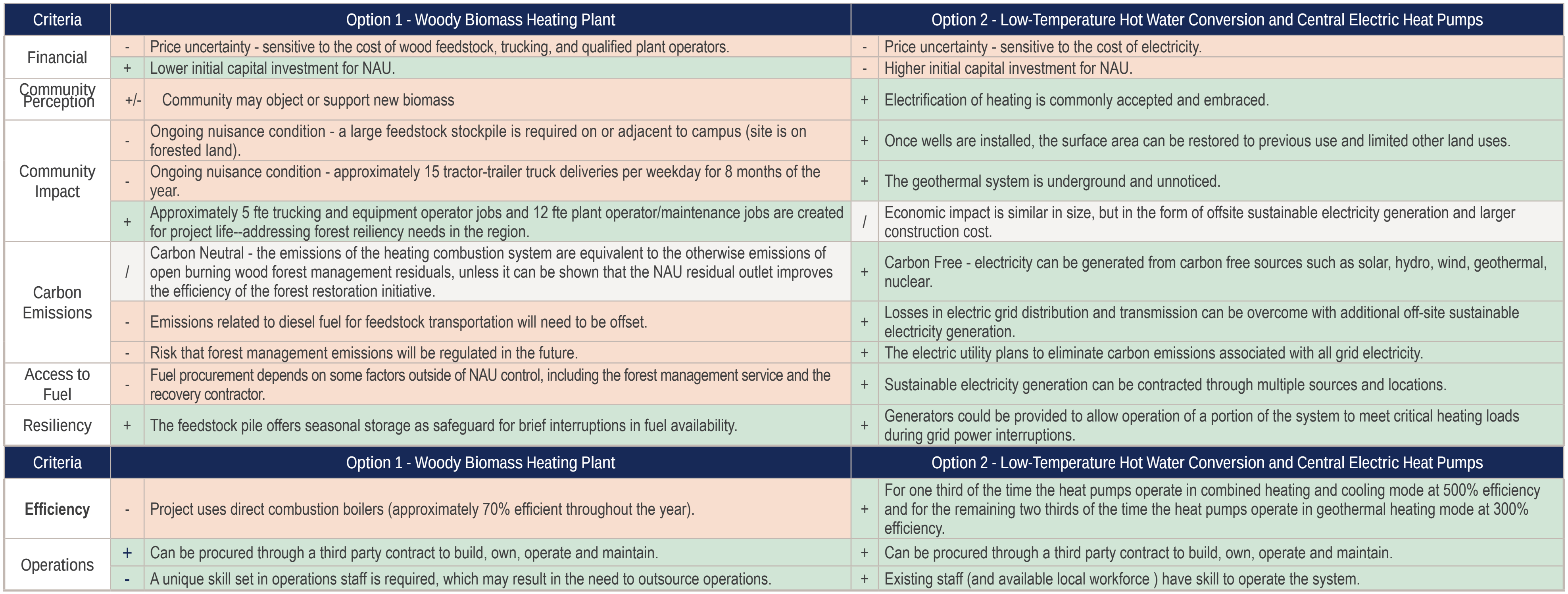


PHASE 4

REPLACEMENT OF EXISTING HOT WATER PIPING IN SOUTH CAMPUS AT END OF LIFE.


PHASE 5
CONVERSION OF EXISTING GAS HEATING BUILDINGS TO HOT WATER SYSTEM.
LEGEND
CONVERTED BUILDING
18" HWS&R
12" HWS&R
10" HWS&R
8" HWS&R
6" HWS&R
4" HWS&R
3" HWS&R
EXISTING PIPE
APS
0
1/8
1/4
GRAPHIC SCALE (IN MILES)


PHASE 6
CHILLED WATER INTERCONNECTION BETWEEN NORTH AND SOUTH PLANTS. CONNECTION TO 35 ACRE GEOTHERMAL HEATING AND COOLING ARRAY.
LEGEND
HEAT PLANT
GEOTHERMAL ARRAY
24" CHWS&R
10" CHWS&R
EXISTING PIPE
APS
0
1/8
1/4
GRAPHIC SCALE (IN MILES)



Criteria		Option 1 - Woody Biomass Heating Plant		Option 2 - Low-Temperature Hot Water Conversion and Central Electric Heat Pumps
Financial	-	Price uncertainty - sensitive to the cost of wood feedstock, trucking, and qualified plant operators.	-	Price uncertainty - sensitive to the cost of electricity.
	+	Lower initial capital investment for NAU.	-	Higher initial capital investment for NAU.
Community Perception	+/-	Community may object or support new biomass	+	Electrification of heating is commonly accepted and embraced.
Community Impact	-	Ongoing nuisance condition - a large feedstock stockpile is required on or adjacent to campus (site is on forested land).	+	Once wells are installed, the surface area can be restored to previous use and limited other land uses.
	-	Ongoing nuisance condition - approximately 15 tractor-trailer truck deliveries per weekday for 8 months of the year.	+	The geothermal system is underground and unnoticed.
	+	Approximately 5 fte trucking and equipment operator jobs and 12 fte plant operator/maintenance jobs are created for project life--addressing forest reiliency needs in the region.	/	Economic impact is similar in size, but in the form of offsite sustainable electricity generation and larger construction cost.
Carbon Emissions	/	Carbon Neutral - the emissions of the heating combustion system are equivalent to the otherwise emissions of open burning wood forest management residuals, unless it can be shown that the NAU residual outlet improves the efficiency of the forest restoration initiative.	+	Carbon Free - electricity can be generated from carbon free sources such as solar, hydro, wind, geothermal, nuclear.
	-	Emissions related to diesel fuel for feedstock transportation will need to be offset.	+	Losses in electric grid distribution and transmission can be overcome with additional off-site sustainable electricity generation.
	-	Risk that forest management emissions will be regulated in the future.	+	The electric utility plans to eliminate carbon emissions associated with all grid electricity.
Access to Fuel	-	Fuel procurement depends on some factors outside of NAU control, including the forest management service and the recovery contractor.	+	Sustainable electricity generation can be contracted through multiple sources and locations.
Resiliency	+	The feedstock pile offers seasonal storage as safeguard for brief interruptions in fuel availability.	+	Generators could be provided to allow operation of a portion of the system to meet critical heating loads during grid power interruptions.
Efficiency	-	Project uses direct combustion boilers (approximately 70% efficient throughout the year).	+	For one third of the time the heat pumps operate in combined heating and cooling mode at 500% efficiency and for the remaining two thirds of the time the heat pumps operate in geothermal heating mode at 300% efficiency.
Operations	+	Can be procured through a third party contract to build, own, operate and maintain.	+	Can be procured through a third party contract to build, own, operate and maintain.
	-	A unique skill set in operations staff is required, which may result in the need to outsource operations.	+	Existing staff (and available local workforce) have skill to operate the system.

Figure 45. Qualitative Attributes of Energy Options

Water use in buildings and campus utilities is appealing as means of protecting the environment, for cost savings and as means of reducing greenhouse gas emissions. For the City of Flagstaff, provision of water and wastewater management is its single largest activity as an electricity consumer. NAU student studies[18] suggest the emissions embodied in NAU's 2019 access to the public water supplies is 530.87 metric tons CO2e emissions and 324.77 metric tons CO2e emissions for wastewater management.[19]

The Flagstaff Mountain Campus data on water use starts in 1996 and shows reductions over this time period. In 2019, the campus consumed 222 million gallons of water, 78% of which was potable water and the remainder was reclaimed water. If the university converts from steam to a heat pump system, it will reduce campus water and sewer use by an estimated 6.2% per annum. Other initiatives to reduce water use in buildings can reduce demand by about 25%, depending on building use, space type and condition. Water conservation of managed landscapes almost always offers a better return on investment.

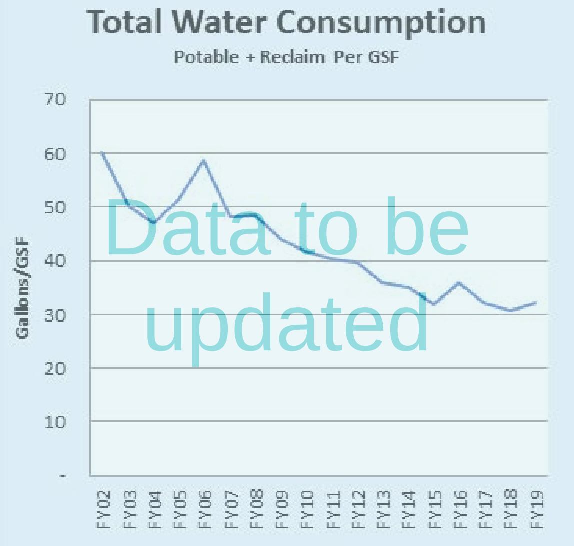


Figure 46. (NAU to provide caption)

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[18] Climate Science and Solutions (CSS) student Taylor Wyum (2019-2020 cohort)

[19] This includes provision of reclaimed water.

Landscape

Campus landscape design and management is guided by the university's 2015 landscape master plan[20], the guide to design and management of the 700 acres of open land on the Flagstaff Mountain Campus. This plan looks at landscape design and maintenance and use of outdoor water use from a different perspective: which activities to maintain and modify to reduce associated greenhouse gas emissions. Elements of the landscape master plan offer value to the NAU 2021 CAP perspective. It provides specifics to use of an integrated pest management approach on 150 campus acres[21]. Important innovations have resulted from the plan. 13 campus sites
(approximately 20 acres) are now serviced by highly water efficient ("smart") irrigation systems.

The NAU 2021 CAP prioritizes these strategies in forest and landscape management:

- Reduce chemical use.
- Increase use of native and naturalized plants.
- Reduce the footprint of campus managed landscapes.
- Install and plant materials to reduce heat island effect.
- Improve stormwater management.
- Employ restorative and regenerative site design[22], and
- Adapt designs and management practices to climate change.

Through this assessment, the Landscape Committee recommends these specifics steps:

- Plant beds with organic, local rock and native grasses is an available and effective strategy to serve as the next generation of campus landscape aesthetic.
- Study how manicured lawn areas are used by students and use this to guide strategic use of chemicals and of planting strategies. The objective is to refrain from intensive lawn maintenance where it isn't justified by use patterns.
- Expand use of highly water efficient irrigation systems.
- Improve metering to generate a reliable understanding of landscape water use and establish a starting point for articulating landscape water use reduction goals and strategies.
- Assess means of improving campus stormwater management. This will support improved groundwater recharge. A regional priority, the City of Flagstaff wants to redirect its reclaimed water supply to use as a source for recharge.
- Further invest in forest management as it impacts climate change and is integral to the Flagstaff Mountain Campus. NAU owns forested land on its campus and manages a forest that is east of Flagstaff. The Arizona State Land Department granted NAU permission to educate, conduct research and help manage nearly 50,000 Centennial Forest acres. NAU is responsible for generating an inventory and assessment of value for the uses and natural resources in the Centennial Forest at least every 10 years and submitting annual operating plans to the Arizona State Land Department. NAU is responsible for submitting long-term plan for the forest health, restoration, and ecosystem management[23].

NAU has ongoing projects that contribute to preserving the natural carbon cycle in its forest management and are valued living laboratory experiences. These include:

- Silviculture treatments.
- Pine needle composting.
- Campus landscape management to promote use of native and naturalized species.
- Inventories of forest plots, and
- Biocrust restoration projects.

NAU can use its forest management plans as a framework to lend NAU's unique expertise in forest management to other projects, avoiding carbon emissions through forest preservation and increasing sequestration through restoration projects. Forest management is a critical part of carbon offset projects nationally and internationally and an opportunity for NAU to invest expertise and resources in meaningful global greenhouse gas emissions reductions that can offset Scope 3 related emissions on and off campus.

The university's opportunities to influence forest management in the region are significant and a valued component of the university's identity. The following elements of these practices will work to reduce greenhouse gas emissions and the threat of forest fire. Further university cost-benefit analysis and budgeting is needed to turn this list into an action plan.

- Fill and maintain forest manager position for the Centennial Forest and NAU-owned forest land.
- Develop a forest management plan for NAU-owned and managed lands. This should address silviculture, trimming and fuel reduction projects; expanding the pine needle composting program; ecological prescribed burns for fire-adapted forest areas; biocrust restoration projects; rapid reforestation projects for disturbed areas; and preservation of native species including Ponderosa Pine and Gambel Oak.
- Undertake regular carbon inventories of NAU owned and managed forests.
- Adapt management practices to climate change. This is an excellent living laboratory challenge that might call on the faculty, staff and students of the College of Engineering, Informatica and Applied Sciences in collaboration with the College of the Environment, Forestry and Natural Sciences. With university staff, the study will be accomplished by applying local climate change modeling and comparing that to current forest management practices. The outcome will be a plan that guides a transition in practices over the next few decades.
- Thin pines and improve understory to support general health of forest ecology.
- Cultivate plant life for sequestration benefit. The university possesses the essentials of knowledge of how to do this and might need a consultant to undertake a peer review or to support their analysis.
- Employ university expertise to provide guidance and then undertake student projects to achieve rapid reforestation of disturbed forest and improved rangeland management.

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[20] | "2015 NAU Landscape Master Plan", authored by WLB Group, Inc. and Civitas, Inc.

[21] | The US EPA says it is "an effective and environmentally sensitive approach to pest management that relies on a combination of common-sense practices. IPM programs use current, comprehensive information on the life cycles of pests and their interaction with the environment."

[22] | Regenerative site design is anchored in respect for ecology. It recognizes that healthy ecosystems are resilient and seeks to create or enhance those in the landscape design.

[23] | 1999 Intergovernmental Agreement between NAU and the Arizona State Land Department

Transportation

The Transportation Committee's recommended means of transitioning to a carbon-free fuel source and of further motivating faculty, staff and students to employ non-motorized transit and use mass transit. Committee recommendations stem from these observations:

- The university should better locate and design pedestrian walkways and expand micro-mobility alternatives (bicycles, scooters and skateboards and electric micro-mobility solutions such as e-bikes, e-scooters and motorized personal vehicles). NAU should monitor the impact of these investments in motivating more non-motorized transit on campus.
- Easy availability of on-campus parking undermines efforts to reduce commuting by passenger vehicles. A study should identify means of dampening demand for on-campus parking with value to ensuring equity.
- ecoPASS utilization should be improved. In fiscal year 2019, employee ecoPASS[24] commuter use is about 35%, assuming an average of 10 commuting trips per week.
- The City of Flagstaff is valued as a partner for trip planning and other strategies – educational and operational – to encourage use of electric vehicles and mass transit trip planning as a strategy to reduce emissions and may be a partner for trip planning.
- Trip planning is valuable and should be an important element of the university's transportation demand management offerings.
- The Flagstaff Mountain Campus should continue to offer ride sharing programs. Currently, a student-run Facebook page offers ride sharing for students and Northern Arizona Intergovernmental Public Transportation Authority-Mountain Line offers a vanpool program for campus commuters.
- A university program to allow for some employees to work at home can be impactful to demand reduction.
- Electric vehicles performance works well in the Flagstaff

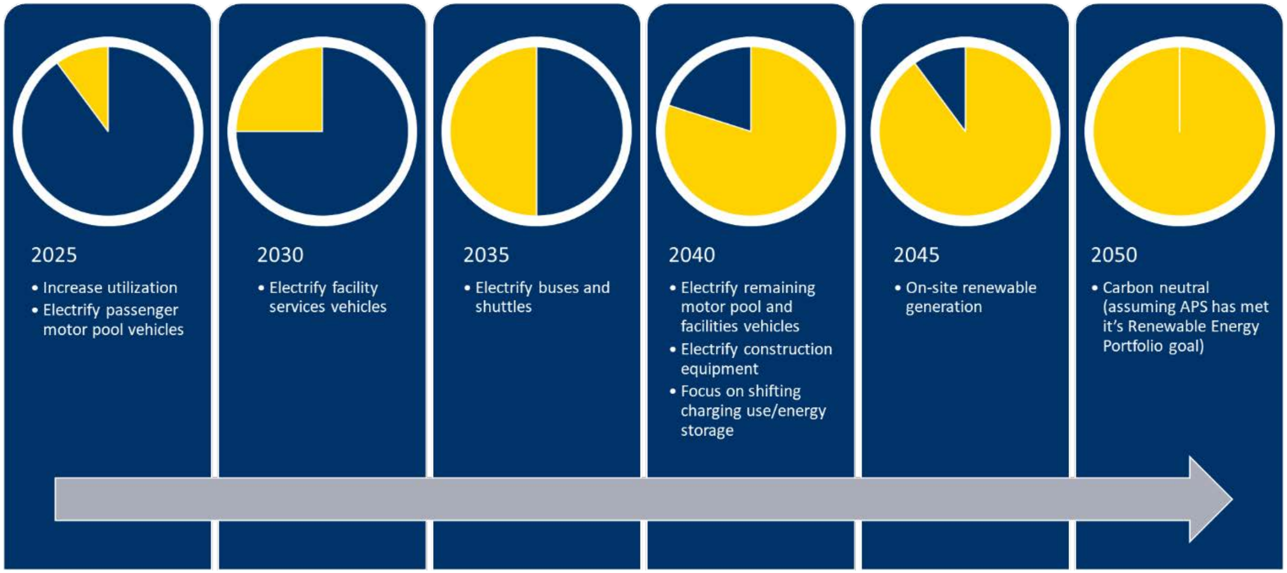

Figure 47. NAU Fleet Emissions Electrification Plan

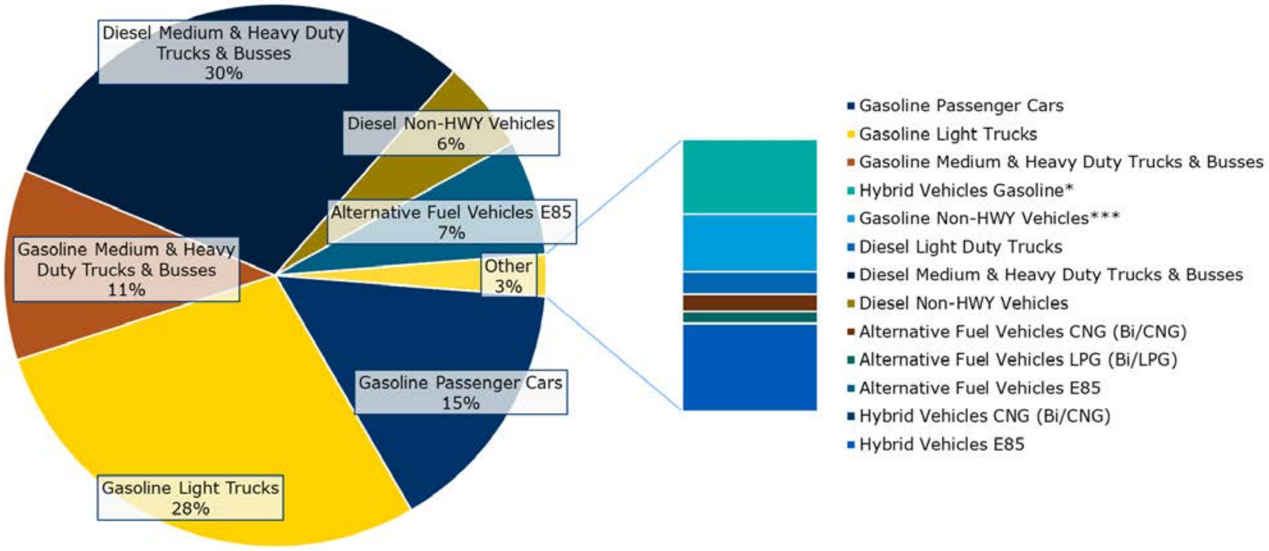

Figure 48. Distribution of NAU Fleet Emissions by Vehicle Type

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[24] Usage data from NAIPTA for 2019: employee ecoPASS utilization ranged from 402 to 770 unique passes per month. Total boarding ranged from 4,392 to 10,492 per month. Total boarding ranged from 4,392 to 10,492 per month.

climates[25]. Electric vehicle use for fleet and non-fleet vehicles will be facilitated through university investment. An electrical infrastructure plan and funding is needed to develop the specifics.

- NAU should consider the student-proposed carbon tax on all NAU funded and approved air travel to fund carbon offsets for air travel. This is modeled after similar programs at Arizona State University[26] and the University of Washington. This program is most impactful if using a central booking system for all university-sponsored air travel.

The committee's work was informed by the 2018 Northern Arizona University Multimodal Assessment (NAUMA)[27] which documented traffic patterns of pedestrians, bicycles, transit and automobiles and offers means of reducing traffic congestions and demand for parking to achieve safety and convenience. The Transportation Committee supports NAUMA recommendations for travel demand management. These include employer/institutional support actions (such as car-sharing, preferential parking, bicycle and pedestrian education, a bicycle co-op and a bike share), financial incentives or disincentives, alternative work arrangements and local and regional infrastructure and policy. The committee urges continued effort to establish university policies and funding to provide and/or promote financial incentives, alternative work arrangements and integration of university activity in support of local and regional infrastructure policies.

The NAU fleet[28] is estimated to account for 2,000 MTCO2e of greenhouse gas emissions under Scope 1 with a small amount of electric vehicle charging captured under the university's Scope 1 purchased electricity. As a near-term strategy the university will downsize its fleet with the expected to result in reduced trips and increased use of fuel efficient vehicles. It will phase-in transition to electric vehicles as is practical to market opportunities. The Transportation Committee recommends electrifying the NAU Flagstaff Mountain Campus fleet over the next 30 years[29] through a program that replaces vehicles at the end of their useful life. The plan's targets will be based on an understanding that competitive battery electric options are currently available for passenger vehicles, UTVs, shuttles and buses however many heavy-duty vehicles including trucks and construction vehicles have fewer options currently available[30]. Heavy duty electric vehicles are expected to become more commercially available and competitive in the next five to fifteen years based on announcements from vehicle manufacturers. The proposed university fleet transition schedule is:

- By 2025, downsize fleet and electrify most of the passenger motor pool vehicles.
- By 2030, electrify most of the facility service vehicles.
- By 2035, electrify most of the NAU bus and shuttle fleet.
- By 2040, electrify remaining vehicles in motor pool, facilities, buses and shuttles, electrify most of the NAU owned construction equipment and focus on shifting charging and energy consumption to non-peak and low emission periods, and
- By 2050, achieve carbon neutrality as APS achieves 100% renewable energy or purchase renewable power for all fleet vehicles.

The process comes with challenges: limiting the high energy demands of license-plate readers and other vehicle accessories, improving the university's capacity to plan its long-range trips particularly, and ensuring that the replacement fleet performs in the weather and climate conditions of the campus vehicles.

Vehicle Type	Miles/yr	Rated kWh/mi	kWh/yr
Cars	1,005,790	0.22	217,233
SUVs	351,759	0.27	94,195
Light Trucks	239,694	0.35	83,893
Med-Heavy Trucks	159,705	1.89	301,842
Buses	290,254	2.15	624,046
Vans	547,902	0.60	330,385
Construction	15,046	4.30	64,698
UTVs	26,682	0.34	9,179
C-38	4,141	1.89	7,826
Total	2,640,973	0.66	1,733,297

Figure 49: Fleet Electrification Projected Charging Demand BY Vehicle Type

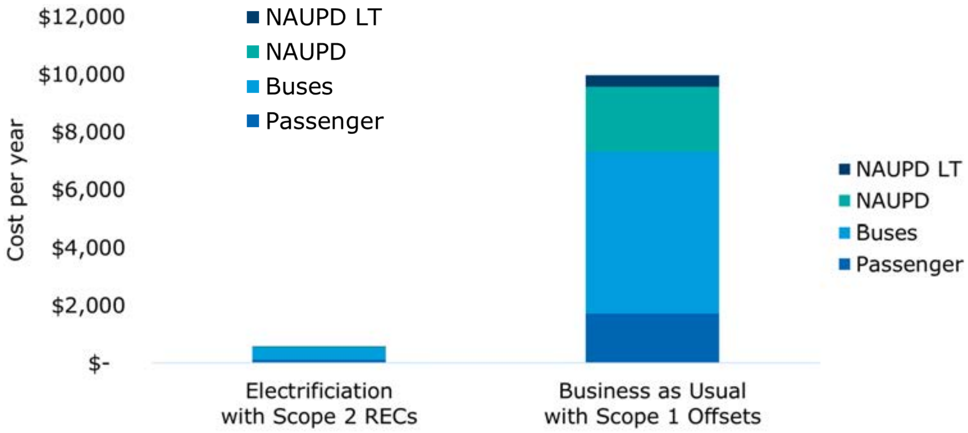

Figure 50. Comparison of Electrification and Natural Gas Costs with RECS and Offsets

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[25] | https://www.hyundai.com/worldwide/en/company/newsroom/hyundai-kona-electric-makes-it-to-guinness-world-records%E2%84%A2-feat-0000016389

[26] | https://cfo.asu.edu/carbon-project

[27] | https://www.flagstaff.az.gov/DocumentCenter/View/57576/NAU-Multimodal-Assessment-Recommendations-Memorandum?bidId=

[28] | The Flagstaff Mountain Campus maintains 569 vehicles. These include passenger vehicles, sports utility vehicles, trucks, police cruisers, light construction vehicles, utility terrain vehicles, miscellaneous vehicles in smaller quantities, buses, shuttles, passenger and delivery vans.

[29] | A strategy for electrifying NAU's fleet, developed by NAU graduate Miles Davis, was considered as a viable structure for the university to endorse and follow.

[30] | Climate Science and Solutions (CSS) student Miles Davis (2019-2020 cohort)

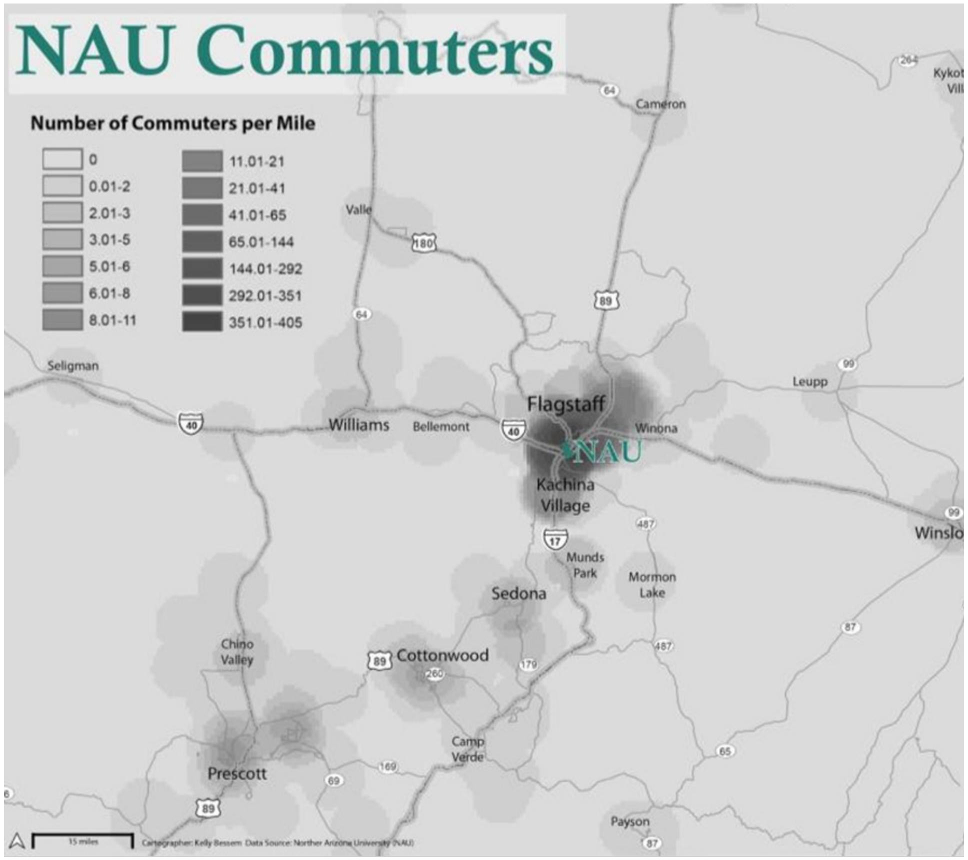

Figure 51. NAU Student Commuting Pattern

As with most entities committed to carbon neutrality, reducing Scope 3 emissions associated with air, commuting and on campus travel is an important objective as NAU. In the immediate, the university needs to expand its resource allocation to identify and track this activity as a measure of emissions. A student project used to estimate student commuting emissions calculated at 12,727 MTC02e in 2020[31]. This methodology can be expanded for the entire university commuting community and is, perhaps, an excellent living laboratory exercise.

NAU students calculated Scope 3 emissions associated with faculty air travel at 2,184 MTCO2e (2019)[32]. They then proposed assigning a carbon tax on all NAU funded/approved air travel to be invested in carbon offsets[33]. The program requires centralized reservation booking and other administrative responsibilities.

Figure 52. Climate Action Planning Underscores Value of Effective Public Transportation

Year	Commuter	Resident	Garage	Total
2009-10	2577	3266	775	6618
2010-11	2660	2818	698	6176
2011-12	2332	2472	712	5516
2012-13	1897	2391	1198	5486
2013-14	1704	1991	1571	5266
2014-15	1810	2086	1679	5575
2015-16	2032	2281	2147	6460
2016-17	2557	2272	2061	6890
2017-18	2529	2548	2068	7145

Figure 53. NAU Permit Parking Profile

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[31] Climate Science and Solutions (CSS) students Kelly Bessem, Tasha Nez and Matthew Ruiz (2019-2020 cohort)

[32] Climate Science and Solutions (CSS) students Elizabeth Lancione, Tristan Smit, Emily Haworth (2019-2020 cohort)

[33] See details of the ASU project that inspired this recommendation: https://cfo.asu.edu/carbon-project

Waste Management

NAU Flagstaff Mountain Campus on-site composting is a valuable alternative to the far greater greenhouse gas emissions per ton associated with municipal landfill waste disposal. The waste committee recommends that this program be expanded to better capture campus food and yard waste and, potentially, opening its service to organic waste generated within the larger City of Flagstaff community.

NAU diverts many waste streams from disposal: papers, plastics, glass, metals and other containers; food, including cooking oil; plant materials; white goods; electronics; laboratory equipment; furniture; student move in/move out materials; scrap metal; pallets; and tires. The NAU Environmental Health & Safety Department leads a Green Labs Program which serves to reduce the generation of hazardous waste in labs. The Purchasing Services Department values durable products, lower toxicity products, biodegradable products, high recycled content projects, highly recyclable products and minimal packaging shipment. These values are integrated into purchases where possible, practical and feasible.

The NAU 2021 CAP recommends the following waste management practices (high priorities are indicated with an asterisk):

- Improve record keeping[34]* Adequate staffing is needed to establish a data collection protocol for tracking volumes of waste minimization, waste diversion and waste disposal and administering that protocol. Issue annual reports.
- Continue the scope of materials included in the university's current waste minimization and diversion programs.
- Prioritize waste diversion activities to expand construction and demolition waste recycling, food waste diversion and municipal solid waste recycling.*
- Once the university record keeping is of desired quality, establish waste minimization and waste diversion goals*. These should be broad and specific to each university waste minimization and diversion program.

Figure 54. NAU Student Landscape Volunteer Program Exemplifies the University's Living Laboratory Identity

- Explore partnerships with the City of Flagstaff to better support the vitality of its recycling program.*
- Explore banning sale of single use plastic products on campus.
- Establish best means of reducing toxicity of the waste stream – generally to be associated with use of refrigerants and from lab waste. Prioritize those activities.*
- Reduce the volume of waste associated with university dining.

Resilience

This plan's goal to align NAU Flagstaff Mountain Campus and collaborate with the City of Flagstaff to meet university and city climate goals and objectives recognizes the tie of university to city and region. The City of Flagstaff undertook a climate vulnerability assessment in 2018. It found that the community is vulnerable to the possibility of widespread forest fires, projections of insufficient water supply combined with stressed infrastructure, and the vitality of water related recreation to the health of the tourism economy. The highest at-risk communities in Flagstaff are the same as in every urban setting: those who are in need and reluctant to seek aid, the homeless and those with low-income. The assessment was followed by the 2018 Climate Action and Adaptation Plan which offered 164 actions. A key objective of the plan is to establish financing mechanisms and funding to support adaptation specific to reducing wildfire risk and promote ecosystem health. Other objectives are to maximize groundwater recharge (support ecological health and forestall the need to expand the public water supply), improve the health and emergency services provided to the most vulnerable with in the city, support neighborhood action and support economic transition.

As the NAU 2021 CAP goes to print, the city is considering a draft Carbon Neutrality Plan[35] which offers two paths to reducing greenhouse gas emissions. The goal is to be carbon neutral by

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[34] | The university reported that it generated 2,064 tons of waste in 2019. Of this, 390 tons were recycled, 397 tons were composted, 23 tons were donated or resold, and 1, 254 tons were disposed. Because this waste disposal number is suspect (suspect data and it appears to be low on a per capita basis compared to that of peer institutions) this report assumes no increase in waste diversion over the term of the study and recommends that the university revise this assumption once it is satisfied that it is generating more credible data for waste diversion and disposal.

[35] | Dated March 2021

2030, including reducing emissions by 44% as compared to the business as usual emissions projection. It offers two paths: the first dwells on reducing building energy use, consumption and waste and promotes clean transportation energy. The second emphasizes the value of carbon sequestration.

Understanding this broad municipal perspective and its exhaustive exploration, the Resilience Committee defined resilience for the NAU 2021 CAP and established priorities:

- Strengthen connections to carbon reduction interests that the university and city share (goal #3).
- Support campus carbon neutrality (goal #1).
- Enrich the living laboratory experience (goal #2), and
- Provide for the university to commit to Second Nature's Climate Commitment (goal #4).

Unlike the other NAU 2021 CAP committees and unique to goal #4, this committee was tasked with making recommendations that will prepare the university for a public commitment: to pledge to the Second Nature Climate Commitment. The Resilience Committee's recommendations are listed below with an asterisk to identify those it believes are most important:

- Transition to a carbon free heating/cooling and power infrastructure*.
- Reduce greenhouse gas emissions associated with university transportation without sacrifice to service*.
- Improve forest and landscape management*.
- Expand relationship with ASU and UA to jointly approach the state legislature to fund campus resilience.
- Improve campus IT infrastructure.
- Promote climate awareness.
- Improve NAU emergency planning and management*.
- Resolve the university community's food and housing insecurities.
- Provide for the public's health during an epidemic or pandemic.
- Promote equity by ensuring that each university program, policy and standard practice undertaken to reduce campus greenhouse gas emissions is free from bias in its impact.
- Manage water use – conserve water use and reduce off-site impact of campus stormwater runoff.

Employing its commitment to be a living laboratory, the Resilience Committee recommends that the university should:

- Improve forest management by the university and in the region*.
- Better incorporate equity as a lens for living laboratory activities.
- Resolve the university community's food and housing insecurities.
- Make the NAU 2021 CAP a living document, and
- Improve campus emergency preparedness.

Collaborate with the City of Flagstaff to ensure sustainability and resilience in a coordinated effort, this committee recommends that the two should work to:

- Improve waste management*.
- Improve forest management*.
- Reduce university's demand for municipal water and burden on municipal wastewater volumes, and
- Accelerate the transition to renewable sources for the region's electricity.

In approaching collaboration with the City of Flagstaff, the NAU Flagstaff Mountain Campus might start with exploring city initiatives that parallel or complement the university's and ones that the university finds appealing to take on as new efforts. For example, the municipal document "Rethink Waste: A Framework for Transitioning to Sustainable Materials Management"[36] aims to divert 90% of waste from its landfill with waste reduction as the major driver. Its implementation schedule is one that the university might interpret for itself, as follows:

- Fill gaps in data and knowledge.
- Create a long-range plan based on experiences in filling gaps in data and promoting general knowledge of the issue, and
- Implement the plan priorities through behavior change, infrastructure improvements, and policy enhancements.

The city's plan lists its perceived barriers to and opportunities to success. As part of the larger community, the university is likely to find it faces different barriers and can leverage other opportunities. Still, it is useful to approach collaboration by adopting the city's framework for addressing the issue. This will make transparent the best opportunities for coordinate activity.

The plan makes two overriding recommendations relative to the campus living laboratory initiatives:

- Incorporate equity as the lens for all living laboratory activities, and
- Create an institutional administrator to be the repository for proposals, assignments, funding and grant proposal making, and to track outcomes.

Specific suggested living laboratory experiences found elsewhere in this document are:

- Promote silviculture treatments as part of forest management.
- Identify means of and implement pine needle composting on campus.
- Promote expanded use of native and naturalized species in campus landscape design and management.
- Inventory forest plots.
- Undertake biocrust restoration projects.
- Adapt landscape management practices to climate change.
- Resolve the university community's food and housing insecurities.
- Make the CAP a living document.
- Improve campus emergency preparedness.
- Create means of collecting data and reporting on Scope 3 emissions associated with the Flagstaff Mountain Campus.

Figure 55. Pedestrians Use Streets During Peak Hours

Institutional Structure to Guide NAU to Carbon Neutrality

There are many at NAU Flagstaff Mountain Campus whose teaching, research, and advocacy advance efforts to reduce campus greenhouse gas emissions. Institutional leadership is key to this momentum. The Office of the Vice President of Capital Planning and Campus Operations and its units -- Facility Services (Utility Services and Sustainability); Environmental Health & Safety; Contracting, Purchasing & Risk Management (Purchasing); University Transportation Services; Campus Services and Activities (Campus Dining Operations) -- are most impactful and were most involved in developing this assessment. Of these, Facility Services is distinct in having a mission that is explicitly committed to sustainability. Within it, the Office of Sustainability is responsible for engaging students, employees and community members in activities that support the vision of NAU as “a leading university for sustainability and inclusivity by creating forward thinking, impactful and resourceful leaders”[37]. Its vision is to showcase the university’s living laboratory activities as means by which its students’ study and participate in the “development of social equity, economic stability and environmental stewardship.”

Committee members for the NAU 2021 CAP embrace NAU as a living laboratory and sustainability as a very visible attribute of the university’s identity. This plan’s development revealed that its stakeholder community believe it is imperative that the university formalize its activities to meet the plan’s goals. This is to be accomplished by:

1. Accepting this plan’s recommended investments and schedules for making them.
2. Strengthening and bringing greater focus to this plan’s goals in NAU’s living laboratory activity with the Sustainable Campus Ecosystem Initiative as the anchor for this effort. This will accelerate university initiatives to makes its living laboratory platform more sophisticated and an evidence-based learning initiative that will bring broader student engagement.
3. Launching use of a comprehensive dashboard (currently being developed) that will be managed by the Facilities Services Department. This tool will house data to be used as metrics of success for the full range of activities described in this document. As a dashboard, it offers the valuable attribute of transparency to the entire university community and beyond.
4. Generating new and updating campus policies and practices that support this plan’s goals.

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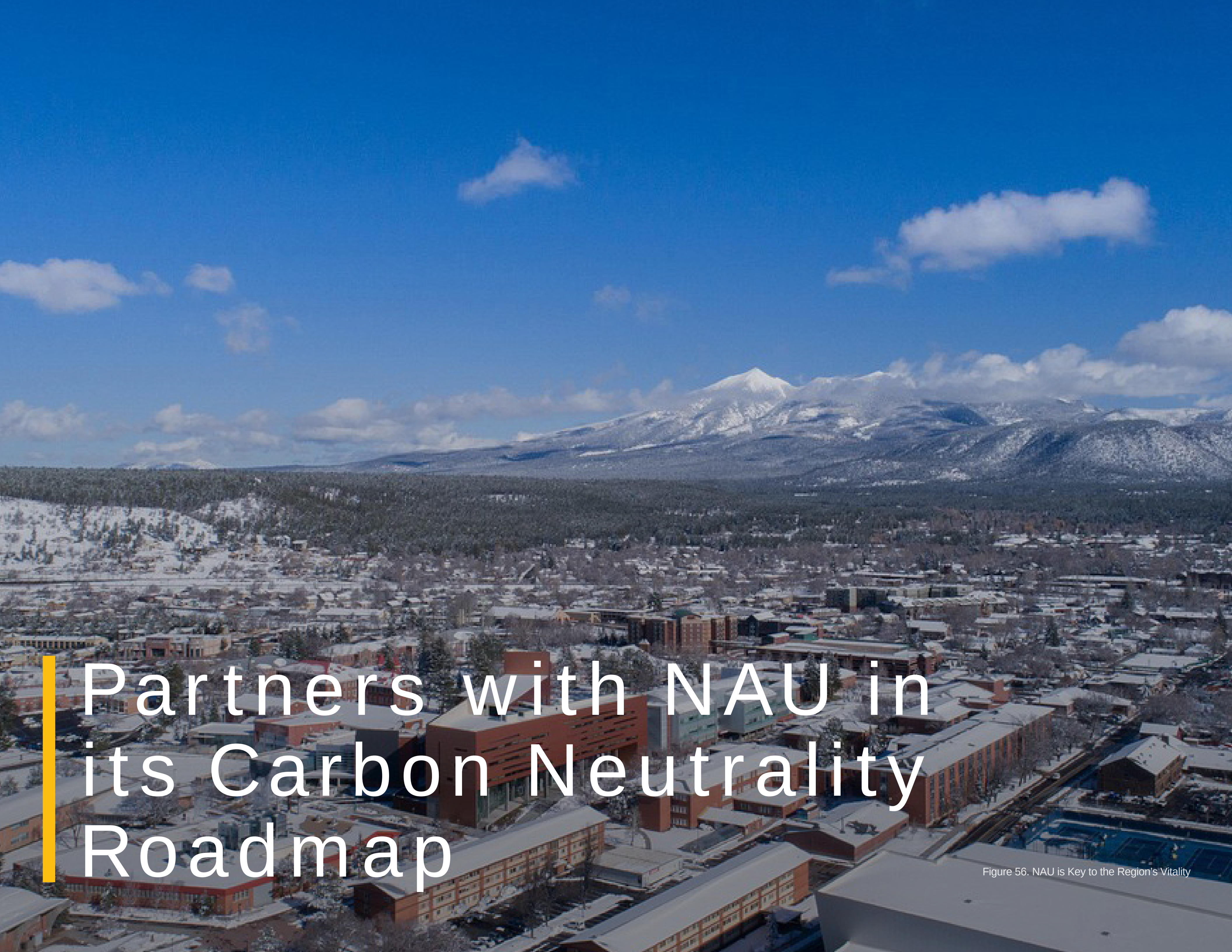
[37] https://in.nau.edu/green-nau/office-of-sustainability/



Partners with NAU in its Carbon Neutrality Roadmap

Figure 56. NAU is Key to the Region's Vitality

Partners with NAU in its Carbon Neutrality Roadmap

The single most important regional partner to Northern Arizona University in the university's pursuit of carbon neutrality and resilience is the City of Flagstaff. The two have strong bonds of collaboration in managing waste (including waste diversion) and providing robust options for public transportation and safe streets for pedestrians, bicyclists and motorists. The NAU 2021 CAP offers more substance to add to those relationships. The NAU 2021 CAP reveals the university's interest and commitment to managing some of the region's forests, another key objective of the city in establishing its sustainability and resilience. Finally, as the university engages further in the Second Nature's Climate Commitment, it will formalize its relationship with the City of Flagstaff to optimize its party's activities to serve individual and shared needs.

A second and key partner group to the university is Arizona State University and the University of Arizona. As each of the state's universities endeavors to reduce its carbon emissions and promote its sustainability and resilience, there are endless opportunities for the three to learn from each other. When related, shared interests and concerns are brought to the Board of Regents and/or the Arizona Legislature, they are logically more compelling than if articulated by a single one of the three institutions.

Carbon neutrality at NAU is accomplished through access to renewably sourced energy. Thus, the local electricity utility, Arizona Public Service, is also a critical partner to NAU.

Figure 57. NAU's Living Laboratory Experiences Embrace Wind Technology

Appendix

Figure 58. Gradaution Joy

Appendix

A. Near-term Investments to Launch the NAU 2021 CAP

The following investments are recommended for the first two years after NAU issues its CAP.

Energy and Indoor Water Use

1. During Summer 2021, engage the USDA to advance the woody biomass concept and undertake tests of campus soil conditions as an indication of viability of Option 2. The university will spend $53,000 for bore tests.
2. After the university selects its preferred option and its procurement approach for the project, engage a consultant(s) to advance that. Cost estimate: $350,000.
3. Interconnect the heating plants with heating hot water prior to the end of the economic life of South Plant hot water boilers (this is a common element in the business-as-usual case and both Option 1 and 2). Cost estimate: $26.9 M (project cost)
4. Centralize the heating systems in all buildings on the Flagstaff Mountain Campus when existing unitary systems reach the end of their economic life (this is a common element in the business-as-usual case and both Option 1 and 2). Cost estimate: $22.1 M (project cost).
5. Engage a district energy consultant to advance the conceptual design of campus-wide heating water conversion (this is a common element in the business-as-usual case and both Option 1 and 2). Cost estimate: $200,000.
6. Engage a building HVAC consultant to advance the feasibility and planning of low temperature heating water (160°F or less) in all buildings on the Flagstaff Mountain Campus (specific to Option 2). Cost estimate: $200,000.
7. Invest in detailed audits, retro-commissioning and retrofits in the four buildings with the most energy savings potential. Cost estimate: $1.2 M.
8. Hire a full-time energy manager as a deputy to the Associate Director of Utility Services. Energy Manager . This position will secure utility rebates, review energy efficiency proposals submitted for sustainability revolving fund financial support, develop the scopes and oversee execution of energy efficiency projects. A full-time energy manager is anticipated generate energy savings in excess of the position’s salary after three years. Cost estimate: $100,000.

Landscape and Outdoor Water Use, Forest Management

1. Add metering where missing. Expand existing network of landscape water use metering and highly efficient watering systems. Cost estimate: at least $500,000.
2. Classify Flagstaff Mountain Campus landscape types, analyze the environmental impact of each type and use that to inform direction for future installations, management policies and practices. Identify best practices for maintaining the different types. Cost estimate: about $50,000 (consultant study).
3. Study and quantify the embodied carbon of campus landscape products and materials. Incorporate this into a technical standard to use as basis for future landscape product selection. Cost estimate: about $50,000 (consultant study).
4. Expand staff to accomplish needed data collection and analysis re: water use and greenhouse gas emissions associated with campus landscape management and university forest management. Cost estimate: .75 fte.

Resilience

1. Coordinate with the City of Flagstaff re: identifying the needs for and creating enhanced resilience. Generate a baseline of resilience activities for the campus to undertake in response to its assessment of need and capabilities to respond to them. Commit details of NAU’s planned resilience activities in the form of a written document. Cost estimate: .5 fte.

Transportation

1. Establish the scope of capital investments, costs and potential funding sources and partnerships to electrify the fleet including the charging station infrastructure for it. Cost estimate: at least $500,000 (consultant study).
2. 2. Undertake a pilot study of student bus passes (1 year pilot). execute and analyze the effectiveness of the pilot. Cost estimate: $150,000.
3. 3. Support and provide alternative transportation to single occupancy vehicle. Identify, execute and analyze the effectiveness of car-free options such as bike share/scooter program in collaboration with the City of Flagstaff, rideshare via 3rd party, ride share app for students to share ride, and a trip planning tool. Cost estimate: $200,000.

Waste Management

1. Expand campus composting facility and associated education/outreach to secure volume of uncontaminated materials. Cost estimate: $150,000 capital, $10,000/year operating cost.
2. Increase education initiatives towards reducing contamination rate of waste going to municipal recycling facility. Cost estimate: about $40,000/year operating cost.
3. Procure scale for waste and recycling leaving campus. Cost estimate: about $100,000.
4. Expand staff to guide all waste diversion programs. Cost estimate: 1 fte.

Institutional Structure to Guide NAU to Carbon Neutrality

1. Maintain NAU’s commitment to improve data management such that the university can be accurate in its reports on greenhouse gas emissions, emissions reduction activities and on sustainability progress. The offices of Facilities Services and Information Technology are collaborating to create a dashboard tool to store emissions and sustainability information/data which is scheduled to be piloted in 2022. As a well-designed and well-managed tool, this will be the vehicle to transform the current situation of insufficient data and lack of confidence on the part of university users in its quality. The cost estimate to maintain this comprehensive system as the plan’s contributors desire is 2 ftes.

B. Long-term Resource Needs[38] by Phase

The university can access funds for studies, design and construction through a number of vehicles, such as the Green Fund, annual operating budget, revenue (as from the transportation system), and state capital allocations. NAU intends to pursue additional avenues such as energy-as-a-service companies and other public/private arrangements that allow the university to avoid or limit its capital investment in utility functions. NAU will explore additional options to provide it with the opportunity and ongoing discretion to invest in its greenhouse gas emissions reduction at a rate that accelerates that available to the university today. This can help fill the gap to support to support appealing investments that are too large for the Green Fund and too small to be part of a normal capital request and/or for which the compelling reasons to execute them is frustrated by the schedule to secure state funds.

Energy and Indoor Water Use

The Energy and Indoor Water Use Committee arrived at this long-term development plan for the university's preferred options. These costs are summarized below. Note that Appendix C provides a full picture of energy system costs: capital investments of the business as usual model in addition to alternatives, capital expenditures, operating expenditures and expected life cycle values.

The university needs a more robust energy metering plan for new and existing buildings. Fault detection and diagnostic program is needed for buildings constructed after 2000 to identify and prioritize the maintenance regiment. LED lighting upgrades, economizer diagnostics and envelope audits should follow targeting appropriate buildings. Plans for major system replacements and building renovations should trigger energy audits or building assessments to leverage energy savings investments as core to those projects.

Arizona Public Service plans to use 100% renewable power by 2050. Until then, should the university elect to continue purchases of offsets, that cost is about $220,000/year at current and will decrease as the utility increases the proportion of renewables in its portfolio.

With each new building construction project and with every renovation, the university will adapt best practices for indoor water use reduction. Obvious indoor water use targets are through procurement of low water use kitchen equipment (and food preparation practices), scientific equipment, and lavatory fixtures. As the university makes these investments, it is critical that adequate metering also be installed. Water reuse projects are generally cost justified in large buildings. Finally, studies show that conservation education can be impactful (though they make a small impact as compared to capital investments).

Landscape and Outdoor Water Use, Forest Management

The short-term investments outlined for landscape and forest management prepare the university to make capital investments that will reduce the greenhouse gas emissions associated with its landscape design and maintenance, outdoor water use, and forest management. Specific elements of this are:

1. Modify plant palate to convert to organic, local rock and native grasses.
2. Reduce acres of lawns managed with chemicals.
3. Expand use of high efficiency irrigation systems.
4. Improve campus stormwater management.
5. Elevate the role of climate change in forest management plans, education, and practices.

Resilience

The resilience committee believes that the university's top long-term priority is to improve NAU emergency planning and management. This is a broad statement which may well also address these objectives that the committee identified:

1. Funding - expand relationship with ASU and UA to jointly approach the state legislature to fund campus resilience.
2. Resilience infrastructure - improve campus IT infrastructure.
3. Public health - provide for the public's health during an epidemic or pandemic.

Other committee objectives can be considered to provide for the infrastructure of resilience rather than preparing for emergencies. These are:

1. Environment - reduce off-site impact of campus stormwater runoff.
2. Environment - reduce university's demand for municipal water and burden on municipal wastewater volumes, and
3. Environment - accelerate the transition to renewable sources for the region's electricity.
4. Living Lab -promote climate awareness.
5. Social well-being -resolve the university community's food and housing insecurities.
6. Social well-being - Promote equity by ensuring that each university program, policy and standard practice undertaken to reduce campus greenhouse gas emissions is free from bias in its impact.

The near-term resilience activities described in this document ready the university to make a public pledge to addressing resilience (Second Nature). The immediate process of assessing a campus baseline and direction should be executed with the preparedness goal and infrastructure needs listed above as the focus for both of these steps.

Transportation

The Transportation Committee sees the need to spend nearly $1.5 million in the next two years to:

1. Detail the university fleet transition from fossil fuels.
2. Establish the potential to reduce car trips through expanded bus subsidies, and
3. Advance the range of incentives and accommodations that it provides to stimulate transition from single occupancy travel to other means.
4. An electrical infrastructure plan to prepare for campus installation oF charging stations, both fleet and passenger vehicles.

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[38] | All dollar values in this section are 2021 dollar values.

Though capable of charting a logical schedule for fleet transition based on expected technology innovations matched with the need to retire existing vehicles, as follows:

- By 2030, electrify most of the facility service vehicles.
- By 2035, electrify most of the NAU bus and shuttle fleet.
- By 2040, electrify remaining vehicles in motor pool, facilities, buses and shuttles, electrify most of the NAU owned construction equipment and focus on shifting charging and energy consumption to non-peak and low emission periods, and
- By 2050, achieve carbon neutrality as APS achieves 100% renewable energy or purchase renewable power for all fleet vehicles.

NAU fleet investments have been sporadic and limited. Thus, Transportation Committee members lack confidence in the university's ability to execute the schedule outlined above. Given this, no capital costs for long-term investments in the fleet were suggested.

The cost of the second immediate initiative, quantifying the impact on expanded bus subsidies to reduce use if single occupancy vehicles commuting to campus and on campus, will be made evident through the proposed study.

Similarly, efforts in the near term to stimulate additional reliance on transportation other than single occupancy vehicles will be vetted through the recommended study to occur in the next two years. This is a study that should involve a number of university units to address and ensure public safety, aesthetics, campus urban design, understanding of capital and operating costs, etc.

Waste Management

The Waste Management Committee recommends near term operating costs that should be perpetuated: $10,000/year for the on-campus composting, $40,000/year for education and 1 fte to guide these efforts. In addition, the university should expect a steady need for investment in recycling equipment and receptacles.

Institutional Structure to Guide NAU to Carbon Neutrality

The recommendation of 2 ftes to manage sustainability and resilience related data, generate regular progress reports, expand the support of NAU as a living lab and guide related policies and procedures should be budgeted as permanent university investments.

C. Energy System Model: Assumptions and Detailed Results

A rough order of magnitude life cycle cost analysis compares the two options for carbon neutrality milestones of 2030, 2040, and 2050 against the business as usual campus energy system. This planning tool is interactive and has numerous, adjustable parameters to evaluate many distinct scenarios.

Inputs to the planning tool are[39]:

- Electricity. The initial cost of electricity has been based on the FY2020 average rate of $0.0686 per kWh, which equates to $20.11 per MMBtu. Future electricity cost in nominal dollars for industrial customers in the region was downloaded from the US EIA 2020 Annual Energy Outlook through 2050 for the reference case and all side cases available, then normalized to current price and charted as shown in Figure 59. Using the reference case, the electricity cost escalation through 2050 is an average of 2.6% per year.

  Based on the US EIA 2019 Figure 7 electric power industry emissions rates for Arizona, an initial electric utility carbon content of 844 lbs CO2e per MWh has been considered. This equates to 0.383 MTCDE per MWh. It is projected for this to decrease 50% by 2030 and 100% by 2050. Linear interpolation has been used for intermediate years.

  Based on the US EIA 2019 electric power industry emission rates, the electric utility transmission losses are estimated to be 3.7%. This is adjustable from 0% to 5% in the Energy Action Planning Tool, which will increase the calculated Scope 2 emissions but will not change electricity cost.

- Natural Gas. The initial cost of natural gas has been based on the FY2020 average rate of $3.80 per MMBtu. Future natural gas cost in nominal dollars for industrial customers in the region was downloaded from the US EIA 2020 Annual Energy Outlook through 2050 for the reference case and all side cases available, then normalized to current price and charted as shown below. Using the reference case, the natural gas cost escalation through 2050 is an average of 5.9% per year.

  The industry standard carbon content for natural gas combustion is 117 lbs CO2e per MMBtu[40]. This equates to 0.053 MTCDE per MMBtu.

  Natural gas direct leakage is estimated to be 2.3%[41]. This is adjustable from 0% to 5% in the Energy Action Planning Tool, which will increase the calculated Scope 1 emissions using a GWP of 34 for methane, but will not change natural gas cost.

- Water and Sewer. The initial cost of water and sewer has been based on the FY2020 average rate of $5.63 and $4.70 per 1,000 gallons, respectively. The average annual escalation of water and sewer cost since fiscal year 2006 has been 7.4% and 5.5%, respectively. The Energy Action Planning Tool has been set based on this direction (rounded to the nearest 0.5%).

  The carbon content of water and sewer was not considered in the Energy Action Planning Tool. It is expected the greenhouse gas emissions associated with water treatment and distribution systems is accounted for by the utility. Any leakage of water prior to point of delivery is not considered in this analysis. It is expected for this to be accounted for by the utility.

  The Energy Action Plan's primary impact on water consumption is based on cooling tower operation for heat rejection. The electric heat pump option will recover a portion of the heat that has historically been rejected at the cooling towers, which will reduce water consumption at the cooling towers. Evaporation and blowdown are considered, but leakage, drift, and wind losses have been excluded. Blowdown is considered based on 15 cycles of concentration.

- Internal Carbon Cost. The Energy Action Planning Tool allows the Internal Carbon Cost to be adjusted separately for Scope 1 and Scope 2 from $0 to $600 per MTCDE in $5 increments. These costs escalate equal to the set escalation rate for operations and maintenance costs.

- Wood Feedstock and Ash Removal. The Four Forest Restoration Initiative (4FRI) is restoring 2.4 million acres throughout the Coconino, Kaibab, Tonto and Apache-Sitgreaves National Forests. This includes approximately 10,000 acres per year of mechanical thinning where timbers are recovered for forest products manufacturing leaving behind approximately 100,000 green tons of sub-merchantable tops and limbs (also known as forest operations residuals or hog waste) which can be levered as woody biomass feedstock. The residuals/waste would otherwise be piled and burned, but can be delivered to a stockpile at NAU for approximately $40 per bone dry ton today. This flat rate cost covers loading the material where it is generated at the roadside landing with a grapple into a chipper/conveyor and then into a chip van for transfer of 25 tons per trip (interstate net weight limit). Depending on the exact location of the forest operation, the cost of this process ranges from $38 to $62 per bone dry ton. Sometimes the forest restoration contractor needs to load and transport this material a short distance due to open burning limitations, so the $40 per bone dry ton is a fair average rate to cover the added expense of delivery to NAU. It is assumed that the ash will be removed at no cost by other industries. Wood costs are assumed escalate equal to the set escalation rate for operations and maintenance costs.

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[39] | Metrics for FY2020 actual are:
- Annual Heating Load: 313,234 MMBtu
- System Efficiency: 75%
- Natural Gas Consumption: 417,645 MMBtu (FY20 ACTUAL)
- Electricity Consumption: 67,710,000 kWh (FY20 ACTUAL)
- Water Consumption: 195,146,298 gallons (FY20 ACTUAL)
- Sewer Discharge: 129,120,940 gallons (FY20 ACTUAL)
- Average Conventional Chiller Efficiency: 0.5 kW/ton

[40] | Source: Frequently Asked Questions (FAQS) (https://www.eia.gov/tools/faqs/faq.php?id=73&t=11)

[41] | Source: Assessment of methane emissions from the U.S. oil and gas supply chain by Ramón A. Alvarez, Daniel Zavala-Araiza, David R. Lyon, David T. Allen, Zachary R. Barkley, Adam R. Brandt, Kenneth J. Davis, Scott C. Herndon, Daniel J. Jacob, Anna Karion, Eric A. Kort, Brian K. Lamb, Thomas Lauvaux, Joannes D. Maasakkers, Anthony J. Marchese, Mark Omara, Stephen W. Pacala, Jeff Peischl, Allen L. Robinson, Paul B. Shepson, Colm Sweeney, Amy Townsend-Small, Steven C. Wofsy, Steven P. Hamburg. SCIENCE13 JUL 2018 : 186-188 (https://science.sciencemag.org/content/361/6398/186)

- The carbon content of wood feedstock has been taken as less than neutral, assuming the feedstock would otherwise have been piled and burned at the roadside and the carbon equivalent emissions are the same if combusted at the biomass heating plant and that the additional trucking and handling of the feedstock consumes diesel fuel at a rate of 5 gallons per bone dry ton and the diesel fuel combustion emissions are equivalent to 22.4 pounds of carbon dioxide per gallon. If the feedstock would not have otherwise been piled and burned, then the combustion is not carbon neutral. Carbon capture is not immediately viable, but it is possible for carbon capture to become viable prior to any policy changes that reduce open burning of the forest management residuals.
    - Financial Term. The Energy Action Planning Tool presents results in terms of total present cost, based on a term that is 20, 30, 40, 50, or 60 years. It is recommended to consider a longer term for major shifts in campus energy systems like those considered here. The baseline term is 60 years.
    - Discount Rate. The discount rate is utilized in the total present cost equation. This represents the time-value of money and is initially set at 3% per annum, but is adjustable to between 3% and 6% per annum. A higher discount rate will lessen the impact of future energy prices on the analysis, which will tend to favor lower capital cost options.
    - Operations and Maintenance Cost Escalation Rate. The operations and maintenance (O&M) cost escalation rate is assumed to be 3% but is adjustable between 1% and 3%.
    - Material Cost Escalation Rate. The material cost escalation rate for future capital expenditures is assumed to be 2% but is adjustable between 1% and 3%.

Capital Cost

Option 0: Baseline. The baseline option requires the lowest capital expenditure of the options considered. The three newer steam boilers in North Plant are adequate to serve the entire northern and southern portions of the campus and accommodate growth and are expected to have 40 years of remaining life. The steam and high temperature hot water distribution systems will require ongoing renewal. The first renewal project is to replace the south campus hot water piping that was installed in 1970, and then distribute hot water from South Plant to North Plant back feeding the steam and converting the associated buildings to utilize hot water, which will cost approximately $21.5 million today (phase 1). This project is to be completed prior to the end of the economic life of the existing south campus hot water boilers.

The next project is to replace the north campus steam and condensate distribution at the end of its economic life, around 2040. This has been separated into an east phase at approximately $12.5 million today (phase 2) and a north phase at approximately $12 million today (phase 3).

The remaining south campus hot water piping should be planned for replacement in approximately 2050 at the end of its economic life for a cost of approximately $2 million today (phase 4).

The buildings with local heating systems should be considered for centralization at the end of the economic life for the respective local heating system. The total cost of these centralization projects is approximately $16 million today (phase 5).

The renewal cost for North Plant steam system in approximately 2060 is taken as $13.5 million today (Phase R).

All costs are marked up based on design contingency and owner soft cost listed below and then escalated to the year of construction and then discounted to present cost as described on the Financial Inputs page.

The woody biomass heating plant (option1). This option includes the same cost for ongoing replacement of distribution systems with an additional connection to the biomass heating plant across Lone Tree Road (approximately $5.5 million additional cost today in Phase 1). Rather than future renewal for North Plant steam system, a capital expenditure for a new biomass heating plant is taken as $33 million today (phase P) with full renewal every 30 years (phase R). The biomass heating plant cost is dependent on the selected carbon neutrality milestone of 2030, 2040, or 2050. All costs are marked up based on design contingency and owner soft cost listed below and then escalated to the year of construction and then discounted to present cost.

Note that an increase in operations and maintenance cost is also applied to the woody biomass heating plant option. This is initially estimated to be twelve staff at average cost including overhead of $200,000 per year and is escalated based on parameters described

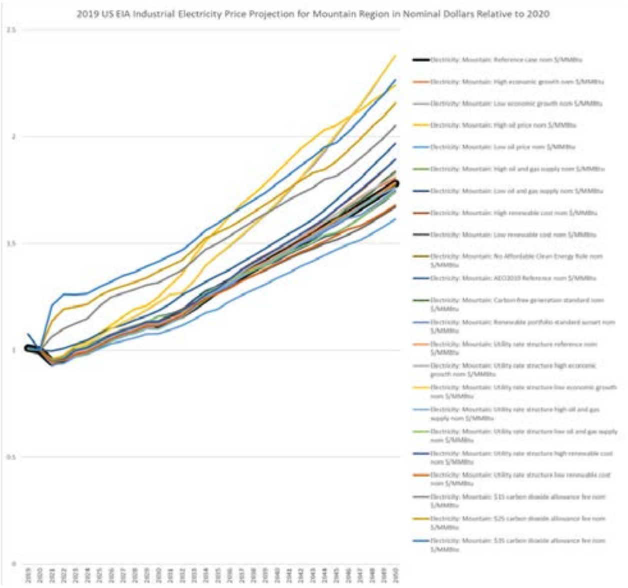


Figure 59. 2019 US EIA Electricity Price Projection

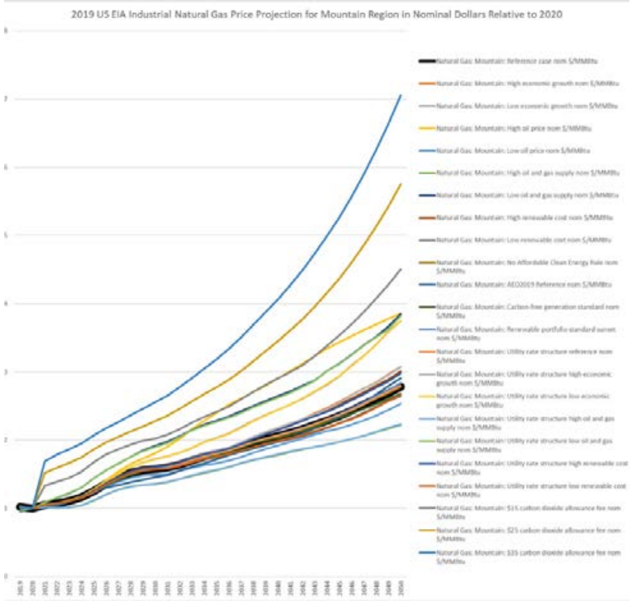


Figure 60. 2019 US EIA Natural Gas Price Projection

on the Financial Inputs page. The twelve staff include nine operators, two maintenance technicians and stockpile equipment operators, and one manager. Other campus energy operations and maintenance costs are excluded from the Energy Action Planning Tool and assumed to be the same in all options (the existing staff of eight will continue to be responsible for conventional chillers, natural gas boilers as back-up, and the new steam to hot water convertors and high temperature hot water steam generators).

Low-temperature heating water conversion with central electric heat pumps (option 2). Additional cost is incurred for distribution system in option 2 because the south campus buildings need to be modified to make use of lower temperature hot water; this is estimated to be approximately $4.5 million today (phase 0). Option 2 also requires distribution systems to be advanced to the carbon neutrality year because the heat pump system cannot generate steam. Rather than capital expenditure for a new biomass heating plant, the new central heat pump plant cost is taken as $40 million today (phase P) with renewal of heat pumps every 30 years at $15 million today (phase R) and full renewal of the facility every 60 years. A geothermal heating and cooling (GHC) array is also necessary to supplement the source of heat and is taken at $16 million today plus $6.5 million today for connection to the heat pump plant and interconnection between north and south campus chilled water (phase 6). These capital expenditures are dependent on the selected carbon neutrality milestone of 2030, 2040, or 2050. All costs are marked up based on design contingency and owner soft cost listed below and then escalated to the year of construction and then discounted to present cost.

There has not been any net operations and maintenance cost taken because the geothermal system requires minimal maintenance and the heat pumps replace conventional chillers.

Design contingency. All cost estimates above are marked up by 15% for design contingency.

Owner soft cost. All cost estimates above are marked up by 22% for owner soft costs (design and permit fees, insurance and bonds).

Capital cost by year. Including design contingency and owner soft cost but excluding escalation and discount rates, for each year on a 60 year term amongst the seven options that are included in the Energy Action Planning Tool. The negative cost in the final year represents salvage value. The parenthetical number following the cost represents the phase identifier. Within the Energy Action Planning Tool, these costs react to input escalation rate, discount rate, and term to determine the total present cost of capital.

Campus Growth

The Climate Action Plan Steering Committee decided on an upper and lower building square foot growth rate assumption to be used in the CAP. In both cases, the CAP will show the proposed growth for 2020-2030 as detailed in the university's capital plan. For the 2030-2050 decades it will test no net increase in GSF and 0.47% per annum GSF increase (relates to historic growth of occupiable space). Campus building growth does not directly correlate to increase in campus energy demand. It is assumed that there will not be any change in campus energy demand, but an adjustment of up to 0.5% additional or 0.5% less campus energy demand can be applied in the Energy Action Planning Tool.

Other Inputs

- Existing Heating System.
  - Annual Heating Load: 313,234 MMBtu.
  - System Efficiency: 75%.
  - Natural Gas Consumption: 417,645 MMBtu (FY20 ACTUAL).
- Electricity.
  - Electricity Consumption: 67,710,000 kWh (FY20 ACTUAL).
- Water and Sewer.
  - Water Consumption: 195,146,298 gallons (FY20 ACTUAL).
  - Sewer Discharge: 129,120,940 gallons (FY20 ACTUAL).
  - Average Conventional Chiller Efficiency: 0.5 kW/ton.
- Biomass Heating Plant.
  - Direct Combustion Efficiency: 71.0% (TSS Report).
  - Higher Heat Content: 16 MMBtu/BDT (8,000 Btu/lb).
- Central Heat Pumps.
  - Ratio of annual combined heating and cooling: 38% of heating.
  - Heat Pump COP: 2.87.

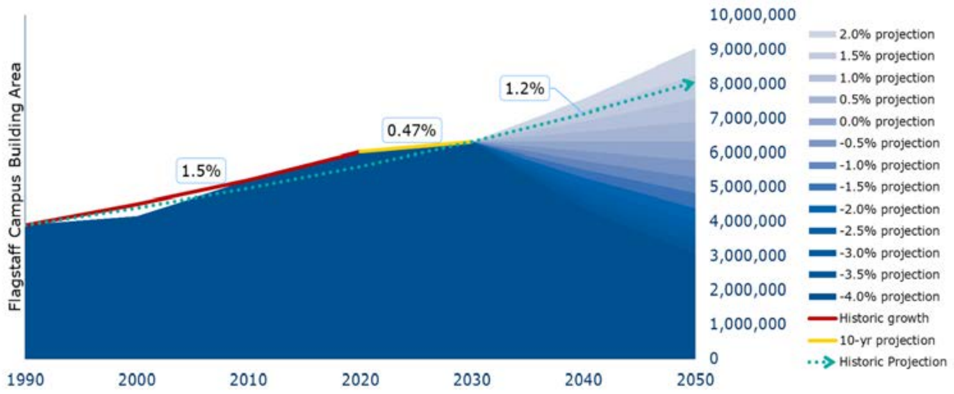
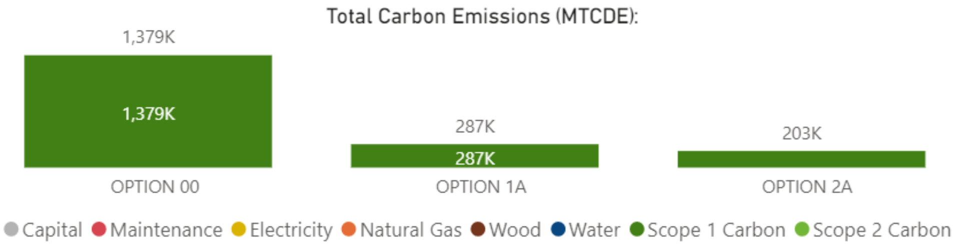


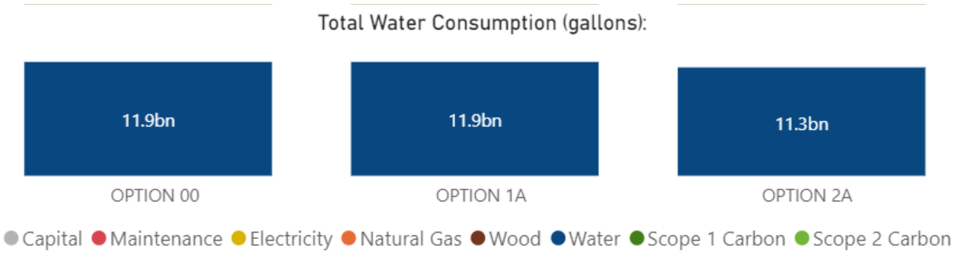
Figure 61. Flagstaff Mountain Campus Building Growth

Life Cycle Cost Analysis

An interactive quantitative comparison of the life cycle cost analysis is available on this page[42]. The business-as-usual case is labeled Option 00. A suffix A, B, or C is added to Option 1 and 2 identifiers for 2030, 2040, or 2050 carbon neutrality milestones, respectively. The first page of the quantitative comparison shows four stacked column charts. These are snipped below, showing the baseline inputs. In the project planning tool, inputs are adjustable with sliders and the baseline can be restored by refreshing the page. The first stacked column chart shows the total carbon emissions in the term. A radio button titled "Carbon Neutral Imported Electricity" allows the reader to toggle Scope 2 emissions on and off. This is off in the baseline case to focus on a Scope 1 carbon neutrality decision. The total carbon emissions in a 60-year term are 1,379,000 MTCDE for the business-as-usual case, 287,000 MTCDE for option 1A, and 203,000 MTCDE for option 2A. The reason that emissions are shown in option 2A is that natural gas will continue to be utilized during the campus transition from now to 2030. The reason that option 1A has more emissions than option 2A is that handling and transport of wood feedstock will result in ongoing emissions associated with diesel combustion in equipment and truck internal combustion engines.



The next stacked column chart shows the total water consumption in the term. Option 1 is not taken to have any change in water consumption relative to the business-as-usual case. Option 2A is estimated to reduce water consumption by 600 million gallons relative to the business-as-usual case associated with combined heating and cooling operation where heat that would have been rejected to the atmosphere via conventional chillers and evaporative cooling towers is instead recycled and converted via electric water-to-water heat pumps as useful heating water.



Option	Option 00	Option 1A	Option 1B	Option 1C	Option 2A	Option 2B	Option 2C
Description	Business as Usual	Woody Biomass Heating Plant			Low-Temperature Hot Water Conversion and Central Electric Heat Pumps		
Carbon Neutrality Milestone	N/A	2030	2040	2050	2030	2040	2050
Each Year	Annual Capital Expenditure Budgetary Estimate in 2020 Dollars as if Constructed Today; Including Design Contingency and Owner Soft Cost; Excluding Escalation and Discount Rates						
2021	$-	$-	$-	$-	$-	$-	$-
2022	$-	$-	$-	$-	$-	$-	$-
2023	$-	$-	$-	$-	$-	$-	$-
2024	$-	$-	$-	$-	$6,070,000 (0)	$-	$-
2025	$-	$-	$-	$-	$26,930,000 (1)	$-	$-
2026	$-	$-	$-	$-	$16,930,000 (2)	$-	$-
2027	$-	$-	$-	$-	$16,160,000 (3)	$6,070,000 (0)	$6,070,000 (0)
2028	$29,540,000 (1)	$37,200,000 (1)	$37,200,000 (1)	$37,200,000 (1)	$2,910,000 (4)	$26,930,000 (1)	$26,930,000 (1)
2029	$-	$45,310,000 (P)	$-	$-	$54,920,000 (P)	$-	$-
2030	$-	$22,050,000 (5)	$-	$-	$52,930,000 (5&6)	$-	$-
2031	$-	$-	$-	$-	$-	$-	$-
2032	$-	$-	$-	$-	$-	$-	$-
2033	$-	$-	$-	$-	$-	$-	$-
2034	$-	$-	$-	$-	$-	$-	$-
2035	$-	$-	$-	$-	$-	$-	$-
2036	$-	$-	$-	$-	$-	$16,930,000 (2)	$-
2037	$-	$-	$-	$-	$-	$16,160,000 (3)	$-
2038	$16,930,000 (2)	$16,930,000 (2)	$16,930,000 (2)	$16,930,000 (2)	$-	$2,910,000 (4)	$16,930,000 (2)
2039	$-	$-	$45,310,000 (P)	$-	$-	$54,920,000 (P)	$-
2040	$16,160,000 (3)	$16,160,000 (3)	$38,210,000 (3&5)	$16,160,000 (3)	$-	$52,930,000 (5&6)	$16,160,000 (3)
2041	$-	$-	$-	$-	$-	$-	$-
2042	$-	$-	$-	$-	$-	$-	$-
2043	$-	$-	$-	$-	$-	$-	$-
2044	$-	$-	$-	$-	$-	$-	$-
2045	$-	$-	$-	$-	$-	$-	$-
2046	$-	$-	$-	$-	$-	$-	$-

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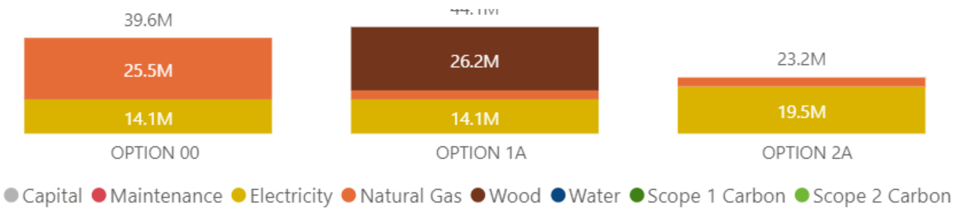
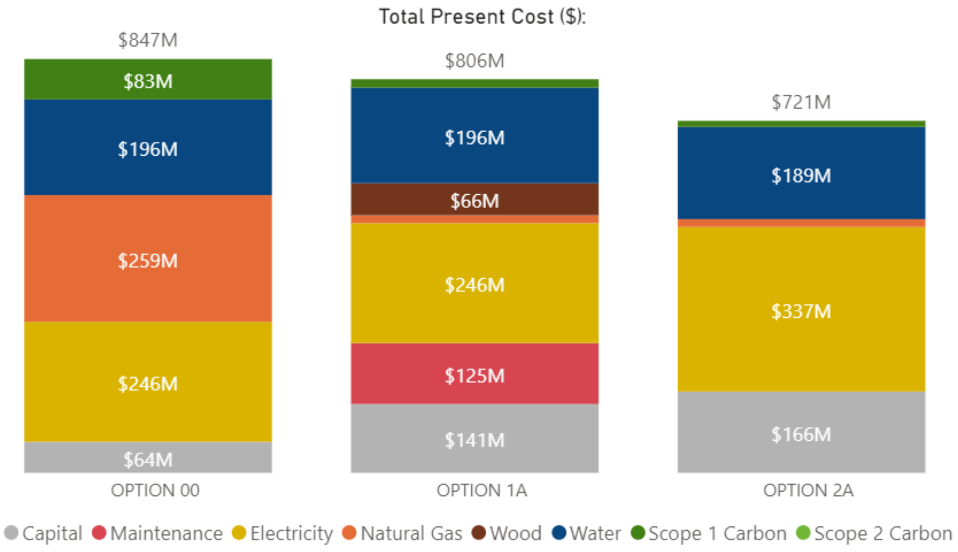
[42] | https://app.powerbi.com/view?r=eyJrIjoiYWZlZmY3OWUtODQ0Ni00ZjQzLTgxZGEtNDAyZjY0ZmJhYjAzliwidCI6ImExZDE0OGYzLWIwMzktNGUyZC04ZDJlLTllMjZiZDRmYmQ2NCIsImMiOjN9&pageName=ReportSection

The next stacked column chart shows the total energy consumption in the term. Option 1 is not taken to have any change in electricity consumption relative to the business-as-usual case. Both option 1 and 2 continue to utilize natural gas during the campus transition. Option 1A is estimated to increase energy consumption by 500,000 MMBtu (1e6 Btu) because the woody biomass boilers are less efficient than natural gas boilers. Option 2A is estimated to decrease energy consumption by 16,400,000 MMBtu (1e6) Btu because heat pumps are more efficient than combustion heating technologies.



The final stacked column chart shows the total present cost in the term. The business-as-usual case is estimated to have a total present cost of $847,000,000 including the internal cost of carbon or $765,000,000 excluding the internal cost of carbon. Option 1A is estimated to have a total present cost of $806,000,000 including the internal cost of carbon ($41,000,000 NPV[43]) or $789,000,000 excluding the internal cost of carbon ($24,000,000 NPC[44] or -$24,000,000 NPV[10]). Option 2A is estimated to have a total present cost of $721,000,000 including the internal cost of carbon ($126,000,000 NPV) or $709,000,000 excluding the internal cost of carbon ($80,000,000 NPV[10]).



Option	Option 00	Option 1A	Option 1B	Option 1C	Option 2A	Option 2B	Option 2C
2047	$-	$-	$-	$-	$-	$-	$-
2048	$2,910,000 (4)	$2,910,000 (4)	$2,910,000 (4)	$2,910,000 (4)	$-	$-	$2,910,000 (4)
2049	$-	$-	$-	$45,310,000 (P)	$-	$-	$54,920,000 (P)
2050	$-	$-	$-	$22,050,000 (5)	$-	$-	$52,930,000 (5&6)
2051	$-	$-	$-	$-	$-	$-	$-
2052	$-	$-	$-	$-	$-	$-	$-
2053	$-	$-	$-	$-	$-	$-	$-
2054	$-	$-	$-	$-	$-	$-	$-
2055	$-	$-	$-	$-	$-	$-	$-
2056	$-	$-	$-	$-	$-	$-	$-
2057	$-	$-	$-	$-	$-	$-	$-
2058	$22,050,000 (5)	$-	$-	$-	$-	$-	$-
2059	$-	$45,310,000 (R)	$-	$-	$20,600,000 (R)	$-	$-
2060	$-	$-	$-	$-	$-	$-	$-
2061	$18,540,000 (R)	$-	$-	$-	$-	$-	$-
2062	$-	$-	$-	$-	$-	$-	$-
2063	$-	$-	$-	$-	$-	$-	$-
2064	$-	$-	$-	$-	$-	$-	$-
2065	$-	$-	$-	$-	$-	$-	$-
2066	$-	$-	$-	$-	$-	$-	$-
2067	$-	$-	$-	$-	$-	$-	$-
2068	$-	$-	$-	$-	$-	$-	$-
2069	$-	$-	$45,310,000 (R)	$-	$-	$20,600,000 (R)	$-
2070	$-	$-	$-	$-	$-	$-	$-
2071	$-	$-	$-	$-	$-	$-	$-
2072	$-	$-	$-	$-	$-	$-	$-
2073	$-	$-	$-	$-	$-	$-	$-
2074	$-	$-	$-	$-	$-	$-	$-
2075	$-	$-	$-	$-	$-	$-	$-
2076	$-	$-	$-	$-	$-	$-	$-
2077	$-	$-	$-	$-	$-	$-	$-
2078	$-	$-	$-	$-	$-	$-	$-
2079	$-	$-	$-	$45,310,000 (R)	$-	$-	$20,600,000 (R)
2080	$-	$-	$-	$-	$-	$-	$-
2081	-$34,448,416	-$28,622,422	-$42,077,822	-$55,533,222	-$20,888,557	-$47,498,732	-$67,733,982

- (#) correlates project cost to associated phase for each option
- (P) correlates project cost for new utility plant
- (R) correlates project cost to renewal of equipment

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43 | NPV = Net Present Value (the amount that the alternative total present cost is lower than the baseline total present cost)

44 | NPC = Net Present Cost (the amount that the alternative total present cost is higher than the baseline total present cost)

The second page of the quantitative comparison shows tabular data and is linked to the same input adjustments as on the first page. These tables, snipped below, employ the baseline inputs. Inputs are adjustable with sliders and the baseline can be restored by refreshing the page.

The first table on the right shows the net present cost of each option divided by the total Scope 1 carbon reduction relative to the business-as-usual case. The findings in this table are that carbon neutrality reduces total present cost except for option 1A (woody biomass by 2030). Even option 1A is only a cost of $22/MTCDE which is less than the $60/MTCDE NAU assignment for the internal cost of carbon. (See this page[45] for more discussion on the internal cost of carbon.) The reason that the total present cost of the decarbonization decreases over time is because of the 20+ year remaining life on the majority of the existing natural gas combustion heating generation and distribution systems. Option 2 is less total present cost than option 1 and eliminates more Scope 1 emissions resulting in better value shown in the NPC/MTCDE metrics.

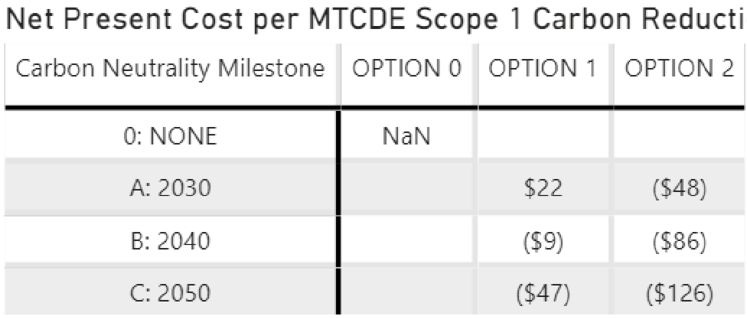
The next table on the right shows the total energy consumption in the term. This is the same information represented by the third stacked column chart on the first page of the tool, but also shows how the carbon neutrality year impacts the result. For Option 1 the energy consumption decreases as the carbon neutrality year increases because the system is less efficient than business-as-usual. For option 2 the energy consumption increases as the carbon neutrality year increases because the system is more efficient than business-as-usual.

The final table on the right shows the total present cost of OPEX (operating expenditures) and CAPEX (capital expenditures). This is similar to the fourth stacked column chart on the first page but more granularly categorizes costs. This table shows how Option 2 has the highest CAPEX and lowest OPEX, while the business-as-usual case has the lowest CAPEX and the highest OPEX. Option 1 is a middle ground between the business-as-usual and option 2 in both CAPEX and OPEX.

The third page of the tool shows key influencers. It compares the net present cost of option 2 relative to option 1. If the net present cost of option 2 relative to option 1 is positive then the total present cost of option 2 is higher than option 1 by that amount. Conversely, if the net present cost of option 2 relative to option 1 is negative then the total present cost of option 2 is lower than option 1 by that amount.

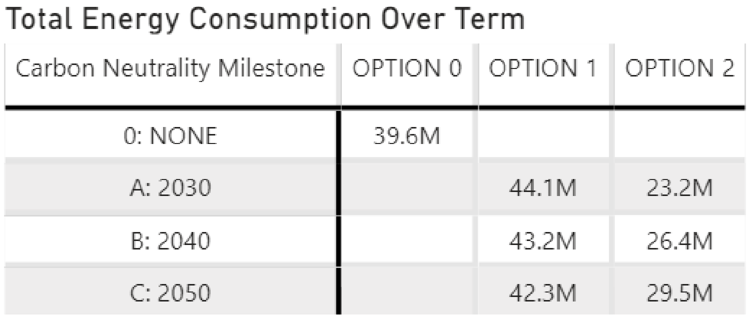
The first two charts in the upper row on the left side are sensitivity to primary fuel. Option 2 is sensitive to electric cost escalation and option 1 is sensitive to wood feedstock cost. The first chart shows that with 4% or higher electric cost escalation and no other changes option 1 is lower total present cost than option 2. The second chart shows that option 1 can become much higher total present cost than option 2 within the realm of wood feedstock delivery costs (this depends on the amount of cost offset by timber sales and government).

The upper-right chart shows that if cost of labor for operations and maintenance only increases at 1% per year over the term then the total present cost difference between option 1 and 2 is negated.



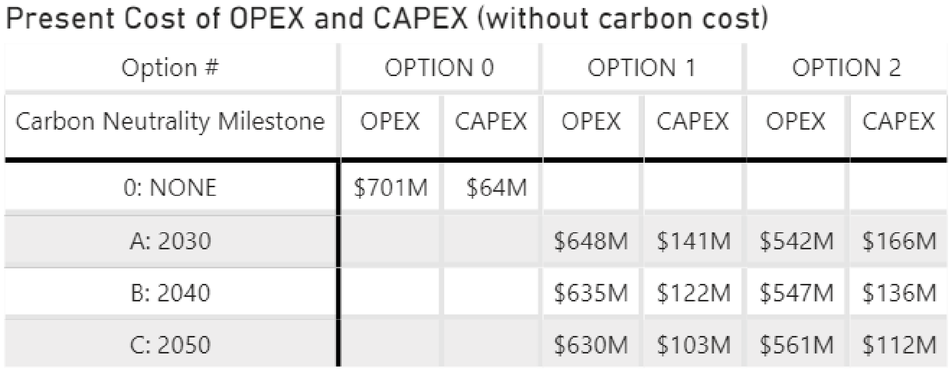
Net Present Cost per MTCDE Scope 1 Carbon Reduction

Carbon Neutrality Milestone	OPTION 0	OPTION 1	OPTION 2
0: NONE	NaN		
A: 2030		$22	($48)
B: 2040		($9)	($86)
C: 2050		($47)	($126)



Total Energy Consumption Over Term

Carbon Neutrality Milestone	OPTION 0	OPTION 1	OPTION 2
0: NONE	39.6M		
A: 2030		44.1M	23.2M
B: 2040		43.2M	26.4M
C: 2050		42.3M	29.5M



Present Cost of OPEX and CAPEX (without carbon cost)

Option #	OPTION 0		OPTION 1		OPTION 2	
Carbon Neutrality Milestone	OPEX	CAPEX	OPEX	CAPEX	OPEX	CAPEX
0: NONE	$701M	$64M				
A: 2030			$648M	$141M	$542M	$166M
B: 2040			$635M	$122M	$547M	$136M
C: 2050			$630M	$103M	$561M	$112M

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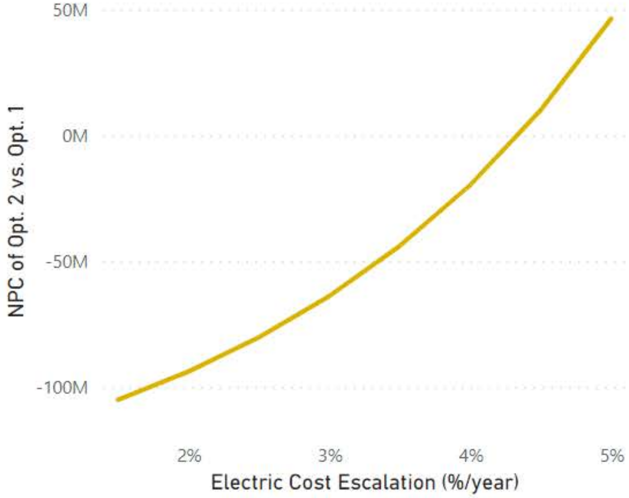
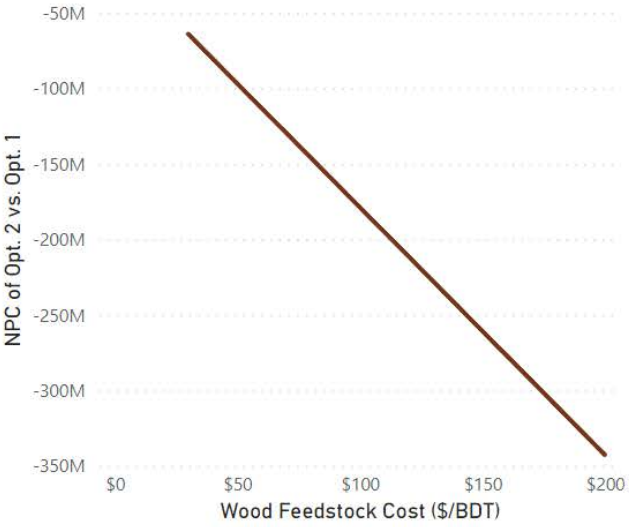
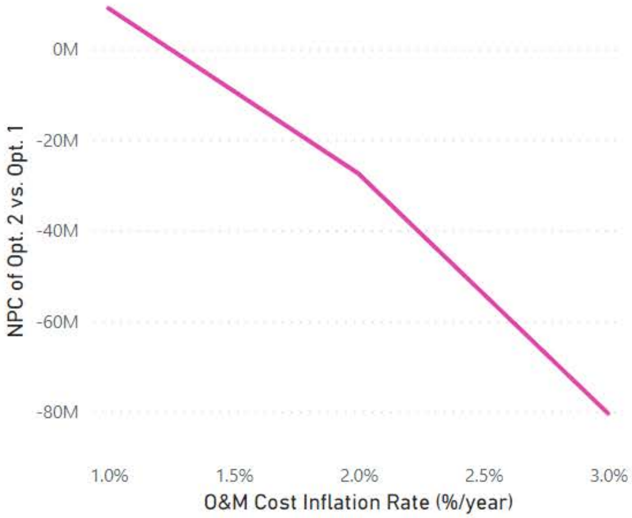
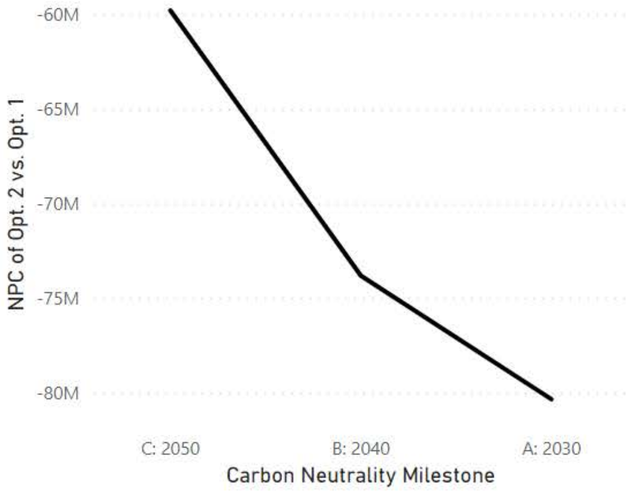
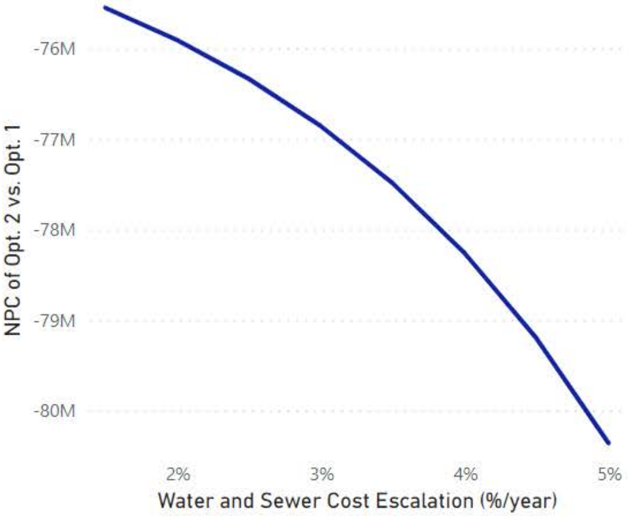
[45] | https://sites.google.com/view/internalcostofcarbon/home











Key Influencers

These criteria have the largest impact on the Net Present Cost of Option 2 (electrification with heat pumps) vs. Option 1 (wood biomass).

The lower-left chart shows that achieving carbon neutrality sooner rather than later is more favorable for option 2 than option 1 (because of the effect of OPEX on the total present cost).

The bottom-middle chart shows that water and sewer cost escalation increases will reduce the total present cost of option 2 relative to option 1, but the sensitivity is less than the other four key influencers.

Note that changing an input on the previous slides will update these charts (except for the chart associated with the input that is changed). To restore the baseline analysis, refresh the page.

D. Internal and Social Costs of Carbon

The internal cost of carbon is a metric use to advance consideration of climate solutions. This metric is most commonly formatted in terms of dollars per metric ton of carbon dioxide equivalent emissions, or $/MTCDE. Before an institution can utilize the internal cost of carbon it must arrive at a value to employ. In some situations, and likely in the future, there may be an actual cost of emissions. This cost likely takes the form of a carbon tax or cap and trade program. Minimally, it is the speculated actual cost of carbon.

Air emissions can be equated to carbon dioxide emissions by multiplying the mass of the underlying emissions by the appropriate global warming potential. For example, refrigerant HFC-134a has a global warming potential of 1,300, so a release of 1,000 pounds of refrigerant HFC-134a is equivalent to 1,300,000 pounds of carbon dioxide emissions. There are 2,205 pounds in a metric ton, so 1,300,000 pounds of carbon dioxide equivalent emissions equates to 590 MTCDE.

If an institution uses an internal cost of carbon of 20 $/MTCDE, then that institution would value avoiding 1,000 pounds of released refrigerant HFC-134a at $11,800. This amount of emissions is approximately equivalent to ten to twenty years of leakage from a 500-ton medium pressure packaged chiller, or one to two years of leakage from a 5,000-ton medium pressure packaged chiller. This institution may then consider the cost of carbon as one metric when selecting a new chiller and given the choice between HFC refrigerant versus HFO or natural refrigerants. For example, the institution may select the new chiller on the basis of lowest life cycle cost including the initial capital cost, the present cost of lifetime preventative maintenance, the present cost of lifetime repair, the present cost of lifetime energy input, and the present “cost” of lifetime emissions.

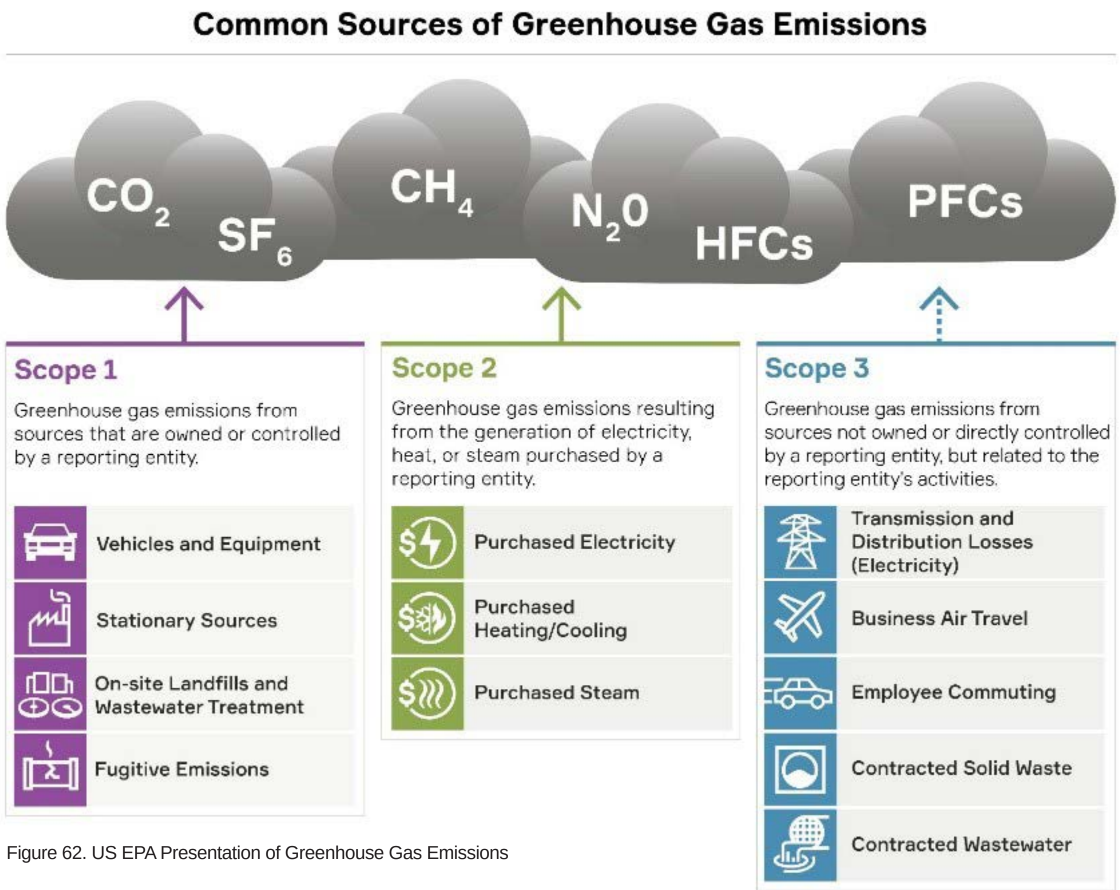


Figure 62. US EPA Presentation of Greenhouse Gas Emissions

Scope 1 emissions are those emitted by sources owned by the institution. Institutions apply discretion in applying the internal cost of carbon to scope emissions. For example, many chillers are driven by purchased electricity. Here, the institution would determine if Scope 2 emissions will carry the same internal cost of carbon as Scope 1 emissions, if at all, when developing the related life cycle cost analysis. In other cases, chillers may be driven by carbon neutral electricity, purchased steam, steam generated on-site, conventional power generated on-site, direct-combustion of fossil fuels, or other sources of energy and could be considered with the appropriate value on associated emissions.

The social cost of carbon incorporates the value assigned as the internal cost of carbon and is a more abstract concept. It captures all indirect costs associated with economic harm from emissions, such as increased cost of healthcare due to higher rates of disease, damages caused by extreme weather events, lower productivity of agriculture due to changes in weather, loss of land due to rising sea level, and many other impacts. U.S. higher education and corporate entities often employ the US EPA’ stated social cost of carbon. However, much literature exists that argues against it. Alternative calculations are also publicly available, including some developed by U.S. higher education institutions.

In the absence of clear initiatives by an institution for applying the Internal Cost of Carbon, a reasonable starting point is to quantify all Scope 1 emissions and apply the Social Cost of Carbon recommended by the U.S. E.P.A. in December of 2016 (EPA Fact Sheet). The schedule of these values equates to approximately equivalent to 42 $/MTCDE in 2020 with escalation of 1.75 %/year.

E. Carbon Neutral Technology Options Considered for NAU

Following, are carbon neutrality technology options, both generally available and promising as future technologies. Each was tested as a concept for the Flagstaff Mountain Campus.

Biomass

Biomass technologies include heat and/or power generation equipment that directly source their energy from biological matter. Common examples of energy sources are wood, agricultural waste, and livestock waste. A crop can be harvested for the sole purpose of providing biomass energy to an end user. These technologies differ from renewable natural gas in that the biological matter is delivered directly to the end user as a fuel rather than being converted to useful gas in a separate location and transported via natural gas infrastructure.

There are two main categories of biomass: direct combustion and gasification. Direct combustion biomass systems utilize solid fuel boilers to produce steam which can be used for power generation and/or heating. In some cases, existing coal boilers can be converted to direct combustion biomass boilers. Gasification systems utilize equipment that converts the energy in the feedstock to gaseous fuel that is piped to a boiler or an engine. Gasification systems that utilize boilers operate in a very similar manner to direct combustion systems, producing steam that is used for power generation and/or heating. In some cases, existing natural gas boilers can be converted to operate with a biomass gasifier. Gasification systems can also utilize engine generators with exhaust heat recovery to provide combined heat and power.

Biomass fuels are considered carbon neutral if they would have otherwise contributed to methane release to the atmosphere. For example, wood feedstock that is removed via sustainable forest management avoids the emissions associated with wildfires caused by not managing the forest or open burning or composting of wood that is removed. Wood can also be recovered waste from mills or manufacturing that would have otherwise been burned or composted. Agricultural or livestock waste are biomass resources that, similarly, are considered to be carbon neutral for as long as they would have otherwise decayed and openly released methane to the atmosphere. If the emissions of those processes are reduced in the future, then it would preclude the biomass fuel from being considered carbon neutral. Harvesting a dedicated crop for use as biomass fuel can be considered carbon neutral because the amount of carbon equivalent emissions that are released during combustion is equivalent to the amount that was sequestered during growth. The farming practices would also need to be sustainable with limited or zero emissions.

In the future, these waste streams may be regulated as carbon positive. In the immediate, however, new biomass could be designed for the ability to retrofit carbon capture equipment in the future when that technology is viable. Thus, this reduces the risk of the fuel losing its carbon neutral status.

A final complication to this technology relates to its transportation. Typically, the fuel source is not immediately adjacent to the end user and the fuel for the trucking fleet would need to be carbon neutral, such as biodiesel, electric, or hydrogen fuel cells. Other considerations for the trucking fleet are emissions associated with manufacturing of the vehicles, and maintenance such as tires and lubricants.

In sum, for biomass to be a viable carbon neutral combustion fuel there needs to be substantial organic waste from an adjacent process that is expected to continue for decades to come. In addition, use of this type of fuel brings materials handling and transportation challenges.

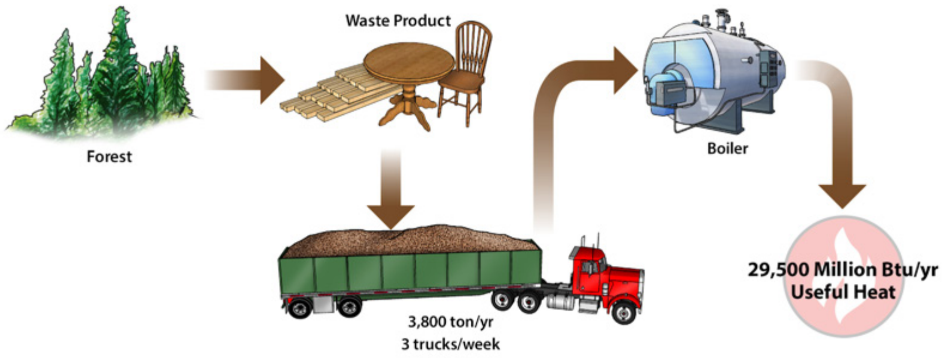


Figure 63. Example of Wood Feedstock Biomass

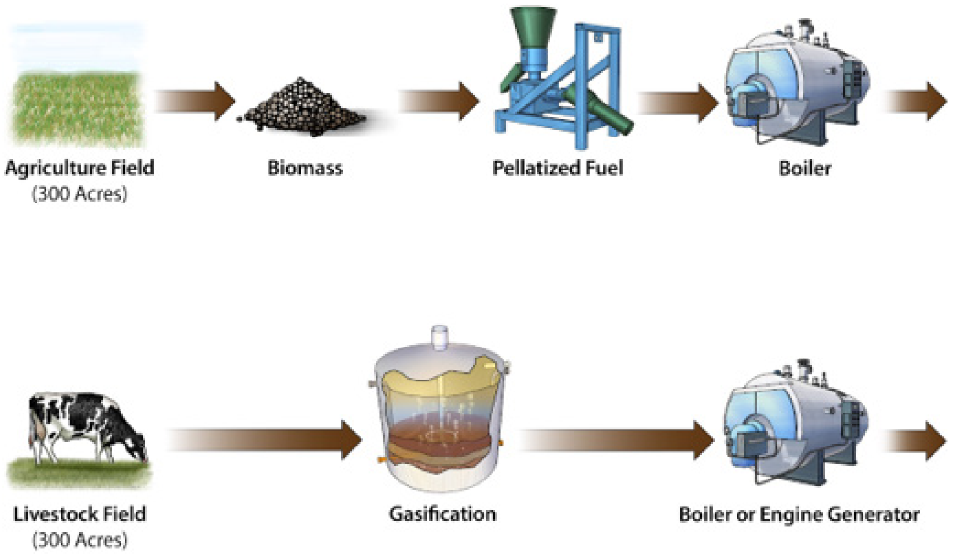


Figure 64. Example of Agricultural Waste Biomass

Combined Heating and Cooling

Combined Heating and Cooling (CHC) is a very efficient process that recovers waste heat from an existing district cooling network and converts that heat to a higher temperature that is useable to meet heating demands.

An appealing CHC arrangement is a conventional water-cooled chilled water system and heat recovery chiller arranged with the evaporator in parallel to the evaporators of conventional chillers, which can be done in the same or in separate plants. When there is a demand for heating, the heat recovery chiller is staged on and a portion of the chilled water return is pumped through the evaporator where heat is removed by evaporating refrigerant and useful chilled water is supplied to the cooling load. Some of the energy associated with the heat recovery chiller is offset by the reduced use of energy in the conventional chillers, cooling tower fans, and tower water pumps. The refrigerant that has evaporated is compressed to a higher pressure than typical for conventional chillers so that hot water return from the heating load can be passed through the condenser and heated to setpoint by condensing the higher pressure refrigerant. If the heating water supply temperature setpoint is not reached due to insufficient chilled water demands or if the heat recovery system is operating at maximum capacity, then the other sources of heat need to be added before the heating water is supplied to the load. The amount of additional energy required for the heat recovery system depends on the heating water supply temperature requirement and the type of equipment that is utilized, but due to the effects of the vapor compression cycle this heating source is much more efficient than any conventional heating system.

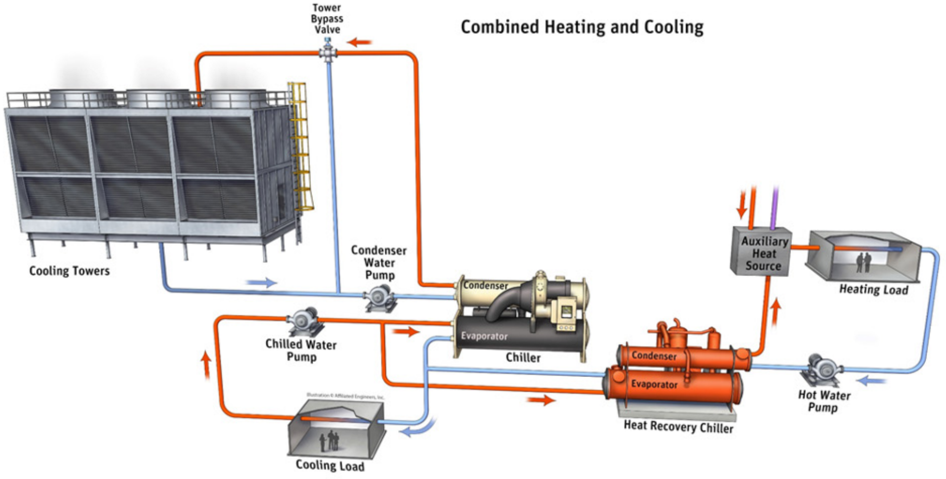


Figure 65. Combined Heating and Cooling Arrangement

The theoretical heating coefficient of performance (COP) for a 170°F heating supply temperature is 2.75 to 3[46]. When this is combined with the fact that the heat extracted from the evaporator is useful chilled water production, the resulting combined heating and cooling COP is 4.5 to 5. Compare this 450% to 500% efficiency against conventional heating technologies which are typically 70% to 90% efficient. In a new heating system that can be designed to accept 110°F heating supply temperature the heating COP can be approximately 5 resulting in a 900% efficient CHC system.

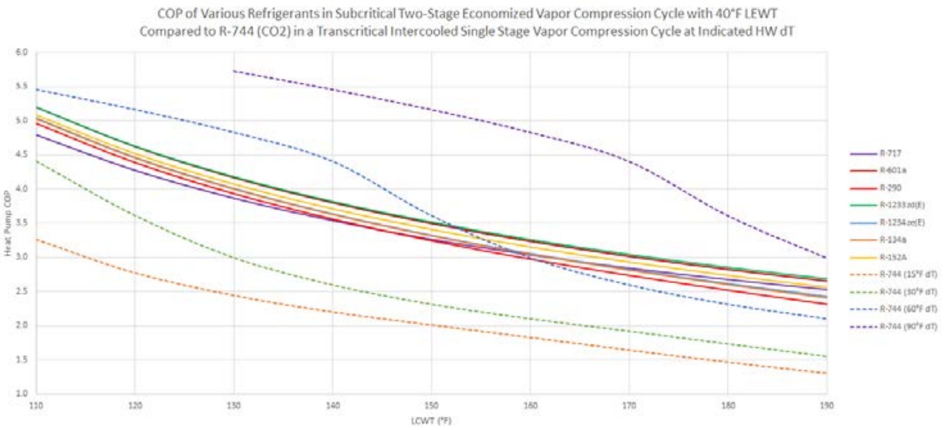


Figure 66. COP Based on Leaving Condenser Water Temperature

Figure 67. Available Heat Recovery Chillers for Different Design Conditions

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[46] The heating coefficient of performance can vary with leaving condenser water temperature (LCWT; also heating water supply temperature) on the heat recovery chiller. Refrigerants also have an impact, though small, if utilized in a two-stage economized subcritical vapor compression cycle (solid curves). Transcritical carbon dioxide vapor compression cycle can be beneficial when there is a high range on the heating system temperatures, but that is not normally the case for heating systems.

Ideally, many refrigerant options exist in two stage cycles across a wide range of heating water supply temperatures, but the needed equipment for this is not yet available in the U.S.

Readily available heat recovery chillers in the U.S. are limited. They offer options at lower heating water supply temperatures, especially at lower evaporator capacities. A heat recovery chiller that is oversized relative to the load can be applied in combination with thermal energy storage to charge the storage during parts of the day and cycle off for the remainder of the day while the storage discharges.

Combined heating and cooling system could be integrated with chilled water and hot water thermal energy storage in a plant that also contains conventional heating and cooling systems. The evaporators of the heat recovery chillers are arranged in parallel to the evaporator of the conventional chillers and the condensers of the heat recovery chillers are arranged in series upstream of supplemental heat sources. The thermal energy storage tanks are arranged as thermal bridges that decouple the heat recovery chiller loops from the conventional equipment loops. This allows the heat recovery chiller to stage on and off and operate at a fixed output regardless of variations in load.

Heat recovery chillers do not modulate capacity very well so thermal energy storage should be considered unless more than five heat recovery chillers are provided in parallel to meet variable loads by staging up and down. Centrifugal compressors can only maintain maximum lift with near maximum refrigerant flow, so they should typically be operated between 80% and 100% load. Screw compressors can maintain maximum lift at partial refrigerant flow, but their efficiency significantly degrades below 80% load. If the heat recovery chiller system is only intended to meet base system loads with supplemental capacity from other systems, then the thermal energy storage tanks can be avoided.

A heat recovery chiller can be capable of unparalleled capacities and temperature capabilities. The smallest capacity unit available is 600 tons and can provide heating water temperature up to 155°F. The largest unit available is 2,500 tons. When these units are selected for between 1,800 and 2,000 tons capacity, they are able to deliver heating water temperature up to 170°F. Refrigerant choices are HFC-134a or HFO/HFC-513a. Heating COP is approximately 3.5 at 150°F or 3.0 at 170°F.

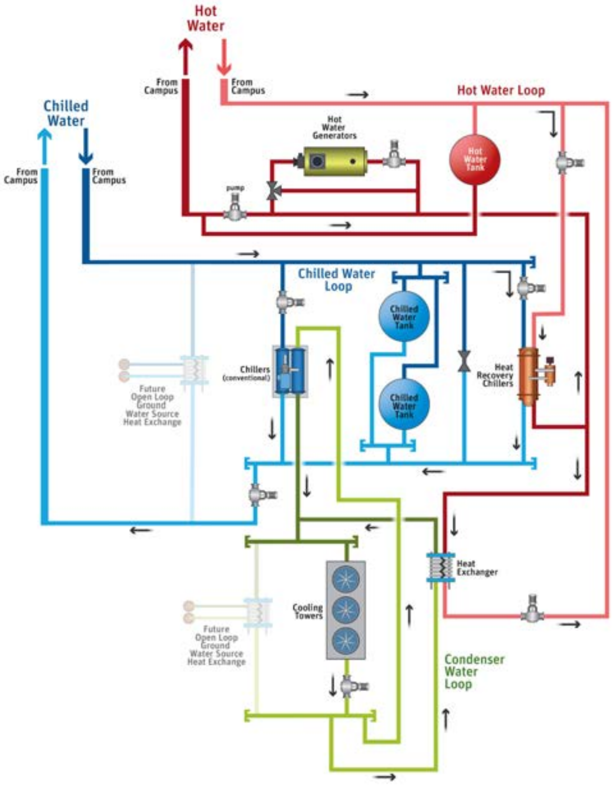

Figure 68. Combined Heating and Cooling Interfaced with Thermal Energy Storage and Conventional Heating and Cooling

Screw heat recovery chiller models are capable of approximately 200 tons at 140°F. Refrigerant choices are HFC-134a or HFO/HFC-513a. Heating COP is approximately 2.9 at 150°F or 3.9 at 130°F[47].

In sum, combined Heating and Cooling (CHC) systems are a simple variation of conventional Separate Heating and Cooling (SHC) systems that allows for efficiencies of 450% to 900% to be achieved. The largest barriers to this technology are that it can only produce low temperature hot water of 170°F or lower and the equipment has limited capacity modulation capability. These barriers can be overcome with a low temperature heating water distribution system and thermal energy storage unlocking very high system efficiencies. CHC systems do not provide 100% of annual heating in most climates because of limited need for chilled water during colder months of the year. The same central equipment that is utilized in a CHC system can be supplemented with additional low-grade heat sources (false chilled water loads) to meet additional heating loads.

Figure 69. Combined Heating and Cooling Interfaced with Thermal Energy Storage and Conventional Heating and Cooling

Figure 70. Combined Heating and Cooling Interfaced with Thermal Energy Storage and Conventional Heating and Cooling

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[47] | More information can be found at:https://www.york.com/commercial-equipment/chilled-water-systems/water-cooled-chillers/yvwa_ch and https://www.trane.com/commercial/asia-pacific/ph/en/products-systems/equipment/chillers/water-cooled-chiller/helical-rotary/seriesr-rtwd.html

Concentrated Solar Thermal Systems

Concentrated solar thermal systems were limited to large-scale applications such as electric utility power generation, but are being introduced as campus scale heating systems. One example is Heliogen which utilizes an array of robotic mirrors that redirect the irradiation to a collection tower where a receiver collects the heat into a high-temperature thermal fluid. The advantage of this type of system is increased effectiveness and higher temperature capabilities. This technology can produce steam that can be used for power generation and/or heating needs.

Daily irradiance[48] in January in Phoenix, AZ ranges from 500 to 2,100 Btu per square foot with an average of 1,500 for a panel installed in a grassy field at a 45 degree angle and facing due south. This equates to an average hourly rate of 1,350 MBH per acre using a panel system. The same system in Detroit, MI ranges from 100 to 1,400 Btu per square foot per day with an average of 600. This equates to an average hourly rate of 500 MBH per acre using a panel system. In this location, a concentrated system would only output approximately twice that of a panel system per land area.

If this type of system is sized to meet winter heating demand, then there will be excessive heat capacity in the summer and the system will have a low utilization factor and therefore a very high unit cost.

In sum, high-temperature solar thermal systems are very efficient, needing only power to drive circulating pumps and any motorized panel tracking systems. The main disadvantages are cost and space constraints. A screening analysis using TMY3 data for the project site can determine the land area required, thermal energy storage tank size required, and rough order of magnitude cost.

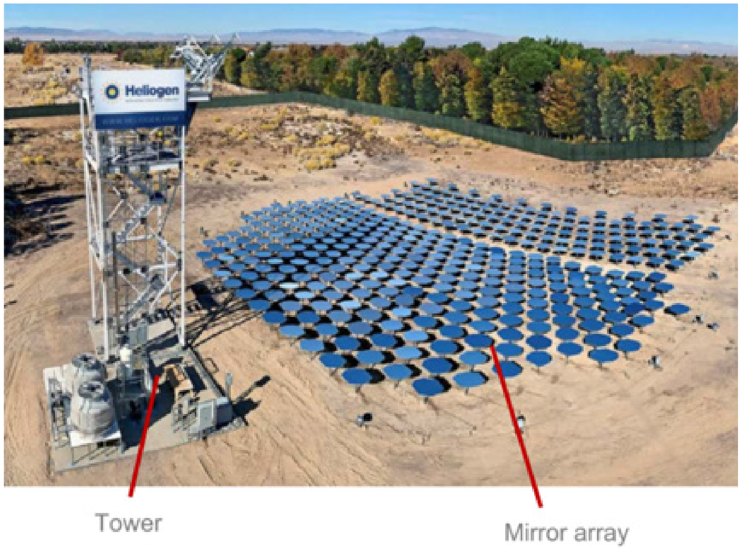

Figure 71. Hydrogen Concentrated Solar Thermal System Test Facility

High-Temperature Geothermal

High-temperature geothermal involves direct use of the earth's heat for heating needs and/or power generation. This technology captures heat that is greater than 150°F and can be used to create heating hot water. Some sources can be over 500°F and be used to generate high temperature hot water or steam that is used to generate power and/or distribute to lower temperature heating water convertors. The cost and availability of this technology depends on the geology and difficulty of drilling to the variable depth at which the necessary temperature is reached.

In a high-temperature geothermal power plant cold water is injected deep into the earth where it is heated and then forced up the hot well to a geothermal power plant. Here, the high temperature hot water is converted to steam to drive a turbine generator before being condensed and reinjected to the same loop. A high-temperature geothermal power plant can be connected to a district heating network if one was readily located to recover low pressure steam or heating water downstream of the turbine generator[49].

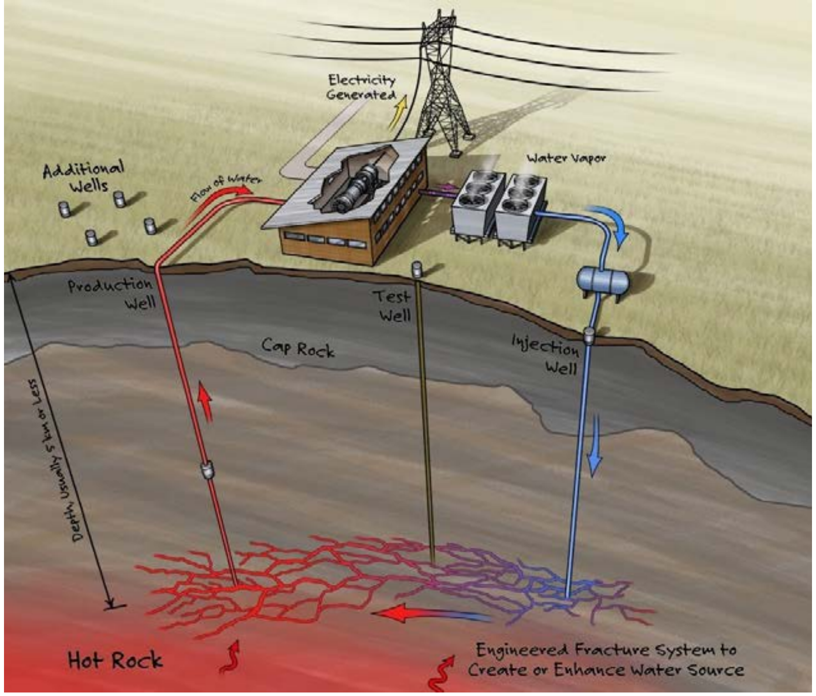

Figure 72. Illustration of High-Temperature Geothermal Plant

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[48] Irradiation is the process by which an object is exposed to radiation. Solar energy collection is an irradiation process that exposes a solar energy collection system to radiation from the sun.

[49] For more detail, see: www.nrel.gov/geothermal/ and https://www.vox.com/energy-and-environment/2020/10/21/21515461/renewable-energy-geothermal-egs-ags-supercritical

Low-Temperature Geothermal Technology

Low-temperature geothermal technology involves circulating chilled water or another thermal fluid through closed-loop piping that is buried underground in either horizontal trenches or vertical bores. Stable underground temperatures enable the colder supply entering the loop to gain some heat before returning to the heat recovery chiller evaporators. This system can be used during the summer to reject heat from the conventional cooling system condensers back into the ground rather than using evaporative cooling towers or other heat rejection systems.

This looped piping acts as a heat exchanger where heat is transferred through the surface of the piping that is in contact with the earth. The capacity of the system is dependent on the specific heat and thermal conductivity of the circulating fluid, the thickness and thermal conductivity of the piping, the thermal conductivity of the backfill/grout, and the temperature difference and thermal conductivity of the surrounding earth (noting that the temperature difference to the surrounding earth varies seasonally and is influenced by the piping system effect). The total capacity of the system is a product of the specific capacity and the total surface area of the piping. The horizontal trench method significantly limits the amount of surface area that is possible per land area, and is therefore only utilized for small buildings or residential systems. The vertical bore method is higher cost, but is necessary to consolidate larger systems into reasonably sized land areas.

There is variety of types of the vertical bore method. The conventional approach is a single U-loop of piping within each vertical bore. A variation of the conventional approach is to install a double U-loop within each vertical bore, which reduces the total number of bores that need to be installed, but increases the cost per bore. Another approach is to utilize concentric piping. The advantage of concentric piping is that the larger pipes can withstand greater pressures and can then be installed in deeper bores. The increased depth of the bores in the concentric piping design allows more surface area per bore which results in the highest capacity per bore.

The appropriate size and type of system can be determined with software modeling and unit costs from local contractors. Typically, a one-acre bore field can yield a capacity of 150 to 750 tons by utilizing approximately 50 to 150 bores, depending on type. Unit costs vary with availability and experience of local contractors, but could be approximately $5,000 to $10,000 per ton capacity.

Low-temperature geothermal is an excellent option for sourcing low-grade heat because it is scalable, works in all climates and most locations, has an expected life of 60 years or more with very low maintenance, and only requires the energy to drive circulating pumps. The largest barrier to this technology is initial capital cost, which is sometimes overcome with a full life cycle cost analysis with appropriate value assigned to reduced emissions. The space for drilling the bores can be repurposed after the system is completed and backfilled for use as open space, agriculture, parking and, in some cases, for building construction.

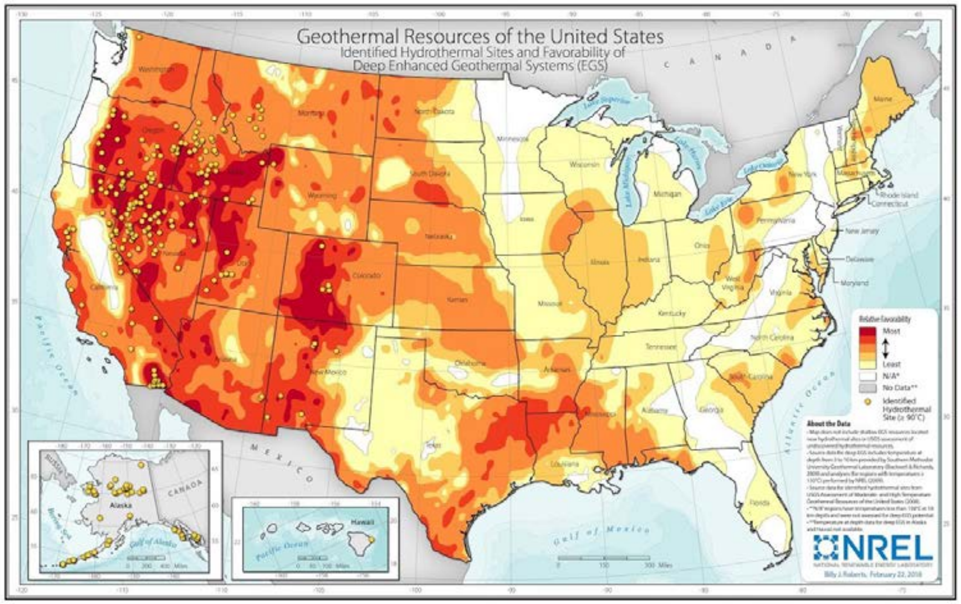

Figure 73. NREL Map of Favorable Geothermal Sites

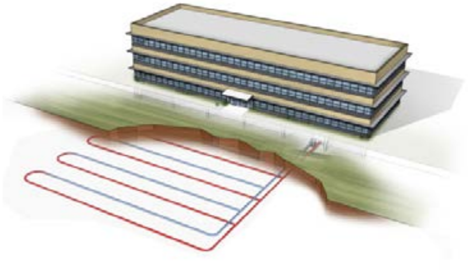

Figure 74. Horizontal Trench method

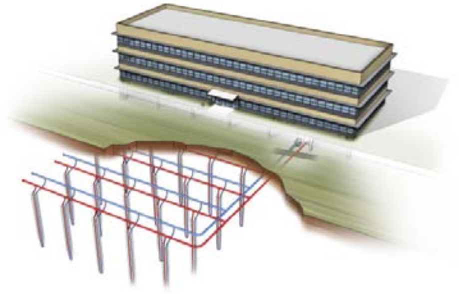

Figure 75. Vertical Bore Method

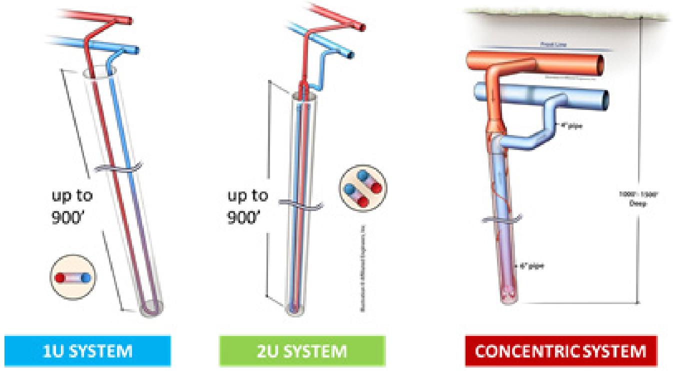

Figure 76. Different Vertical Loop Configurations

High-Temperature Solar Thermal

High-temperature solar thermal involves direct use of the irradiation from the sun for heating needs and/or power generation. This technology captures heat that is greater than 150°F and can be used to create heating hot water. Some technologies can create heat sources over 500°F and be used to generate high temperature hot water or steam that is used to generate power and/or distribute to lower temperature heating water convertors.

There are two main types of high-temperature solar thermal: panel systems and concentrated systems. These systems are rated in terms of their effectiveness, which describes the ratio of useable heat output relative to surface irradiation level. Unfortunately, irradiation levels are lower in the winter when heat is needed the most. The irradiation levels generally peak around 1,000 watts per square meter during the summer but decrease to approximately 400 watts per square meter during the winter; these levels are location-dependent. If a system's effectiveness is 80% then the heat output per square meter of panel area would be approximately 800 watts per square meter (250 Btu per square foot) during the summer and 320 watts per square meter (100 Btu per square foot) during the winter at the above irradiance levels. Note that the important irradiance level to consider is that which is normal (perpendicular) to the panel. The panels are typically fixed at an orientation and angle optimized for the location, but can also track the sun by rotating in one or two directions at increased cost. The cost and availability of this technology depends on the availability of land area and the climate, especially ambient temperatures and irradiation levels.

Renewable Natural Gas

Renewable Natural Gas (RNG) is an excellent carbon-neutral alternative to natural gas. It does not require any changes to equipment or operations on site, because gas combustion continues through the existing natural gas pipeline, yet the volume of gas is added to the pipeline elsewhere. Conversion from natural gas to renewable natural gas simply requires a contract to purchase a set amount for a term (usually five-to-ten years) while continuing to pay the natural gas utility for transportation costs.

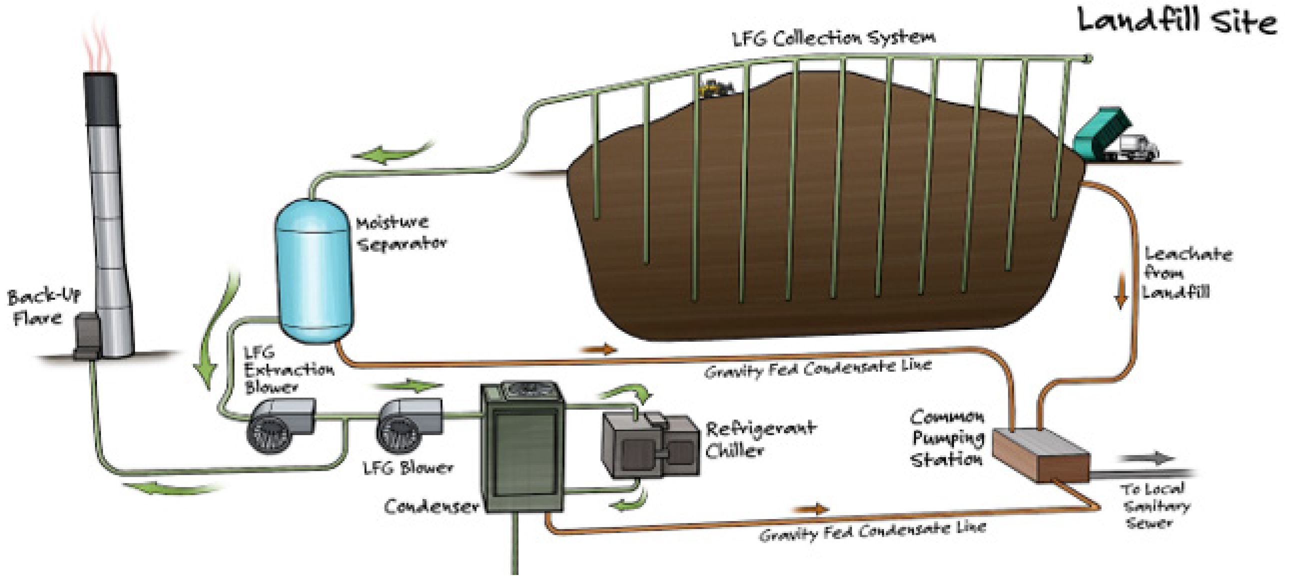

Figure 77. Illustration of Landfill Gas Recovery System

The on-site gas combustion can be considered carbon neutral if it can be established that the source of methane would have otherwise been directly released to the atmosphere and no other entity has claimed the environmental credit for recovering the methane. Methane can be recovered from a variety of processes and converted into pipeline-ready renewable natural gas. Some common processes are landfills, wastewater treatment plants, livestock waste and crop residuals.

This technology's cost depends on the process from which the methane is recovered and any risk that the developer includes in their pricing structure associated with the possibility of the source ceasing to exist. For example, lower cost renewable natural gas can be sourced from landfills because the source is gaseous, and it is highly unlikely that the landfill will be excavated. Livestock waste, by contrast, is a higher cost renewable natural gas because the source is collected in a solid form that must be digested to recover the methane and there is risk that the farm source(s) close before the cost of the renewable natural gas production facility(ies) is fully recovered.

The demand for sources to contract with for renewable natural is limited, but as additional institutions implement climate action plans the demand (and cost) is expected to increase. As the competition drives the cost up for the lower-cost recovery options such as landfill gas then more difficult recovery options will become feasible such as livestock waste (within livestock waste there are significant differences such as swine versus cattle). Demand, production, and cost will continue to increase over time. If end users that require a combustion fuel decarbonize their energy supply, other end users that only require heating, which can be produced via other technologies, may be priced out of the market.

In sum, renewable natural gas is a viable solution to neutralize emissions associated with natural gas combustion on site. The future pricing is expected to increase and may be volatile. If an institution desires emissions reduction and has ten or more years of remaining life on existing combustion equipment then it may be best to procure renewable natural gas as a bridge, using it until existing equipment is retired in favor of next-generation of heating technology.

Solar Thermal Panel Systems

Solar thermal panel systems include manufactured solar collection panels supported on structural racks at grade or on the roof of other structures and are interconnected with hydronic piping. A working fluid is circulated through the piping manifold to collect heat which is then distributed to loads. The effectiveness of this system type depends on panel type, the ambient dry bulb temperature, and the irradiation level. For example, if the irradiance level is 400 watts per square meter, the ambient temperature is 45°F, and the heating water supply temperature desired is 170°F, a flat panel collector will have an effectiveness of approximately 10%, a compound parabolic collector will have an effectiveness of approximately 50%, and an evacuated tube collector will have an effectiveness of approximately 60%. Holding the other conditions constant, if the ambient temperature drops to -10°F, then a compound parabolic collector will have an effectiveness of approximately 40%, and an evacuated tube collector will have an effectiveness of approximately 50%.

Return water from the load of an evacuated tube solar collector panel system is routed through the panels where it is heated and supplied to the load. Not shown in the illustration but typical for these systems is a thermal energy storage tank that allows heat to be generated when there is irradiation and stored for use at other hours of the day. In this type of system there may be one set of circulating pumps for the panel system that charges the tanks and a separate set of circulating pumps for distributing to the load. There may also be heat exchangers that allow the use of heating water for distribution to loads and a glycol-water mixture or other thermal fluid for circulation through the panels to prevent freezing at night.

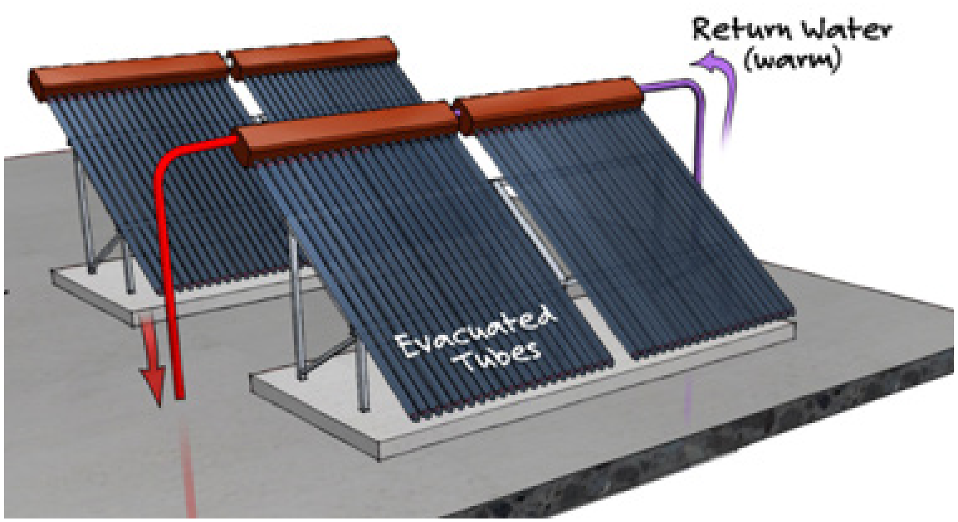

Figure 78. Illustration of Roof Mounted Solar Thermal Array

Water-Source Heat Pumping

Water-source heat pumping is an enhancement to CHC systems. CHC systems do not provide 100% of annual heating in most climates because of limited need for chilled water during colder months of the year. The same central equipment that is utilized in a CHC system can be supplemented with additional low-grade heat sources (false chilled water loads) to meet additional heating loads. Note that since the chilled water generated is not offsetting otherwise needed chilled water generation, the efficiency of the system operating in this mode is only the heating COP and not the CHC COP.

A low-grade heat source, or false chilled water load, is essentially anything that chilled water supply can be distributed to from the evaporator of a heat recovery chiller and warmed up by approximately 5-10°F before returning to the evaporator for that heat to be removed and provided in the condenser of the heat recovery chiller as useful heating. Typically, these low-grade heat sources are utilized with chilled water thermal energy storage to manage the variability between availability of heat and scheduled operation of heat recovery chillers to meet heating load.

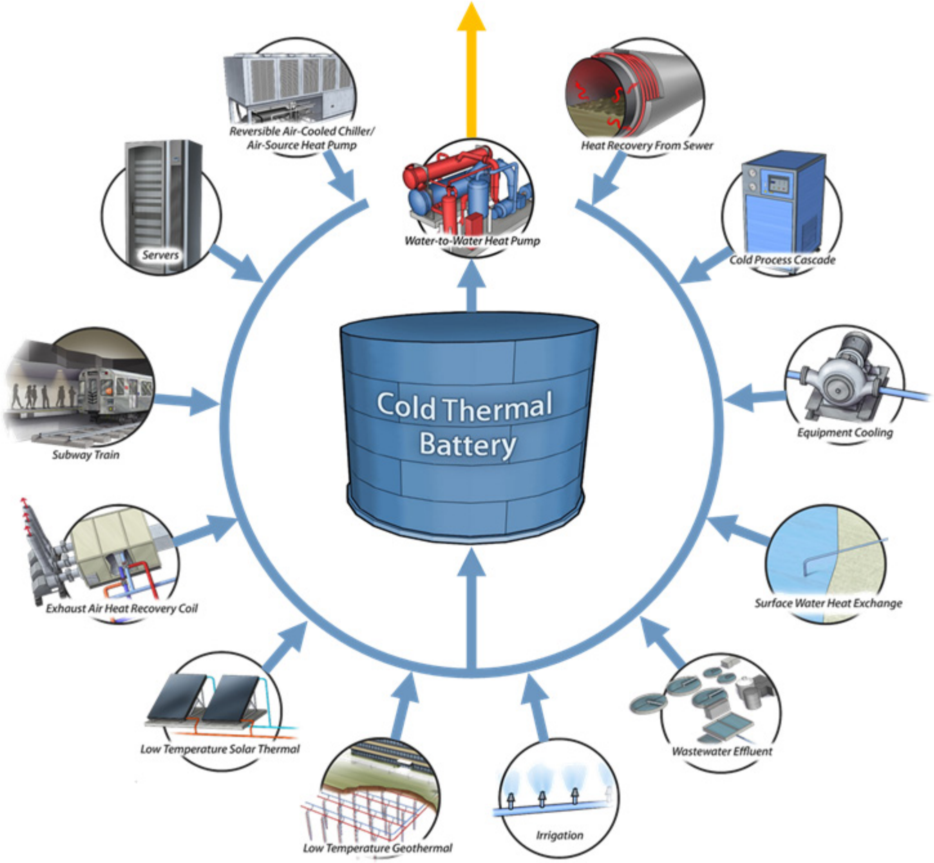

Figure 79. Common Low Grade Heat Sources

Ambient Air

Ambient air is not typically warm enough to use for heat extraction via chilled water when there is need for supplemental low-grade heat. Air-source heat pumps can be used to extract heat from ambient air and cascade the heat into the district chilled water network. The air-source heat pumps can be reversible air-cooled chillers that are utilized for peak summer heat rejection as well. Air-source heat pumps are typically not utilized for direct heating because they have limited heating water supply temperature capability, but they could be connected to a newly designed heating system that is capable of operating at very low supply temperatures (110-120°F).

Building Airside Economizers

This is an excellent means of optimizing to reduce chilled water demand when buildings do not require a high ratio of ventilation air. This system can be selectively de-activated by the central heat recovery chiller control system to add load back to the coil when it is needed for heating only. The airside economizer would operate normally when the false chilled water load is not needed. It is possible to create a chilled water load even when the ambient temperature is below 40°F because of the internal heat gain of large buildings from people, computers, lights, and other internal loads. Chilled water thermal energy storage is a necessity to manage the controls of this airside economizer heat recovery scheme. It also allows for heat to be collected during the afternoons when ambient temperatures are high enough for use overnight and into the morning warmup period. In climates where the daily high temperatures remain below freezing during normal winter conditions this is not a viable low-grade heat source for those times of year.

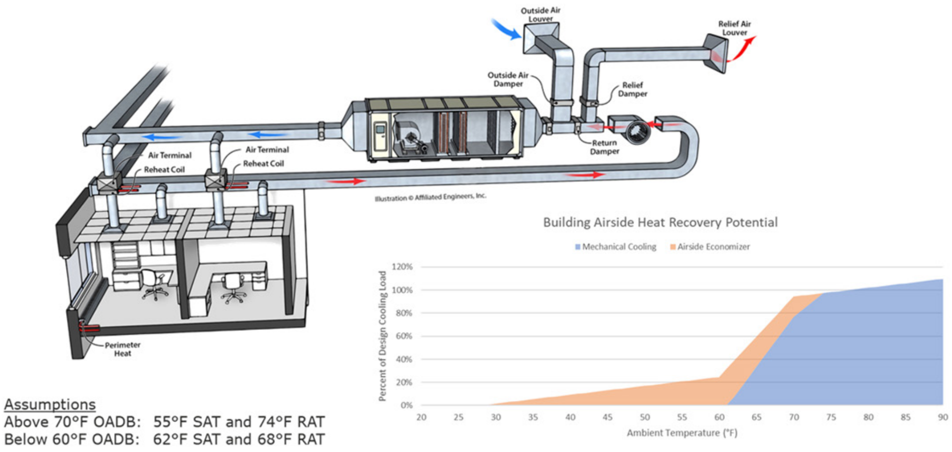

Figure 80. AHU with Airside Economizer; Chilled Water Coil vs Ambient Temperature

Building Exhaust

Some amount of building ventilation air results in an equivalent volume of air being exhausted at approximately 70°F. The volume of air is less in a building equipped with airside economizers or fixed minimum outside air, but laboratories and other specialized facilities can have 100% exhaust air. Some of these buildings may already include run-around energy recovery loops which makes the interface to district chilled water even easier and more heat can be recovered by exchanging water leaving the outside air coil with chilled water. Buildings that do not have heat recovery coils in the exhaust air would require a retrofit of a modular air handling unit with a chilled water coil that circulates air from the exhaust plenum to remove heat. These building exhaust heat recovery projects are more difficult to implement than building airside economizer heat recovery because of the additional chilled water piping and equipment that needs to be installed at each building.

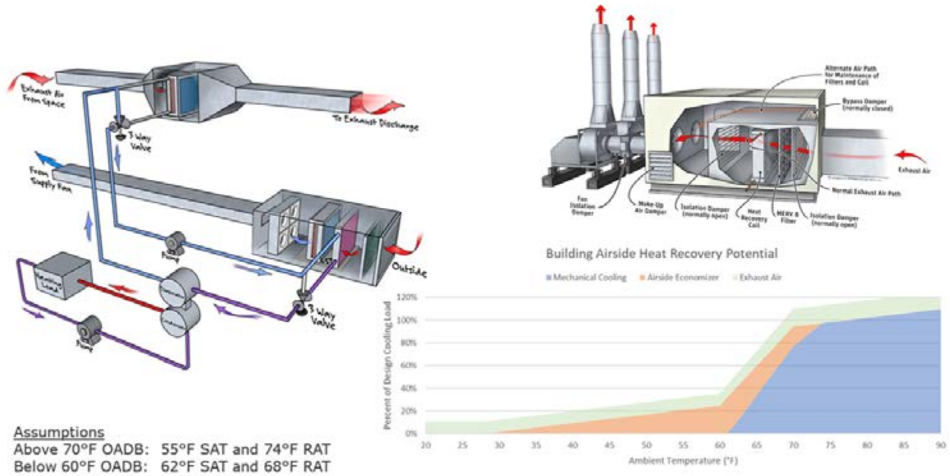

Figure 81. Building Exhaust Recovery Arrangement; Chilled Water Coil vs Ambient Temperature

Carbon Capture

Carbon capture is a technology that is being developed and promises to be an ideal solution to eliminating greenhouse gas emissions associated with heat and power generation[50]. When this technology is ready to be deployed, in theory it would be a plug and play solution that captures greenhouse gas emissions from existing exhaust stacks and redirects those gases to other uses or storage to prevent release to the atmosphere.

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[50] | Additional information is at: https://www.energy.gov/carbon-capture-utilization-storage#:~:text=Carbon%20capture%2C%20utilization%20and%20storage,will%20not%20enter%20the%20atmosphere.

Domestic Water Turbine Generators

The water utility operates booster pumps and utilizes water towers to maintain pressure in the distribution system to overcome head losses during peak flow times and provide adequate pressure to customers. This results in excess pressure being available most of the time and in most locations. This pressure may be throttled at the point of service and at the point of use. Instead of throttling excess pressure with a valve, the pressure difference can drive a turbine which drives an electrical generator. This requires extra dedicated equipment and maintenance for what is usually a minimal quantity of power generation. The turbines operate best in constant flow applications which are not typical for domestic water loads. This technology can be considered on a case by case basis but will not solve the renewable power needs at a campus scale.

Electric/Electrode Boilers

Electric/electrode boilers are a relatively simple technology. They are a packaged feedwater pump sprays water onto energized electrodes where it flashes to steam that collects in the upper portion of the cylinder for distribution to loads or conversion to heating water. The energy conversion efficiency is greater than 99% with only some losses through insulation to the room. The components of a conventional combustion boiler system that are eliminated are:

- Combustion air intakes, louvers, fans, heaters, filters.
- Draft fans.
- Fuel systems and burners.
- Exhaust systems, stacks, emissions monitoring or treatment, feedwater economizers, and
- On site emissions.

The footprint of electric/electrode boilers is much smaller than conventional combustion boilers and the turndown is 100:1 instead of 4:1.

The barriers to this technology are the electrical infrastructure to support the power demand and the cost of energy. As an example, an 80,000 pph steam boiler requires 24 MW peak electrical input. During a peak hour that conventional boiler would utilize 1,000 therms of natural gas at approximately $0.35 per therm for a cost of $350/hour and that electrode boiler would utilizes 24,000 kWh of electricity at approximately $0.05 per kWh for a cost of $1,200/hour. The marginal cost of fuel and marginal cost of electricity during peak winter conditions will vary by location and will change over time. In this example, 5.3 MTCDE of on-site emissions were avoided for that peak hour, so the energy cost difference of $850/hour equates to $160/MTCDE of avoided on-site emissions.

In sum, the energy cost of electric/electrode boilers is likely much greater than that of natural gas. If sufficient value is placed on avoidance of on-site emissions or if the combustion fuel is renewable natural gas, then the energy cost could be more comparable especially if gas prices in the future escalate at a greater rate than electric prices. From a project cost perspective, the significant mechanical system savings will approximately offset with the significant electrical system cost increase.

Figure 82. Two examples of electrode boilers[51]

Equipment Coolant

Some water-cooled equipment such as servers, air-compressors, pumps, engine-generators, etc. may have evaporative cooling systems, dry cooling systems, or even once through cooling systems. These water loops could also be connected to the district chilled water system for selective dispatch as a low-grade heat source. Some lower-temperature refrigeration systems such as walk-in freezers or cold rooms may have split systems with air-cooled condensers; these refrigerant loops could be modified to also be capable of heat rejection into the district chilled water system as a low-grade heat source.

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[51] Visit the manufacturer's websites for more information: Vapor Power International: https://www.vaporpower.com/products/electric-boilers/electrode-boilers/ and Cleaver Brooks: https://cleaverbrooks.com/Catalog/boilers/electric-and-electrode

Exhaust Air from Underground Structures

Utility tunnels, vehicle tunnels, underground parking garages, subway tunnels or similar underground structures beneath or near the campus may have ventilation systems to provide fresh air and remove excess heat from utility line losses, engines or motors, people, and geothermal heat. If chilled water can be distributed to an exhaust air location, then a chilled water coil can be arranged in a bypass arrangement that removes excess heat from the air before it is exhausted to the atmosphere. The advantage of using this air is that it is much warmer than ambient air and so heat can be captured directly into the district chilled water system.

Industry of Utility Plant

Nearby data centers, hospitals, refrigerated warehouses, water or wastewater treatment facilities, manufacturing facilities or other industries that have high energy demands likely have some heat rejection needs and might be willing to transfer that heat to a district chilled water system at minimal cost because they will avoid the operating expense of rejecting the heat.

Irrigation Water Flow

Heat can be extracted from the water flow to irrigation systems utilizing a chilled water heat exchanger. The lowered supply temperature to the irrigation system will reduce evaporation losses but should be confirmed that it will not harm any of the associated landscaping. One of the challenges with utilizing the irrigation water flow as a heat source is that flow rates may be minimal or zero during winter months when the heat is needed.

Low-Temperature Geothermal

This technology involves circulating chilled water or another thermal fluid through closed-loop piping that is buried underground in either horizontal coils or vertical bores. Suitable underground temperatures enable the colder supply entering the loop to gain some heat before returning to the heat recovery chillers. This system can also be used during the summer to reject heat from the conventional cooling system back into the ground rather than using evaporative cooling towers or other heat rejection systems.

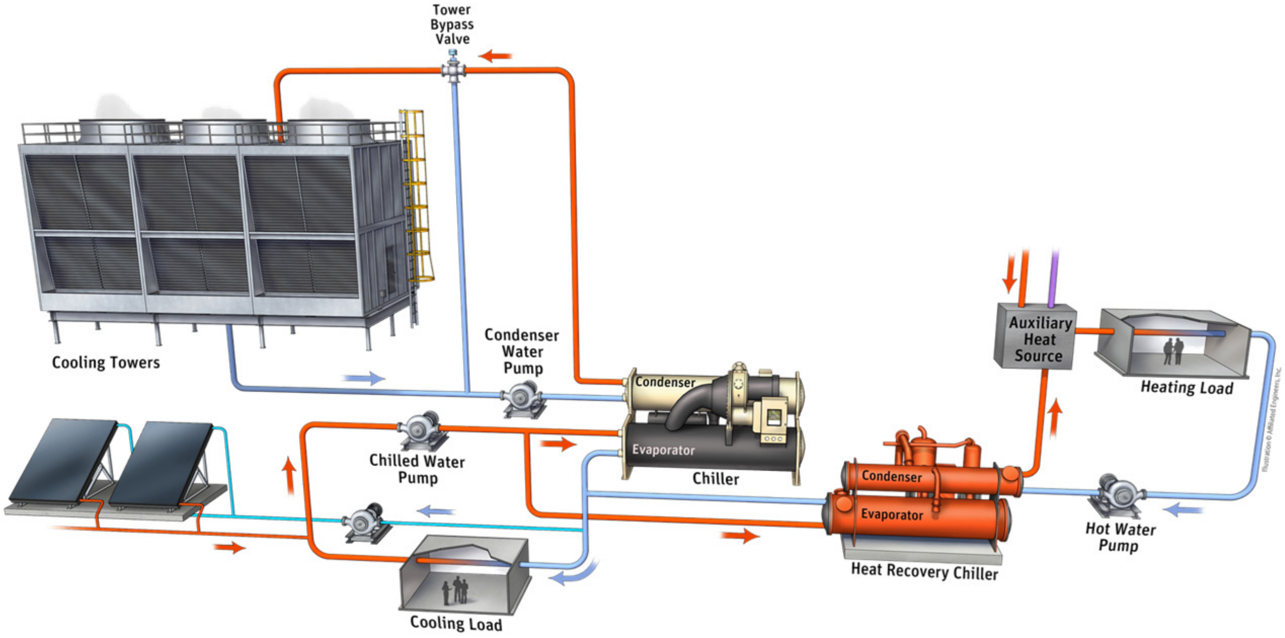

Illustration © Affiliated Engineers, Inc.

Figure 83. Low-Temperature Solar Thermal Arrangement

Low-Temperature Solar Thermal

High-temperature solar thermal is discussed in Section 5.4, involving the direct use of hot water or steam that is generated by solar collectors. As discussed, the effectiveness of standard flat plate collectors is very low when a high temperature differential between ambient air and heating supply is required. This temperature differential can be significantly reduced if the solar collectors are arranged to provide chilled water supply entering the solar collection panel system and return temperatures are only needed to be approximately 50°F leaving the solar collection panel system. Solar collection effectiveness of 80% can be achieved in this arrangement even with simple and economical flat plate collectors. When combined with the heat of compression in the heat recovery chiller the actual heat collected is approximately 100% of the irradiance level.

Renewable hydrogen

Renewable hydrogen can be converted to renewable heat or renewable power on site in a boiler or fuel cell. The obstacle to broad use is supplying the renewable hydrogen to the site. It is produced via electrolysis driven by renewable electricity. The electrolysis process can be approximately 80% efficient, so five parts of renewable electricity can produce four parts of renewable hydrogen. Renewable electricity can be transported across the nations existing electrical infrastructure, but no infrastructure exists for hydrogen. The hydrogen would require transportation via vehicles or pipelines. If vehicles are used, then the fuel for the vehicles would also need to be from renewable sources. If pipelines are used, then the energy for the compressors would also need to be from renewable sources. In both cases the added energy for transportation needs to be accounted for in the overall system efficiency. Both of these methods may also incur challenges from the local community associated with transportation of explosive and flammable gases. Once delivered to the site, the renewable hydrogen may need to be stored to balance supply and demand, which would require pressurized storage vessels, gas detection systems, and other safety measures. Then when it is time to convert the renewable hydrogen to renewable heat or renewable power on site the conversion efficiency will be 60-80%.

The total efficiency from the original source of renewable electricity to the end use of renewable heat or renewable power is approximately 50-60%. The cost of renewable hydrogen would need to include the cost of approximately twice the amount of renewable electricity compared to the actual load (since approximately half of the renewable electricity source is lost in conversion), plus all costs associated with transportation and storage.

Instead of utilizing renewable hydrogen the original renewable electricity could be transported on the existing electrical infrastructure and utilized directly on site as renewable power or converted to renewable heat. In the simplest form of conversion to heat electric/electrode boilers could be utilized with near 100% conversion efficiency. Combined heating and cooling or water-source heat pump technologies could also be implemented to improve the efficiency to 300-900%.

The best case for renewable hydrogen as a solution to renewable on site energy is if the existing electrical grid is not sufficient to electrify all campus energy needs, but it still may be more cost effective to improve the electrical grid than to deploy a renewable hydrogen delivery system.

Renewable hydrogen can be used as an energy storage mechanism. If excess renewable electricity is available at certain times of day or times of year, then it can be converted to renewable hydrogen for storage and later converted back to renewable heat or renewable power. There are many other types of energy storage that can also be considered to meet this need.

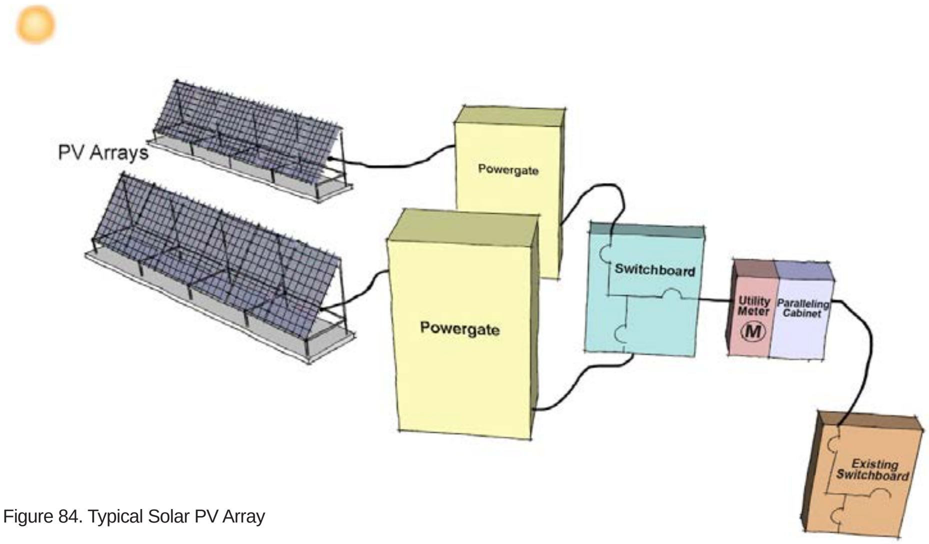

Figure 84. Typical Solar PV Array

Solar Photovoltaics

Solar PV (photovoltaic) technology involves direct use of the Sun’s irradiation for power generation. The cost and availability of this technology depends on the availability of land area and the climate, especially irradiation levels. The most common panel technology is silicon photovoltaic solar cells that produce DC power and typically invert it to AC power for use. These systems are rated in terms of their effectiveness, which describes the ratio of useable electrical output relative to surface irradiation level. The irradiation levels typically peak at around 1,000 watts per square meter during the summer but decrease to approximately 400 watts per square meter during the winter. If a system’s effectiveness is 20% then the electrical output per square meter of panel area would be approximately 200 watts per square meter during the summer and 80 watts per square meter during the winter at the above irradiance levels.

Solar PV panel systems include manufactured solar collection panels that are supported on structural racks at grade or on the roof of other structures and are interconnected with electrical conductors and distribution panels. It is important to consider the variations in electrical generation capacity and electrical demand for the load. Grid-connected systems can potentially export excess generation to the grid if allowed by the utility company. It is also possible to integrate chemical batteries or other energy storage devices behind the meter to keep the renewable power on site until it can be utilized.

In sum, solar PV systems can be owner-furnished, leased, or arranged as a power purchase agreement. The unit cost for solar PV systems on a campus is higher than a utility scale solar farm because of the cost of labor difference, economies of scale, and difficulty performing work on building rooftops or congested campus areas. Solar PV can easily be procured off site and delivered via the existing electric grid unless there are particular capacity limitations on existing electrical infrastructure.

Surface Water

Surface Water. Any adjacent lakes, rivers, or bays can be utilized in a very similar manner as low-temperature geothermal. These large bodies of water have suitable temperatures that enable heat extraction in the winter and heat rejection in the summer. Heat exchange can take place via coils that are submerged in the body of water or by pumping the water through heat exchangers. Permitting these types of systems is more challenging than low-temperature geothermal because of the impact to aquatic life.

Wastewater Flow

If a wastewater effluent pipeline is accessible, then a side stream branch of that pipeline can be routed to heat exchangers that can be used for heat extraction in the winter and heat rejection in the summer. Heat exchange can utilize conventional systems because the wastewater effluent is clean water. Wastewater influent is more commonly accessible, but heat exchange is not as effective. Typically heat exchange with wastewater influent is achieved by enclosing the pipe perimeter with a coil of circulating fluid. The wastewater utility may also object to reduction of the influent temperature because it could cause the wastewater treatment facility to require more energy input.

F. Policies and Procedures to Realize Carbon Neutrality and Campus Sustainability

Like other large real estate owners, NAU has a culture of stewardship. When these entities endorse a mission such as realizing carbon neutrality, it stimulates an evolution of their stewardship practices. For many, it triggers drafting of new and revisiting existing policies and practices to deliberately anchor them to carbon neutrality. Following is a list of existing policies and standard operating practices and it is followed by a list of additional ones that are common to colleges and universities that excel at sustainability.

Existing Policies and Standard Operating Practices

Community Resilience

1. Guidance to ensure the public health of its community.
2. Address food insecurity in the campus community.

Facility design, construction and operation

1. Ensure that NAU always undertakes building commissioning as part of its design process. Note that this is characterized by NAU as not often implemented and only for projects that impact university energy and/or security systems.
2. Ensure that NAU building design for new construction addresses energy efficiency. Note that this is characterized by NAU as unevenly applied.
3. Ensure that NAU building design for renovations addresses energy efficiency. Note that this is characterized by NAU as rarely applied.
4. Ensure that NAU building designs consider installing rooftop solar. Note that this is characterized by NAU as unevenly applied.
5. Ensure that NAU building design for new construction address campus objective of reducing water use.
6. Ensure minimizing use of materials that generate hazardous waste.

Human Resource Management

1. Staff recognition for outstanding performance.
2. Comprehensive and mandatory staff training. Note that NAU questions whether the many staff training can/should be revisited to better work to reduce greenhouse gas emissions and support campus sustainability.

Landscape and Forest Management

1. Ensure that NAU landscape management works to increase number of native and adapted plants.
2. Ensure that the vitality of NAU native and adaptive plants is a priority management concern.
3. Ensure that NAU landscape management works to decrease number of non-native plants.
4. Ensure that NAU landscape management works to decrease water use.
5. Guide management of NAU forested lands.

Transportation

1. The no idling policy contributes to NAU reducing its greenhouse gas emissions associated with its fleet management.
2. The transportation subsidy for university employees motivates the university community to reduce its use of single occupancy vehicles.
3. The NAU policy of zone permitting works to limit repeated care use as a daily pattern for those who drive to campus.)

Proposed Policies and Standard Operating Practices for Consideration

Community Resilience

1. Comprehensively collect and analyze data on the health of its community.
2. Expand relationship with ASU and UA to jointly approach the state legislature to fund campus resilience.
3. Provide for the public's health during an epidemic or pandemic.
4. Promote equity by ensuring that each university program, policy and standard practice undertaken to reduce campus greenhouse gas emissions is free from bias in its impact.
5. Accelerate the transition to renewable sources for the region's electricity.

Facility design, construction and operation

1. Ensure that utility plant investments are commissioned during the construction/renovation project.
2. Ensure that utility plants are operated in energy efficient ways.
3. Establish the utility plant and utilities capital investment needs for renewal and replacement.
4. Ensure that the utility billing structure motivates energy use efficiency. (Note that only auxiliaries are billed for utility use.)
5. Ensure regular collecting and analyzing Flagstaff Mountain Campus utility data.
6. Ensure standard means of collecting and analyzing Flagstaff Mountain Campus utility data.
7. Ensure that NAU always undertakes building recommissioning once its buildings are operational.
8. Ensure that NAU regularly undertakes building recommissioning.
9. Ensure efficient building occupancy scheduling.
10. Ensure that campus buildings are operated with energy efficiency as a driver for temperature, humidity, and lighting.
11. Ensure that investments in reducing greenhouse gas emissions and/or conserving energy has a desired return on investment.
12. Ensure that the billing structure for water motivates conservation.
13. Guide data collection and analysis of Flagstaff Mountain Campus water use in the campus buildings on a regular basis.
14. Guide data collection and analysis of Flagstaff Mountain Campus water use in the campus utility systems on a regular basis.
15. Establish standards for executing its solid waste management programs for waste diversion.
16. Establish standards for executing its solid waste management programs for waste collection and disposal.
17. Improve campus stormwater management policies and practices

Landscape and Forest Management

1. Ensure that its landscape management works to comprehensively limit use of chemicals.
2. Collect and report on data to establish that the Flagstaff Mountain Campus landscape master plan is being executed.
3. Guide Flagstaff Mountain Campus data collection and analysis of university water use in the landscape on a regular basis.
4. Prioritize or specify regenerative landscaping, site design and management practices.

Living Lab, Advancing Campus Sustainability

1. Ensure uniform methodology is used for tracking campus greenhouse gas emissions.
2. Ensure adequate education of the university community about the campus sustainability goals, objectives, and opportunities.
3. Track assignments and outcomes of its various forms of city engagement.

Procurement

1. Ensure procurement practices work to advance the campus sustainability goals, objectives, and opportunities.
2. Ensure campus purchase of renewable energy credits (RECs)[52] (standard practice has been to purchase RECs equivalent to 15% of annual electrical consumption.)
3. Guide purchase of specified materials and goods to include life cycle analysis as a determinant.
4. Develop and employ a standard method for tracking embodied carbon in university purchases.

Transportation

1. Ensure that the Flagstaff Mountain Campus provides infrastructure for electric vehicles. An electric vehicle charging station policy to identify a schedule for installation, campus locations, criteria for procurement and pricing.
2. Create a comprehensive electric vehicle fleet procurement policy.
3. 3. Parking pricing to dampening demand for on-campus parking with value to avoiding the unintended consequence of more parking occurring on the outskirts of campus.

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[52] | Renewable energy credits (RECs) are market-based instruments through which a party can purchase renewable electricity generation that is delivered to the grid.

G. Flagstaff Mountain Campus Data Collection and Analysis Challenges

The NAU Office of Sustainability is and will remain as the central office for data collection and analysis relating to greenhouse gas emissions and sustainability. Elements of the existing systems that need improvement include:

1. Energy and water metering. The university needs a standard approach to metering. If capital restricted, the approach can be phased-in over time. At point: Utility Services with support from Office of Sustainability.
2. Procurement of chemicals for buildings and landscape. The university should develop practices to limit toxicity and volume of its chemical use. and At point: Office of Sustainably to lead and coordinate input from the Office of Environmental Health and Safety, Office of Contracts, Purchasing and Risk Management, Facilities Services and Landscape and Outdoor Services.
3. Embodied carbon. The university should develop a standard method for tracking embodied carbon of its purchase. At point: Office of Contracts, Purchasing and Risk Management with support from Office of Sustainably.
4. Monitor the effectiveness of CAP innovations for landscape management, outdoor water use and forest management. At point: Landscape and Outdoor Services with support from Office of Sustainability.
5. Monitor the effectiveness of CAP innovations for transportation management. At point: Facilities Services with support from the Office of Sustainability, NAU Police Services.
6. Monitor the effectiveness of CAP innovations for waste management. At point: Facilities Services with support from the Office of Sustainability and campus hospitality and food service vendors.
7. Living lab. The Office of Sustainably should have a peer review and archival responsibility to ensure that the data used in student studies and the methodologies employed comport with or improve upon previous analysis and that their completed reports are available and appropriately distributed within the university committee.

H. Resources

External Website Links

Internal Carbon Pricing in Higher Education Toolkit,
Second Nature

Carbon Pricing Dashboard,
World Bank Group

CARBON PRICING: What is a Carbon Credit Worth?,
Gold Standard

Carbon Pricing Policies,
ACEEE (American Council for an Energy-Efficient Economy)

The Social Cost of Carbon,
Carbon Brief

Published Reports Embedded to This Website

EPA Fact Sheet,
United States Environmental Protection Agency

Selecting an Internal Carbon Price for Academic Institutions,
Smith College

How-To Guide to Corporate Internal Carbon Pricing,
CDP (formerly Carbon Disclosure Project)

The Business of Pricing Carbon,
C2ES (Center for Climate and Energy Solutions)

State and Trends of Carbon Pricing 2020,
World Bank Group

Expert Consensus on the Economics of Climate Change,
New York University School of Law

Embedding a Carbon Price Into Business Strategy,
CDP (formerly Carbon Disclosure Project)

Note of Appreciation

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