# For the Future

## A REPORT FROM THE PRESIDENT'S CARBON EMISSIONS REDUCTION TASK FORCE

DECEMBER 2021

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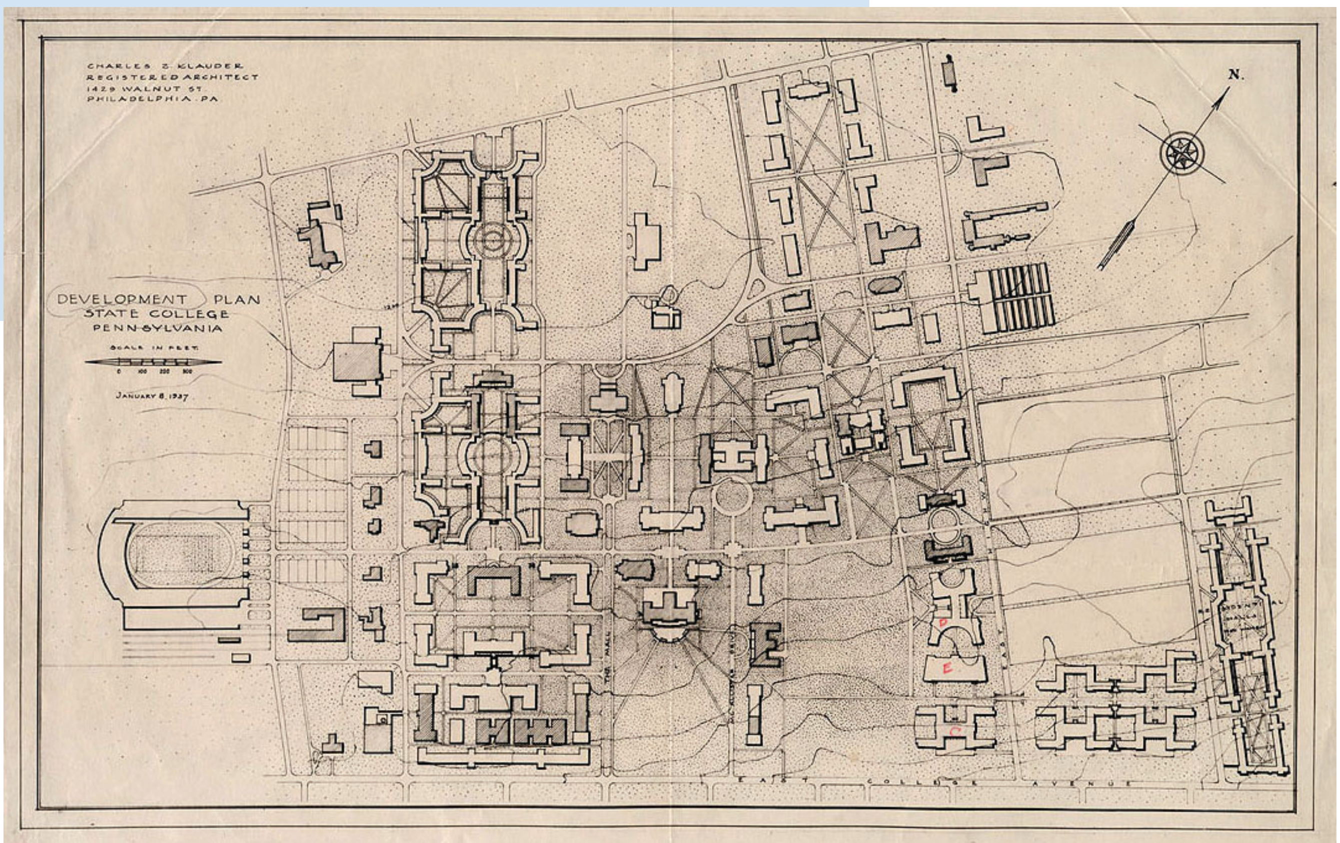
# Acknowledgement of Land

**The Pennsylvania State University campuses** are located on the original homelands of the Erie, Haudenosaunee (Seneca, Cayuga, Onondaga, Oneida, Mohawk, and Tuscarora, Lenape (Delaware Nation, Delaware Tribe, Stockbridge-Munsee, Shawnee (Absentee, Eastern, and Oklahoma), and Susquehannock, and Wahzhazhe (Osage) Nations. As a land-grant institution, we acknowledge and honor the traditional caretakers of these lands and strive to understand and model their responsible stewardship. We also acknowledge the longer history of these lands and our place in that history.




*1937 Masterplan for Penn State University*

# Executive Summary

Penn State has an extraordinary legacy of meeting society's grand challenges with innovation and commitment. For over a century we have been one of the world's leading energy and climate universities. For over four decades our faculty and students have been at the forefront of understanding the scope and magnitude of climate change and pioneering solutions to mitigate that change. Today, we recognize that climate change is one of the most complex and urgent issues of our time. It is affecting our local Pennsylvania (PA) communities ***now***. It is influencing our global communities and partnerships ***now***. It is catalyzing a reorganization of philanthropy and industrial innovation ***now***. Most importantly, it is going to fundamentally harm the future of our current Penn State students, if we don't act ***now***. As evidenced in this report, we are clear-eyed that Penn State has a monumental challenge ahead to address this challenge. But we also recognize this challenge as a monumental opportunity to "bounce forward" toward a climate positive future that benefits all.

We are eager for the University to again demonstrate leadership through innovation and commitment. In the spring of 2021, this Task Force was charged to provide "specific, actionable, practical, and economically viable recommendations that when implemented will position Penn State as a leader in greenhouse gas (GHG) emissions reduction and a model for other institutions and organizations to follow."[1] This report thus focuses on substantive ways Penn State can contribute to solving the challenge of climate change through our operations: our facilities and the emissions directly associated with our teaching, research, and outreach. Looking forward, fully committing Penn State's research, teaching, and outreach breadth and depth will require long-standing commitment and action, and, where appropriate, we signal the additional opportunities to be considered as part of a more comprehensive climate response.

[1] See Appendix A: CERTF Charge

Through the work of a committed Task Force, comprised of faculty, staff, and representative students from across the University, we have worked diligently to balance the challenge of this task with the urgency of the issue. We analyzed internal data, benchmarked across peer institutions, modeled alternative strategies, and constructively discussed alternative pathways for institutional change. Our conversations were sometimes contentious, sometimes revelatory, but always robust, productive, forward-looking, and optimistic about the potential for Penn State's future. At the time of writing this summary, we are confident that we are putting forward our best assessment of Penn State's opportunities for reducing our GHG emissions. Our work does not feel "done" as there are assuredly more assessments to be completed, more scope to be included, and, importantly to our Task Force, more community and stakeholder involvement required. Mostly, we are excited to share this work and look forward to further discussion and action.

Before and during our navigation of the COVID pandemic, Penn State has shown its resilience as an institution by staying true to our mission, vision, values, and commitment to the Commonwealth. Many of the groups and individuals that contributed to this report began their efforts well before COVID occurred. They continued their important work through the pandemic, realizing that the work of a more sustainable future must continue even under difficult circumstances. The work continued also through the nation's collective reawakening to issues of social and racial injustices, further buoying the importance of intentional long-term commitment to addressing the societal and environmental challenges that climate change is exacerbating.

In this report, we emphasize that Penn State has made substantial progress already. We have succeeded in meeting a 2020 goal of a 35% reduction from our 2005 (peak emissions) baseline, and we are ahead of schedule toward meeting our current goal of an 80% reduction by 2050, consistent with the goal set forward by Governor Wolf for the Commonwealth. This progress is laudable, especially given that this progress has been accomplished through regular operational investments. Our challenge now is two-fold: (1) the additional emissions reductions that are required are not "easy" and will require financial commitment, and (2) the urgency of the climate crisis requires that this investment be made soon. However, we also have remarkable opportunity: relative to many of our peer institutions, at Penn State *we have already mainstreamed the capacity for change*. We have made substantial physical infrastructural investments, we have regularized programmatic activities (e.g., energy efficiencies), there is substantial, longstanding buy-in from our operational, research, and educational communities, we have institutional data to track and assess change, and (as will be evident in this report) we have the operational-scientific-social expertise to design strategies that are tractable and impactful. Moreover, while negative impacts of climate change are arriving sooner than expected, so are the positive solutions: many are better, cheaper, and can be implemented faster than just a few years ago. Therefore, this Task Force is confident in recommending that the University can and should set more aggressive goals to reduce our emissions. This report also describes the most cost effective and promising technologies that will help us meet the new goals.


Leveraging this "ecosystem" of success to date, this report puts forward a set of goals that are not only ambitious, but at the same time the most aggressive ***and*** achievable compared to our Big Ten Academic Alliance (BTAA) peers. We are excited for Penn State to not only lead this charge, but more importantly for Penn State to act as a convener and network broker for partnerships and alliances within the BTAA and other institutions globally through our commitment to the International Universities Climate Alliance (IUCA) and other partners. As we and others "learn by doing", we will do what Penn State has always done: discover, innovate, learn, teach, and inspire, helping others to achieve true climate action successes at scale, across our networks throughout the Commonwealth and around the globe.

The structure of the report is as follows. We begin by introducing the background and scope of our action to date, including key driving factors that underlie our call to future action. We also present a summary of our BTAA benchmarking analysis. Then we put forward our proposed GHG reduction goals followed by a detailed roadmap of recommended milestones and strategies for achieving these goals. We then return to a discussion of how these strategies will provide value to Penn State's mission. We offer more detailed analysis in the areas of thermal, electric, transportation, farms, behavioral change, carbon offsets, and operational modeling. We conclude with recommendations for strategies for funding these efforts, as well as a discussion of strategies for institutionalizing these changes to ensure their effectiveness and sustainability. The latter is critical as there is no "solution" to the climate crisis that will be achieved within one strategic plan, one capital campaign, or one generation of a Penn State community.

**In summary, we recommend the following GHG emissions reduction goals for Penn State:**

**Goal 1:** Achieve 100% emissions reduction by 2035

**Milestone 1:** 2022: Initiate action to advance New GHG Reduction Goals
**Milestone 2:** By 2025: Achieve 55% net GHG emissions reduction
**Milestone 3:** By 2030: Achieve 70% net GHG emissions reduction
**Milestone 4:** By 2035: Achieve 100% net GHG emissions reduction
*Goal 1 and Milestones 1-4 are based on our existing inventory and 2005 baseline.*

**Goal 2:** Beyond 2035: Continue beyond 100% GHG emissions reduction, leading the way to a safe, healthy, and just future

Penn State's current GHG emissions inventory stands at 369,300 metric tons of $CO_2$ equivalent (MTCO2e) per year. Of this, 123,400 MTCO2e are direct emissions from University-owned and managed operations (classified as Scope 1 for the purposes of GHG inventories), of which the largest component is producing steam for district heating at University Park (UP). An additional 153,800 MTCO2e are associated with the generation of electricity that Penn State purchases systemwide (Scope 2), and 92,100 MTCO2e are the other indirect emissions associated with Penn State operations (Scope 3) that we have been able to estimate and inventory. UP is by far the largest GHG emitter in the Penn State system, responsible for 76% of the inventory, but it is important to emphasize that the inventory, goals, and recommendations in this roadmap include all the Commonwealth Campuses. There are two locations the Task Force did not include in our analysis, Penn College of Technology and the Penn State Health System. We recommend those units begin to inventory and address their emissions, leveraging the approach and expertise documented in this report.

Task Force members and a few additional subject matter experts explored and evaluated dozens of possible strategies, including some that are proven and already in use by our operations, and others that are novel and particularly promising. In cases where solutions were unproven or costs were uncertain, we include two or more alternatives that could each achieve the needed goal.

Figure 1 illustrates how these strategies could be implemented in stages to achieve the goals effectively and affordably. Note that the figure includes estimated increases in demand from future growth in University facilities, which will be largely offset by energy efficiency and green design. Figure 1 includes a timeline, illustrating the emissions reductions to be achieved by the recommended strategies and actions. To maintain the pace of progress, Table 1 outlines actions necessary to meet the goals and milestones and includes initial estimates of the capital and annual costs.

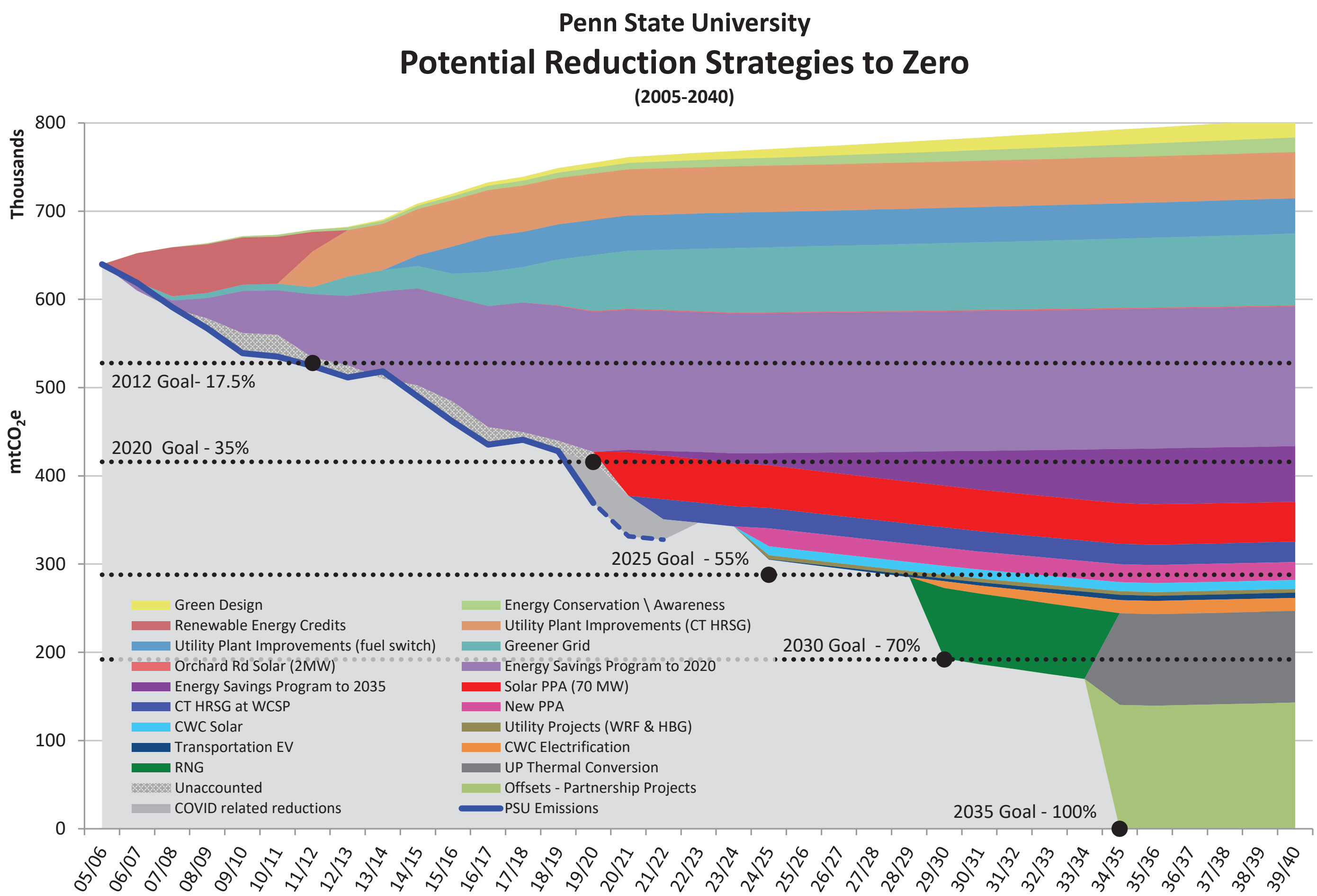



*Figure 1: A Roadmap and Timeline for Penn State Carbon Emissions Reductions*

*Table 1: Selected milestones toward addressing Penn State's new carbon emission reduction goals.*

| Milestone #1 - 2022: Initiate action to advance New GHG Reduction Goals | | |
|---|---|---|
| **Actions** | **Costs** | |
| | **One Time / Capital** | **Annual** |
| Develop a strategic communication plan about new GHG emissions reduction goals for Penn State | $0 | |
| Create independent carbon emission inventories and reduction programs for Penn State Health System and Penn College of Technology | $0 | |
| Develop strategy for President-initiated fundraising campaign | $0 | |
| Begin detailed feasibility/planning/preliminary design and costing study to decarbonize UP Heat and Power Infrastructure. Technologies to include: Biomass, Shallow Geothermal Heat Exchange with Heat Pumps, Deep Well Geothermal, Micro Nuclear Reactors, Conversion of Steam Distribution to Hot Water, impact of additional ESP Projects | $2,000,000 | |
| Initiate study to evaluate/plan to decarbonization university vehicles | $60,000 | |
| Create a policy to require fuel efficiency be part of purchasing decisions and proactively begin purchasing hybrid and electric vehicles and equipment and installing chargers | $1,300,000 | |
| Initiate another large renewable electric generation purchase | | $1,000,000 |
| Develop a net zero emissions infrastructure policy for new construction | $0 | |
| Initiate project planning/design for near-term projects (Harrisburg Biomass, WRF Fuel Cell, Solar at CWC, decarbonizing CWC heating systems) | $1,000,000 | |
| Continue ESP Projects at $12M per year | $12,000,000 | |
| Create a public facing Energy/Carbon Dashboard and start an educational effort | $75,000 | |
| Start process to tighten Scope 3 emission data currently in inventory (Commuters, University sponsored air travel) | $0 | |
| Start the effort to establish processes and procedures to quantify additional Scope 3 emissions that are currently not included (Leased space, all other University sponsored travel, procurement, cloud services, embodied carbon) | $0 | |
| Enhance Green Labs Program - add additional staff to existing program to provide focus on ventilation | | $160,000 |
| Complete a space utilization study. Desired result would be a better utilization of existing space to defer construction of new space and associated operational and embodied carbon emissions | $3,000,000 | |
| Form a committee of experts to explore the role of internal and partnership-based drawdown and offsets projects | $0 | |
| **Total** | $19,435,000 | $1,160,000 |

| Milestone #2 - By 2025: Achieve 55% overall GHG emissions reduction | | |
|---|---|---|
| **Actions** | **Costs** | |
| | **Capital** | **Annual** |
| Renew or replace expiring Hydro PPA | $0 | $1,000,000 |
| Continue ESP Projects at $12M per year | $36,000,000 | |
| Continue phased transition of university vehicles to EV at $1.3M per year | $3,900,000 | |
| Begin 10 year project to decarbonize UP District Heating System at $20M per year | $20,000,000 | |
| Begin 10 year project to decarbonize CWC building heating and cooling systems at $33M per year | $33,000,000 | |
| Complete Harrisburg Biomass Project | $3,900,000 | |
| Complete Water Reclamation Facility Fuel Cell Project | $1,900,000 | |
| Complete installation of solar at CWCs | $41,800,000 | |
| Finish the effort to tighten scope 3 emission data currently in inventory (Commuters, University sponsored air travel) | $0 | |
| Finish the effort to establish processes and procedures to quantify additional scope 3 emissions that are currently not included (Leased space, all other University sponsored travel, procurement, cloud services, embodied carbon) | $0 | |
| **Total** | $140,500,000 | $1,000,000 |

| Milestone #3 - By 2030: Achieve 70% overall GHG emissions reduction | | |
|---|---|---|
| **Actions** | **Costs** | |
| | **Capital** | **Annual** |
| Continue ESP Projects at $12M per year | $60,000,000 | |
| Continue Phased Transition of University vehicles to EV at $1.3M per year | $6,500,000 | |
| Continue 10-year project to decarbonize UP District Heating System at $20M per year | $100,000,000 | |
| Continue 10-year project to decarbonize CWC building heating and cooling systems at $33M per year | $165,000,000 | |
| **Total** | $331,500,000 | $ - |

| Milestone #4 - By 2035: Achieve 100% overall GHG emissions reduction | | |
|---|---|---|
| **Actions** | **Costs** | |
| | **Capital** | **Annual** |
| Continue ESP Projects at $12M per year | $12,000,000 | |
| Continue Phased Transition of University vehicles to EV at $1.3M per year | $6,500,000 | |
| Continue 10 year project to decarbonize UP District Heating System at $20M per year | $100,000,000 | |
| Continue 10 year project to decarbonize CWC building heating and cooling systems at $33M per year | $165,000,000 | |
| **Total** | $283,500,000 | $ - |

The actions required to achieve these goals and milestones represent a major investment, nearly $750 million over the next fourteen years. We recognize that funding this investment will be a challenge, and that there are many other critical University priorities, such as student access and affordability, deferred maintenance, and other strategic initiatives. However, implementing this plan will realize long term cost benefits:

- These capital investments will create savings for the University in terms of reduced maintenance and operating costs. We estimate that the savings realized annually starting in 2035 will be ~$15 million/year.
- The social cost of carbon is currently estimated at $75/ MTCO2e and at this price our 2035 net-zero milestone represents an additional $27 million/year of societal benefit from avoided pollution, heat stress, disease, infrastructure damage and enhanced reliability of socio-ecological and economic systems.
- **The annual maintenance and operating cost savings plus the avoided social harm represents a benefit of $42 million per year and accumulates to $630 million by 2050, comparable to our estimated capital investment of ~$750 million. This capital investment in carbon reduction essentially shifts responsibility for the social cost of carbon from society back to Penn State where it belongs.** We hope this action will be attractive to our students, alumni, and the growing number of private philanthropies and corporate partnerships helping finance climate solutions.

The comprehensive roadmap of goals, milestones and actions described in this report will help establish Penn State as a global leader in reducing carbon emissions. While the focus of this report is on University operations, Penn State can also seize the opportunity to leverage the knowledge and expertise we gain from this investment to also lead in our teaching, research, and outreach about climate solutions. Penn State has long used its physical plant as a living laboratory. In the case of climate solutions, that laboratory already extends beyond the boundaries of our campuses – to the Cube Hydro plant on the Mahoning Creek, to the Lightsource BP solar farm near our Mont Alto campus, to energy efficient buildings in New Kensington and at the Philadelphia Navy Yard. Each of the milestones in this roadmap presents new opportunities for discovery, innovation, teaching and learning, not just within our University community, but with all the communities across the Commonwealth, our nation, and the globe. This roadmap can help energize our relationships with companies, government agencies, other universities and national labs. The climate challenge, and the opportunity, are indeed monumental – and the journey to a climate responsible future is one that Penn State is well positioned to lead.

Meeting these goals will be challenging, but necessary. Doing so will allow us to manifest our University mission to serve our students, the Commonwealth and the world. However, the longer-term cost of inaction will be much higher for our students, our society, and the future generations that we hope to serve. We suggest that now is the time to prioritize a development goal to support these recommended actions.

**There is more to be done:** developing detailed plans, implementing these recommendations, and embodying these commitments to those with whom we work and study, and broadening the scope of climate mitigation and adaptation activities. Our history of success and a clear commitment to the new goals outlined in this report will allow Penn State to say, authentically, that:

***We Are*** *addressing our own emissions,*

***We Are*** *planning to do more, and*

***We Will*** *deliver on our commitment to affect the world in positive and enduring ways.*

Meeting these goals will allow Penn State to lead by example and to establish our University as one of the first "climate positive" universities. This investment will deliver dividends for the climate, for the University, and for our students as a living laboratory ***"for the future that we wait…"***

# Penn State's Greenhouse Gas Emissions Inventory

To understand our proposed goals for the future, it is important to establish the foundation of our strong past in measuring and reducing Penn State greenhouse gas (GHG) emissions. Penn State's GHG emissions inventory has quantified the University's operational emissions profile for two decades and is used to track the progress of emissions reductions. The inventory is managed by the Office of Physical Plant (OPP) and is updated annually. The accounting methodology follows the generally accepted accounting principles provided by the World Resources Institute in the Greenhouse Gas Protocol.[2] This accounting and reporting standard follows the guiding principles of relevance, completeness, consistency, transparency, and accuracy.

Penn State's GHG Inventory organizational boundary follows the operational control approach and includes a separate inventory for each campus, with 22 locations in all. Penn State Health, including the College of Medicine, and the Pennsylvania College of Technology, are excluded from the current inventory. Emissions are calculated for all GHGs including carbon dioxide ($CO_2$), methane ($CH_4$), and nitrous oxide ($N_2O$) as well as hydrofluorocarbons (HFCs) and perfluorocarbons (PFCs). The emissions are normalized into a common unit, metric tons of $CO_2$ equivalent (MTCO2e) using 100-year Global Warming Potential Factors (GWP) for each gas. Source data are collected from various units across the University (OPP, Transportation Services, Financial Information Systems, Farm Operations, Commonwealth Campuses, outside vendors). Some data are carried over from previous years. Fuel or activity-based emissions factors are then used to calculate emissions.

## SCOPES AND SOURCES

Emissions are separated into three scopes (Table 2). **Scope 1** emissions are direct emissions from sources owned and operated by Penn State. **Scope 2** are indirect emissions related to the generation of Penn State's purchased electricity. **Scope 3** emissions cover all other indirect emissions associated with Penn State's operations. Together, the three scopes provide a comprehensive accounting framework for managing direct and indirect emissions (Figure 2).[3] Penn State's current GHG inventory includes all Scope 1 and 2 emissions as well as a few select categories of Scope 3 emissions.

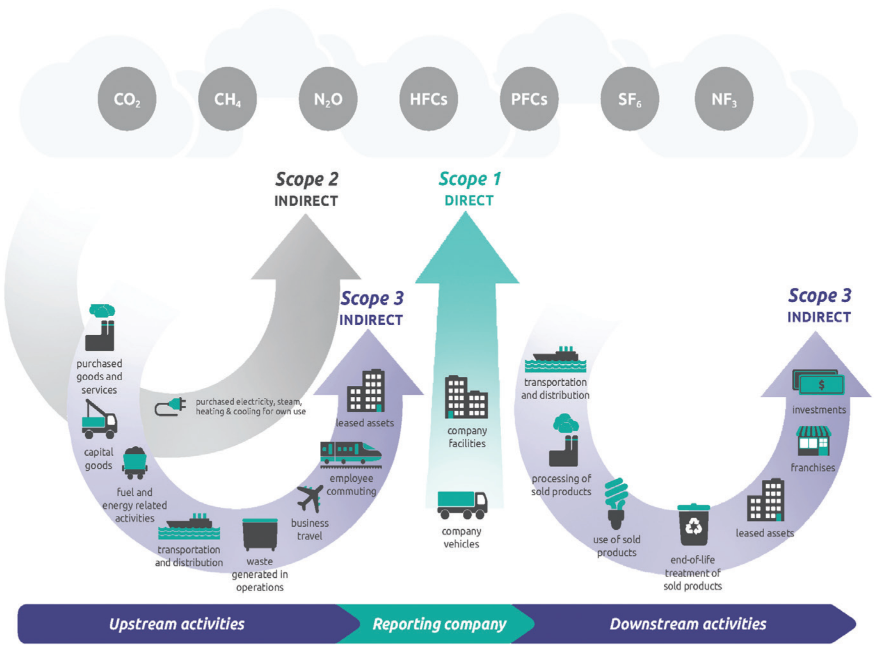



*Figure 2: Overview of GHG Protocol scopes and emissions across the value chain.[3]*

[2] Refer to page 62 of https://ghgprotocol.org/sites/default/files/standards/ghg-protocol-revised.pdf
[3] https://ghgprotocol.org/sites/default/files/standards/Scope3_Calculation_Guidance_0.pdf

*Table 2: Source Categories and Scopes included in Penn State's GHG Inventory*
Note: Blue = Included in Penn State Inventory

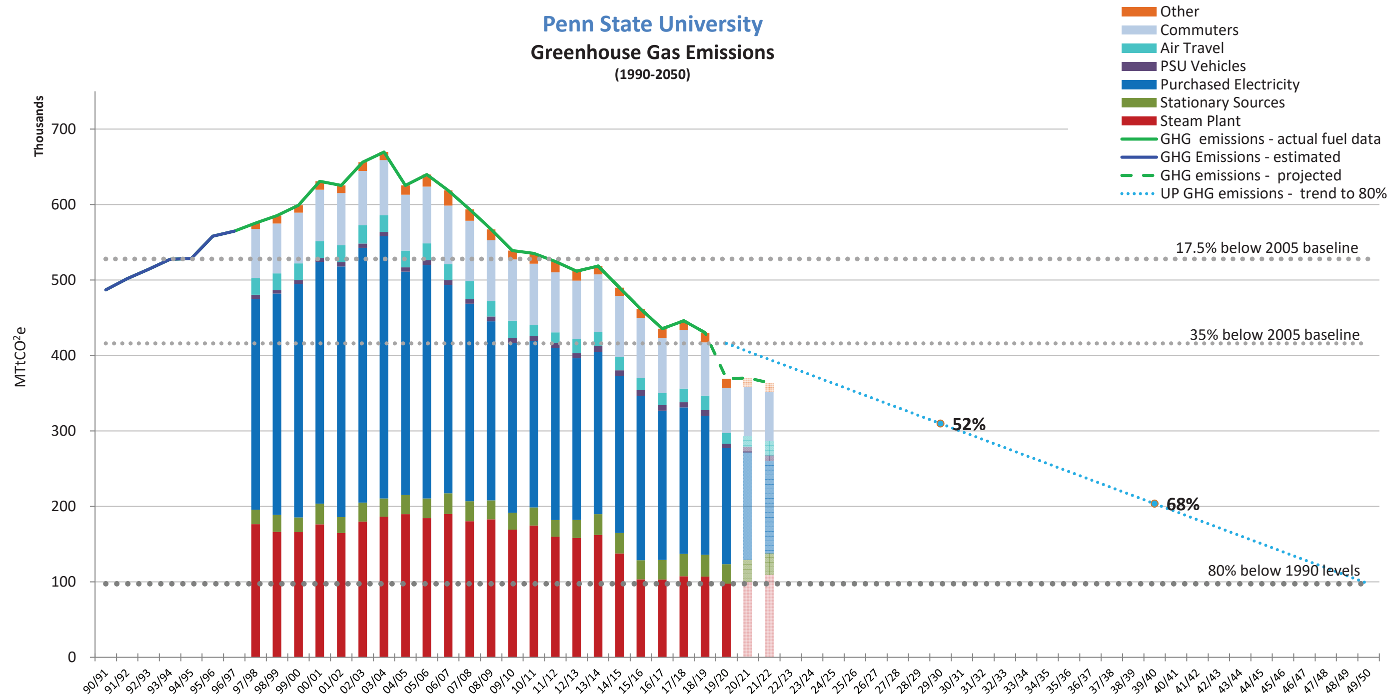
| Scope 1 | Scope 2 | Scope 3 |
|---|---|---|
| Stationary Combustion | Purchased Electricity | Purchased Goods & Services |
| Mobile Combustion | Purchased Utilities (other) | Capital Goods |
| Refrigerants | | Fuel & Energy related activities (T&D loss, extraction) |
| Synthetic Fertilizers | | Upstream transportation & distribution |
| Lime | | Waste generated in operations (Solid Waste, Wastewater) |
| Livestock | | Business Travel (Air Travel, other directly financed travel) |
| Wastewater | | Commuting |
| (UP, New Kensington, Wilkes Barre) | | Upstream leased assets |
| Process \ Fugitive emissions | | Transportation and distribution of sold goods |
| | | Processing of sold goods |
| | | Use of sold goods |
| | | End of life treatment of sold products |
| | | Downstream leased assets |
| | | Franchises |
| | | Investments |

The World Resources Institute GHG Protocol requires all Scope 1 and 2 emissions to be included in an entity-level inventory. Some voluntary reporting organizations identify specific Scope 3 emissions that also must be included. For example, Second Nature[4] requires a basic inventory related to their Presidents' Climate Leadership Commitments[5] to include Air Travel and Commuting. Most of Penn State's peer institutions include Scope 1 and Scope 2 with select Scope 3 emissions in their inventories (see in Appendix D: Benchmarking). Increasingly, organizations are recognizing that emissions across the value chain are important to fully account for the impact of their operations. Addressing Scope 3 emissions in their entirety allows for changes in decision making and policies to make a larger positive impact on sustainability beyond the boundaries of the University. See Appendix C: Scope 3 Analysis.

## GHG INVENTORY TIMELINE AND CURRENT GOALS

The University has been tracking its GHG emissions for two decades (Figure 3). The most recent completed inventory for fiscal year 2019-20 shows that most Penn State emissions come from UP operations, and that most of the system-wide emissions can be classified as Scope 1 and 2 associated with the energy sector (UP steam plants, system-wide electric power purchase agreements) (Figure 4). The first GHG emissions reduction goal was set in 2006 as a 17.5% reduction below the 2005 baseline by 2012. When that goal was met, a new goal of a 35% reduction below the 2005 baseline by 2020 was set and achieved (Table 1). A long-term aspirational goal of an 80% reduction from 1990 levels by 2050 was also developed. This is in line with the Commonwealth of Pennsylvania's GHG emissions reduction goals of a 26% reduction by 2025 and an 80% reduction by 2050 from a 2005 baseline.

[4] https://secondnature.org/
[5] In 2015, Second Nature rebranded and expanded the ACUPCC (American Colleges and University President's Climate Commitment) into a program that includes a Carbon Commitment focused on reducing GHG emissions, a Resilience Commitment focused on climate adaptation and enhancing community resilience to climate change, and a Climate Commitment that integrates both. Penn State is currently not a signatory to these commitments. (see https://secondnature.org/our-history/ for more detail).




Penn State GHG Emissions include stationary sources, purchased electricity, OPP & Fleet vehicles and estimated commuter miles, air travel, waste & wastewater, refrigerants and animal management.
Hershey Medical & Penn College of Technology not included.

*Figure 3: Penn State's Historic GHG Emissions and Reduction Goals*

*Table 3: Emissions Totals (MTCO2e) by Scope Base Year & Current Inventory*

| Fiscal Year | Scope 1 | Scope 2 | Scope 3 | Total |
|---|---|---|---|---|
| 05/06 | 230,367 | 309,163 | 100,294 | 639,824 |
| 19/20 | 138,776 | 145,988 | 84,529 | 369,292 |
| Reduction | 157,392 | 65,191 | 84,529 | 307,112 |
| | 39.8% | 52.8% | 15.7% | **42.3%** |

*Penn State's FY 19/20 GHG Inventory shows a 42% reduction from 2005*

## REDUCTION STRATEGIES

Penn State's GHG emissions reduction efforts have been based on a foundation of energy conservation, increased efficiency, increased levels of combined heat and power, targeted renewable purchases, green design, campus community awareness as well as programs in transportation and waste. See Appendix B for detailed information on the various projects and programs contributing to Penn State's reductions so far.

Although the effects of the COVID-19 pandemic on University operations contributed to the larger reduction seen in FY 19/20 on Figure 3; (also see Table 3), the 35% reduction goal was expected to be met prior to the pandemic. Moving forward, Penn State will have a significant reduction in Scope 2 emissions for FY 20/21 and beyond due to the 70 MW Solar Power Purchase Agreement (PPA) Penn State entered in 2019 and began taking power from in October 2020.[6]

Additionally, a new Combustion Turbine and Heat Recovery Steam Generator will be in operation at the West Campus Steam Plant (WCSP) in 2022. This increase of on-campus cogeneration will reduce the amount of power to be purchased, resulting in additional GHG emission reductions.

*By FY 21/22 it is projected Penn State's emissions will be at 48% below the 2005 baseline.*

Reduction strategies have been implemented in a financially responsible manner and have been at low or no cost to the University or incorporated as part of an existing infrastructure update. Some strategies, such as the 2019 Solar PPA or Energy Savings Program (ESP), are projected to provide a financial savings to the University over the long term.

However, as the University continues to grow, it is less clear what additional projects and programs can be implemented to enable sustainable growth while continuing to reduce Penn State's emissions without additional financial investment.

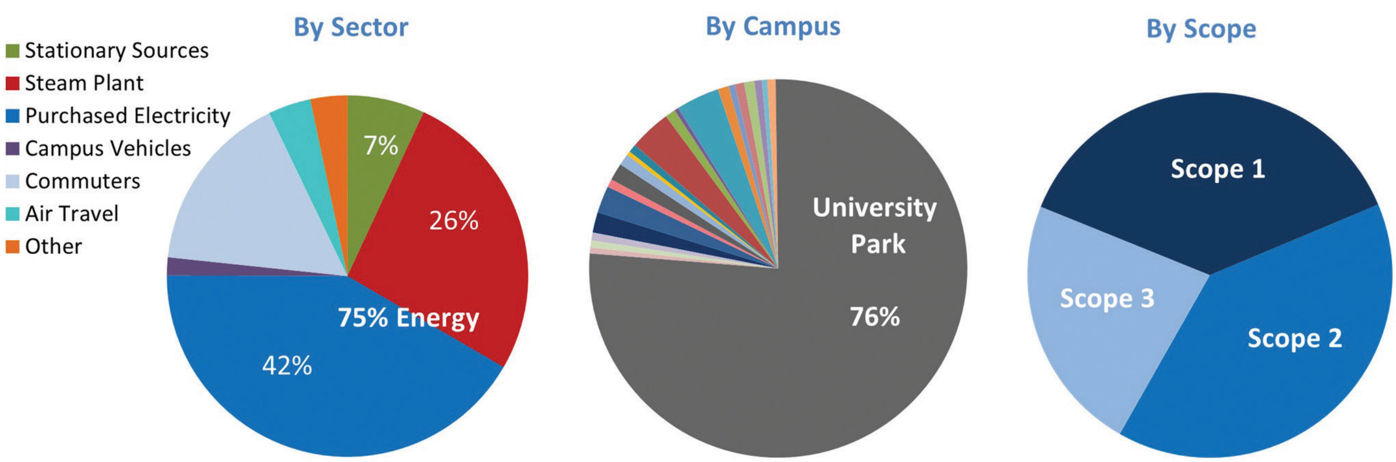



*Figure 4: Penn State's Emissions Breakdown by Sector, Campus and Scope for FY 19/20. The various colors in the middle pie chart represent the 21 Commonwealth Campuses. The pie charts demonstrate that the majority of GHG emissions are associated with operations and activities at University Park.*

[6] https://www.psu.edu/news/impact/story/penn-state-lightsource-bp-break-ground-largest-solar-project-pennsylvania/

# Driving Factors

Rigorous, comprehensive, and transparent reviews of existing science demonstrate what human society has wrought on Earth's climate and how urgent change is needed. The 2021 Intergovernmental Panel on Climate Change (IPCC) report states that humanity has unequivocally warmed the Earth system, and that widespread and rapid changes have occurred.[5] The IPCC 1.5°C Report and the 2021 6th Assessment Reports,[7] [8] the U.S. Fourth National Climate Assessment,[9] and the Global Risk Report 2020 by the World Economic Forum[10] all conclude that climate disruption is a present danger to human health and well-being, especially poor and marginalized communities, to economies globally, and to life on Earth. Limiting human-induced global warming requires limiting cumulative GHG emissions to reach net zero $CO_2$ emissions or net removal.[11]

### HEAT AND RAINFALL EXTREMES

The 2021 IPCC report states that humanity has likely increased the chance of compound extreme events globally including increases in the frequency of concurrent heatwaves and droughts (high confidence); fire weather (medium); and compound flooding in some locations (medium).

In a business-as-usual scenario, temperatures in Pennsylvania are expected to increase an average 5.9°F (3.3°C) by mid-Century and 9.4°F (4.6°C) by end-of-Century.[12] Moreover, Pennsylvania is expected to have an increase of extreme temperature days (>90°F) from 5 days currently to 37 per year by mid-Century and 61 per year by 2100. In addition, extreme rainfall events, currently rare (1%), will increase to 13% of rainfall events by mid-Century while droughts will increase by 7%. These changes will impact human and ecosystem health and threaten agricultural stability. Increased growing degree days may influence crops and pests differently but with likely decreases in production of apples, corn, grapes, and dairy production, key agricultural crops for the Commonwealth. Predicted losses in dairy production could result in >$480 million in effects. Negative impacts on recreation, landslide susceptibility, inland flooding, coastal flooding and erosion, and wildlife are also expected. Many areas of Pennsylvania already have increased flash flooding that burden society, often those who are already economically stressed.

*"Climate change is the single biggest health threat facing humanity." – World Health Organization*

### HARM TO HUMAN HEALTH

The benefits of decarbonization are not just measured in dollars, but also in lives. Fossil fuel production and use emits pollutants that impact lung function, and cause asthma, lung cancer, cardiovascular disease, strokes, preterm birth, and reduced neurological function – the direct public health impact of carbon emissions is greater

[7] IPCC 2018 Special Report, "Global warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty," https://www.ipcc.ch/sr15/

[8] IPCC 2021 Sixth Assessment Report, "Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the IPCC," https://www.ipcc.ch/assessment-report/ar6/

[9] Fourth National Climate Assessment (https://nca2018.globalchange.gov)

[10] World Economic Forum's Global Risk Report 2020 (https://www.weforum.org/reports/the-global-risks-report-2020)

[11] IPCC 2021 Sixth Assessment Report (https://www.ipcc.ch/assessment-report/ar6/)

[12] Pennsylvania Department of Environmental Protection 2021 Climate Change Impacts Assessment (https://www.dep.pa.gov/Citizens/climate/Pages/impacts.aspx)

than smoking.[13] Recent estimates of the number of lives lost to fossil fuel air pollution range from 3.6 million[14] to 10.2 million deaths/year,[15] and the World Health Organization (WHO) estimates that human-caused air pollution kills 7 million people/year. And while heart failure patients in Pennsylvania communities with hydraulic fracturing suffer increased rates of hospitalization,[16] even as those communities received only 10% of the revenue from the fuel extracted,[17] converting 330 U.S. coal plants to cleaner-burning fossil gas has saved an estimated 22,600 lives over 11 years and increased crop yields (Figure 5).[18]

In 2021, 233 health journals warned that "global heating is also contributing to the decline in global yield potential for major crops…… hampering efforts to reduce undernutrition",[19] concluding that, "The greatest threat to global public health is the continued failure of world leaders to keep the global temperature rise below 1.5°C and to restore nature." Similarly the WHO states that "The burning of fossil fuels is killing us. Climate change is the single biggest health threat facing humanity. While no one is safe from the health impacts of climate change, they are disproportionately felt by the most vulnerable and disadvantaged."[20] Almost a third of the U.S. lives where air pollution exceeds national air quality standards.[21] Children are particularly vulnerable:[22] in Pittsburgh, 22% of school children near industrial areas have asthma – nearly 3x the national average.[23] Air pollution is an environmental justice issue too, disproportionately effecting minority communities: 19.3% of Black children in Pennsylvania have asthma, and 39% live with unhealthy levels of air pollution.[24]

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[13] Fabio Caiazzo et al., "Air pollution and early deaths in the United States. Part I: Quantifying the impact of major sectors in 2005," *Atmospheric Environment* 79 (November 2013): 198-208, https://www.sciencedirect.com/science/article/abs/pii/S1352231013004548.
Andrew L. Goodkind et al., "Fine-scale damage estimates of particulate matter air pollution reveal opportunities for location-specific mitigation of emissions," *Proceedings of the National Academy of Sciences of the United States of America* 116, no. 18 (April 30, 2019): 8775-8780, https://www.pnas.org/content/116/18/8775.
J. Lelieveld et al., "Effects of fossil fuel and total anthropogenic emission removal on public health and climate," *Proceedings of the National Academy of Sciences of the United States of America* 116, no. 15 (April 9, 2019): 7192-7197, https://www.pnas.org/content/116/15/7192
[14] Lelieveld et al., "Effects of fossil fuel and total anthropogenic emission removal."
[15] Karn Vohra et al., *Environmental Research* 195 (2021) https://doi.org/10.1016/j.envres.2021.110754
[16] American College of Cardiology, "Fracking sites may increase heart failure hospitalizations across large regions," Medical Xpress, December 7, 2020, https://medicalxpress.com/news/2020-12-fracking-sites-heart-failure-hospitalizations.amp.
[17] https://ohiorivervalleyinstitute.org/new-report-natural-gas-county-economies-suffered-as-production-boomed/
[18] Burney, "The downstream air pollution impacts" and "Author Correction."
[19] Lukoye Atwoli, et al., "Call for emergency action to limit global temperature increases, restore biodiversity, and protect health." *BMJ* (2021), 374:n1734 https://doi.org/10.1136/bmj.n1734
[20] https://www.who.int/publications-detail-redirect/cop26-special-report. See also https://www.who.int/news/item/11-10-2021-who-s-10-calls-for-climate-action-to-assure-sustained-recovery-from-covid-19
[21] See this summary of research on the "Health Effects of Burning Fossil Fuels,“ State Energy & Environmental Impact Center, NYU School of Law, accessed March 21, 2021 from https://www.law.nyu.edu/centers/state-impact/press-publications/research/climate-and-health/health-effects-of-burning-fossil-fuels
[22] Allison Inserro, "Air Pollution Linked to Lung Infections Especially in Young Children," *AJMC* (2018), https://www.ajmc.com/view/air-pollution-linked-to-lung-infections-especially-in-young-children
[23] Deborah A. Gentile et al., "Asthma prevalence and control among schoolchildren residing near outdoor air pollution sites," *Journal of Asthma* (2020) https://doi.org/10.1080/02770903.2020.1840584
See also Kristina Marusic, "Kids with asthma who live near heavy air pollution face greater risk from coronavirus," *The Daily Climate*, (2020) https://www.dailyclimate.org/children-asthma-coronavirus-2645626328/on-the-front-lines-of-air-pollution
[24] If air pollution levels in all of Allegheny County were lowered to match the levels seen in its least-polluted neighborhoods, about 100 fewer residents would die of coronary heart disease every year. James P. Fabisiak et al., "A risk-based model to assess environmental justice and coronary heart disease burden from traffic-related air pollutants," *Environmental Health* 19, no. 34 (2020), https://ehjournal.biomedcentral.com/articles/10.1186/s12940-020-00584-z

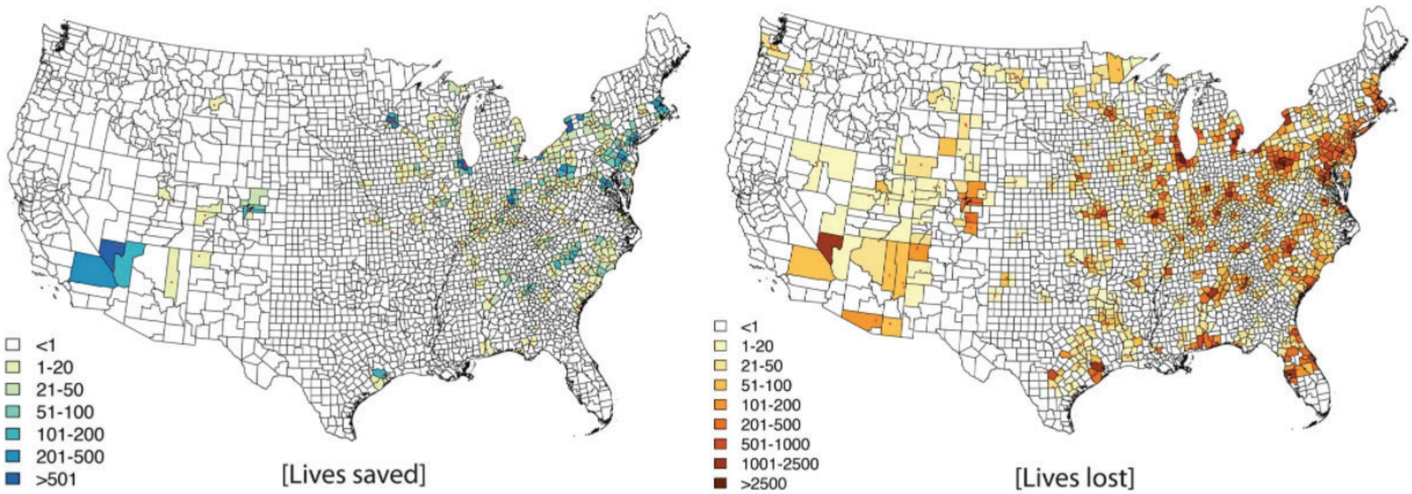


*Figure 5: Lives saved due to closure of 330 coal plants. Projected lives lost due to continued coal use.[18]*

A core value of Penn State is our commitment to act responsibly, to be accountable for our decisions, actions, and their consequences. We have a moral obligation to address these past and ongoing impacts. Decarbonizing our operations and working with our students, partners, and communities to draw down our society's emissions is an opportunity for us to embody our value of responsibility authentically and help save lives by reducing warming and lowering pollution.

*A year of Penn State's emissions is estimated to cause $27,600,000 in social damages*

## SOCIAL COST OF CARBON

GHG pollution causes harm to human health, well-being, and prosperity directly through air and water pollution, and indirectly through increased heatwaves, extreme weather and damage to food, water, and infrastructure.[25] Penn State's most recent completed GHG emissions inventory (2019-20) indicates we are responsible for 369,292 MTCO2e. Those emissions cause impacts that are not incorporated into the price we pay for energy, and amount to a societal subsidy of our emissions sources. The Social Cost of Carbon is a measure of this market failure, estimated by the EPA to be $76/metric ton of carbon,[26] and by the International Monetary Fund at $75/metric ton.[27]

[25] Marina Romanello, et al., "The 2021 report of the Lancet Countdown on health and climate change: code red for a healthy future." *The Lancet*. https://doi.org/10.1016/S0140-6736(21)01787-6

[26] The cost of carbon emissions is affected by the discount rate, which values present spending more highly than future spending. According to some ethicists, higher discount rates unfairly devalue the lives of future generations, which in our case means our students. A relevant real-world index for the discount rate for climate's intergenerational context is the current treasury bond rate, at or lower than 2%, making carbon $125 per ton. At a 2.5% discount rate the EPA puts the social cost of carbon at $75 per ton. At a 3% discount rate, the cost per ton is $50. The 2% rate is recommended by most experts (Drupp et al, 2018 https://doi.org/10.1257/pol.20160240), while New York uses discount rates between 1 and 3%, and Washington State requires utilities to use 2.5% in their calculations (p.35). The UK uses a discount rate that declines over time. See https://www.whitehouse.gov/wp-content/uploads/2021/02/TechnicalSupportDocument_SocialCostofCarbonMethaneNitrou sOxide.pdf, pgs. 19-21.

[27] Parry, IMF Working Papers (2021)

This means that at 2019-20 levels our annual emissions cause $27,600,000 in damages. An alternative view utilizing a Social Cost of Carbon approach is that Penn State has provided a $191.3 million savings to society by preventing ~2,550,000 MTCO2e from being emitted since 2006. That the long-term investment required to reduce our emissions equates to the damage costs to society related to our emissions is discussed in the Modeling of Emissions Reduction Strategies section of this report.

*Keeping global warming below 1.5°C would prevent the worst effects of climate change, but current emissions reduction plans are insufficient to reach that target*

## THE GLOBAL IMPERATIVE TO ACT

**Current emissions reduction plans are insufficient:** According to the IPCC Special Report on Global Warming of 1.5°C, keeping global temperatures below 1.5°C of warming is substantially better than 2°C,[28] and will help to ensure a more sustainable and equitable society.[29]

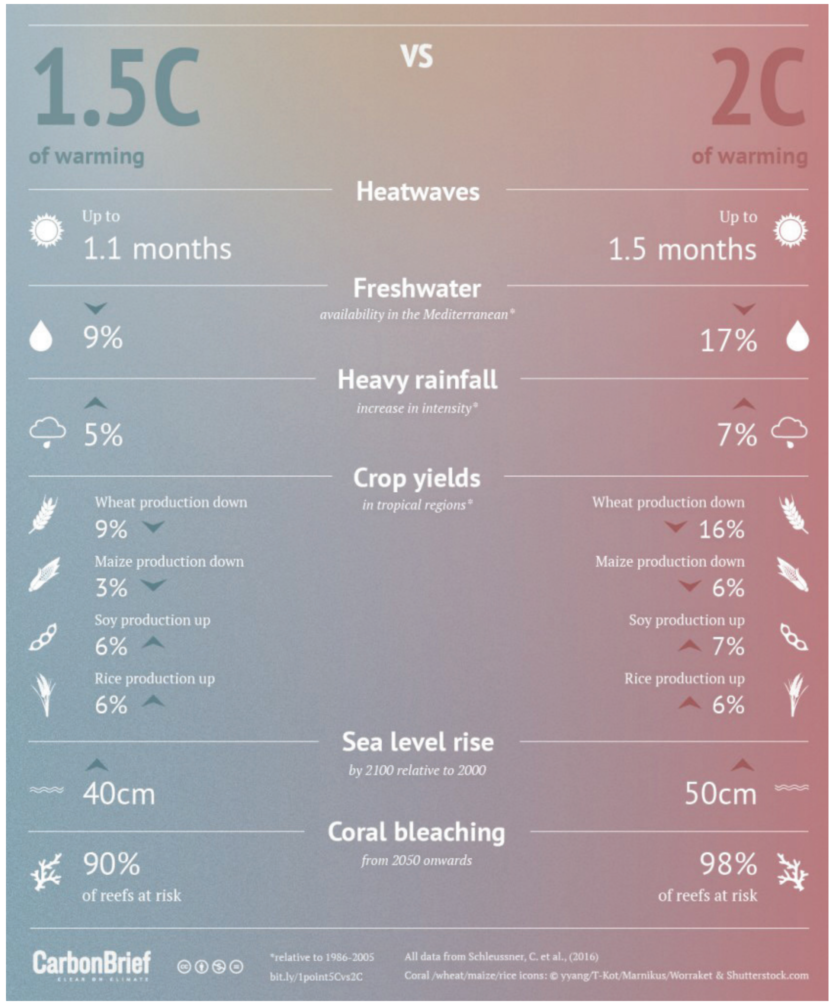


*Figure 6: Impacts of 1.5°C vs 2°C of warming. Infographic: How do the impacts of 1.5C of warming compare to 2C of warming? By Rosamund Pearce for Carbon Brief.*

[28] IPCC 2018 Special Report (https://www.ipcc.ch/sr15/)

[29] Dan Welsby, et al., "Unextractable fossil fuels in a 1.5 °C world," *Nature* 597, pg. 151 (2021). https://doi.org/10.1038/s41586-021-03821-8

To achieve a 1.5°C limit, the world must halve $CO_2$ emissions by 2030 and reach net-zero by 2050.[31] According to the International Energy Agency (IEA), to achieve net-zero by 2050, no new fossil fuels can be developed after 2021,[30] and a separate report details that to have some chance of remaining below 1.5°C, 60% of oil and gas, and 90% of coal must stay in the ground.[29] The IEA estimates that the transition to net zero by 2050 will stabilize energy prices, create 9 million jobs, and increase global GDP.[34] Further, the IEA states that all the technologies and policies already exist to meet a 2030 target. What is necessary is leadership committed to creating a transition.

Unfortunately, current climate reduction pledges from the Paris Accord would lead to 2.7°C warming above pre-industrial levels, and up to 3.6°C in this century.[32] But countries and businesses are not even meeting these commitments and emissions will be reduced by only 7.5%, whereas 30% is needed for 2°C and 55% for 1.5°C.[33] Moreover, actual emissions globally are likely higher than reported by an amount ranging between the annual emissions of the U.S. and those of China (23% of global emissions).[34]

Based on lifespan, existing fossil fuel infrastructure may on its own take us beyond +1.5°C.[35] And since GHGs can last for centuries, we now know that our historical emissions will be warming the planet for a long time to come. We must take responsibility for undoing those harms, setting goals to achieve net zero emissions and to draw down Penn State's historical GHG emissions, helping to ensure a more stable and more just future for our University and the world.

*The scientific evidence is clear that humanity must act boldly and aggressively by 2030. The time for Penn State to lead is **now**.*

## CALLS FOR ACTION

**Penn State can lead:** Our emissions reduction goals must surpass existing state and federal timelines if we intend to position ourselves as leaders. We have the capacity to do so and to draw on our broad and deep partnerships to enable and assist our communities in a just transition to a clean, healthy, prosperous future. The scientific evidence is clear that humanity must act boldly and aggressively by 2030. The time for Penn State to lead is ***now***.

Leadership requires us to understand our actions in their scientific and ethical context and consider the needs of our society and planet. The student-written Penn State Climate Action Plan calls for a shift from the question "are we doing enough on climate?" to "are we doing the best we can?"[36] Our capacities and institutional resources position us to bring our GHG emissions below net-zero by 2035 – properly mobilized, Penn State could be climate positive sooner. We think this is the correct way to approach decarbonization.

[29] Dan Welsby, et al., "Unextractable fossil fuels in a 1.5°C world," *Nature* 597, pg. 151 (2021). https://doi.org/10.1038/s41586-021-03821-8
[30] IEA, "Net Zero by 2050", *IEA* (2021) https://www.iea.org/reports/net-zero-by-2050
[31] Emissions Gap Report 2021 (https://www.unep.org/resources/emissions-gap-report-2021)
[32] https://www.carbonbrief.org/analysis-do-cop26-promises-keep-global-warming-below-2c
[33] https://www.unep.org/resources/emissions-gap-report-2021
[34] https://www.washingtonpost.com/climate-environment/interactive/2021/greenhouse-gas-emissions-pledges-data/
[35] Dan Tong, et al. Committed emissions from existing energy infrastructure jeopardize 1.5°C climate target. *Nature* 572, 373–377 (2019). https://doi.org/10.1038/s41586-019-1364-3
[36] https://psuclimateaction.weebly.com/

# Benchmarking Peer Institutions: Carbon Emissions Reductions

To compare our goals to other Big Ten Academic Alliance universities, we completed a preliminary benchmarking exercise on existing Climate Action Plans (CAPs) or decarbonization strategies (see Appendix D: Benchmarking for more details). The goal of this analysis is to support decision-making in other sections of the report by identifying potential challenges, opportunities, and specific strategies to reduce carbon emissions. This effort helps us define Penn State's unique potential for leadership among peers, and opportunities for BTAA coordination and alignment. We conclude that our aspirations should not be constrained by this analysis, which should be seen as a starting point to catalyze action.

Penn State's emissions are lower than many BTAA institutions of similar size and complexity (Figure 8). We believe this is indicative of the strong institutional investments to date in carbon emissions reduction and energy efficiency. However, Penn State emissions do not consider Hershey Medical School, Penn State Health System and other related infrastructure, or the Penn College of Technology.

Our analysis also shows that most BTAA institutions are responding to the threat of climate change by publicly committing to decarbonization (Table 4). Specifically, most BTAA member universities have existing carbon commitments and Climate Action Plans, with recommendations from the most recent reports (e.g., Rutgers, Michigan, Illinois, and Maryland) being the most ambitious (Table 5). More than half of BTAA member universities have recommended 100% carbon emissions

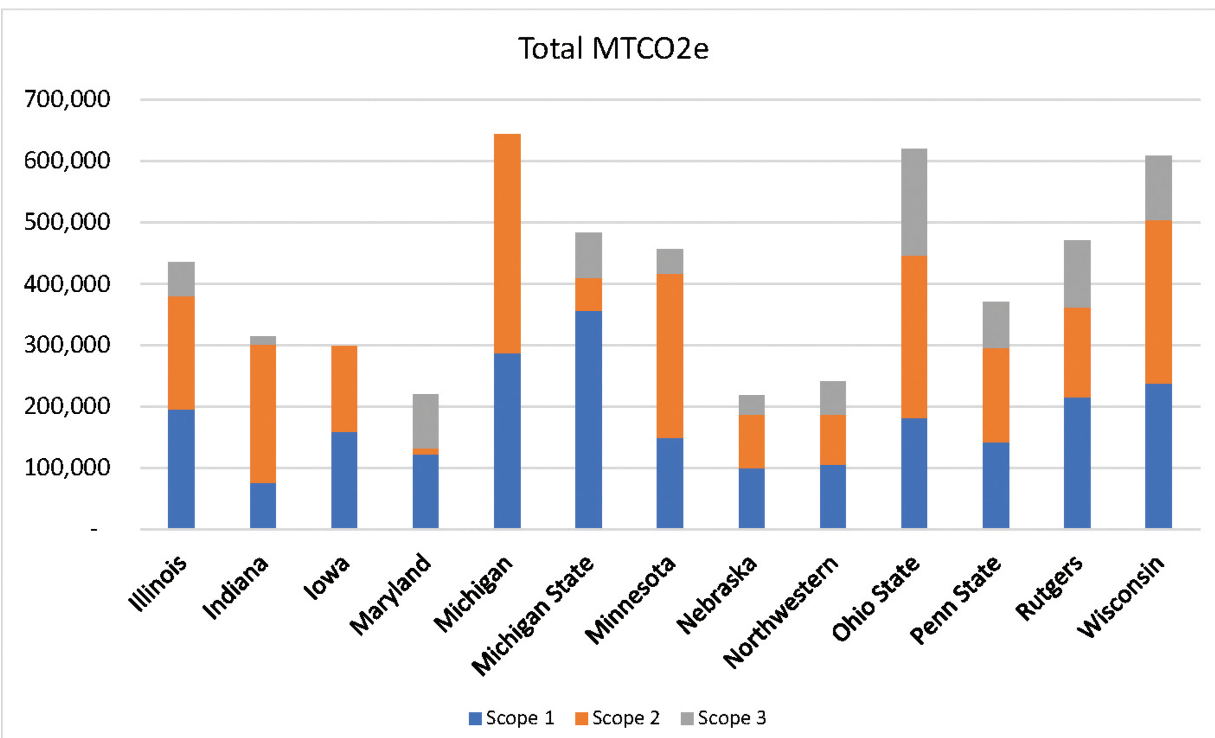


*Figure 8: Scope 1, 2, and 3 emissions (MTCO2e) from BTAA peer institutions. Data was obtained from climate action reports or STARS data, whichever was most recent. Note: Not all institutions report Scope 3 data and some institutions (e.g., Michigan) include a Medical Center, while others (e.g., Penn State) do not.*

reductions by 2050 (7/12); Rutgers and Michigan recommended 100% carbon emissions reductions by 2040 and the Maryland plan recommends 100% of Scope 1 and 2 by 2025. Most institutions have intermediate goals to achieve emissions reductions of 30-65% by 2030, with some commitments beginning as early as 2020 or 2025, depending on the date of the report. Note that the baseline year for reduction efforts differ across institutions, making relative comparisons difficult. Penn State uses a 2005 baseline (earlier than many institutions) because this is peak emissions for our institution. The most aggressive short-term reduction targets include offsets.

*Table 4: Membership signatory commitments with existing networks [Second Nature, International Universities Climate Alliance (IUCA), University Climate Change Coalition (UC3)], and the most updated Climate Action Plan or, most closely related sustainability report, and date, for appropriate BTAA universities.*

| University | Membership Commitments | Existing Climate Action Plan | Year of plan (most recent update) |
|---|---|---|---|
| Illinois | *International Universities Climate Alliance; Second Nature Climate Commitment;* STARS Gold: Feb 2019 | UIC Climate Action Plan (3rd report) | 2020 |
| Indiana | STARS Gold: Feb 2020 | Part of Sustain IU vision | 2020 |
| Iowa | STARS Silver: Jul 2018 | UI 2030 Sustainability Goals (Framework) | 2020 |
| Maryland | *Second Nature Carbon Commitment; UC3* STARS Gold: Feb 2019 | Climate Action Plan 2.0 | 2021 |
| Michigan | UC3 STARS Gold: Jun 2018 | President's Commission Carbon Neutrality | 2021 |
| Michigan State | STARS Gold: Feb 2019 | Sustainability report and Energy Transition Plan | 2017 |
| Minnesota | *Second Nature Carbon Commitment;* STARS Gold: Dec 2015 | Climate Action Plan for the University of Minnesota; Regents 20-21 Sustainability Report | 2011 |
| Nebraska | STARS Silver: Jan 2020 | Environment, Sustainability, and Resilience Master Plan | 2020 |
| Northwestern | STARS Gold: Mar 2020 | Strategic Sustainability Plan: Implementation Roadmap 2017-2021 | 2017 |
| Ohio State | *Second Nature Carbon Commitment; UC3;* STARS Gold: Jan 2019 | Path to Carbon Neutrality: Ohio State Climate Action Plan | 2020 |
| Purdue | n/a | NO, but some commitments in Sustainability master plan | 2020 |
| Rutgers | University Climate Change Coalition; UC3 | President's Task Force on Carbon Neutrality and Climate Resilience | 2021 |
| Wisconsin | *Second Nature Resilience Commitment;* STARS Silver: Aug 2019 | Phase 1 Phase 2 underway; Phase 3 in 2022 | 2021 |
| Penn State | *International Universities Climate Alliance*; STARS Gold: Dec 2020 | This CERTF Report | 2021 |

*Table 5: Recommended % Reductions in Emissions from BTAA Climate Action Plans, where available. Importantly, some CAPs are recent (e.g., Michigan and Rutgers) with institutional approvals at various stages, others are older (e.g., Purdue) or being updated currently (e.g., Wisconsin)*

| Institution | *Baseline Year* | 2020 | 2025 | 2030 | 2040 | 2050 |
|---|---|---|---|---|---|---|
| Illinois | 2004 | | | 40% | | 80% (20% from offsets) |
| Indiana | 2010 | 30% | | 45% | | 80% |
| Iowa | 2010 | | | 50% | | |
| Maryland | 2005 | 100% of Sc2 renewables | 100% (inclusive of offsets) | | | |
| Michigan | 2010 | | Sc1 neutral; Sc2 100% (inclusive of offsets) | 45% | 100% | |
| Michigan State | 2010 | 45% | 55% | 65% | | |
| Minnesota | 2008 | 49% | | | | 100% |
| Nebraska | 2018 | | 25% | | | 100% |
| Northwestern | 2012 | | | 30% | | 100% |
| Ohio State | 2018 | | | 55% (aspirational) | | 100% |
| Penn State | 2005 | 35% | | | | 80% |
| Purdue | 2011 | | 50% (Sc1 and 2) | | | |
| Rutgers | 2019 | | | 20% (Sc1); 100% (Sc2); 30% (Sc3) | 100% | |
| Wisconsin | 2007 | 40% (Sc 1 and 2) | | | | |

## ADDITIONAL FINDINGS:

1. Strategies for Scope 1 and Scope 2 emissions reductions vary among institutions and include some strategies Penn State has already adopted (e.g., solar PPAs, combined heat and power) as well as more ambitious strategies such as geothermal heat exchange, carbon capture, green hydrogen, and renewable natural gas.
2. Scope 3 emissions are not consistently included in accounting or recommendations (beyond air travel and commuting) due to data limitations, but there is clear intentionality for broadened assessment and inclusion moving forward.
3. When offsets were included, they were considered as complementary short-term or "bridge" strategies until real emissions reductions could be achieved. Some universities focused on investing in internal programs and policies, while others invested in offset purchases from external companies or programs. In either case, evolving and continuous assessment of offset portfolios, and policies to oversee their implementation, were seen to be important, given their rapid pace of change.
4. The most robust reports included participatory processes for community and stakeholder inclusion during plan development, and transparency in reporting through online dashboards.
5. Strategies for institutionalization of climate action planning differed widely among institutions, but commonly included modified governance structures and policies, including (a) direct lines of reporting to the executive branch of the institution, and (b) clear, institutionalized partnerships with Operations and the other University units responsible for CAP implementation.

See Appendix D: Benchmarking for more details of these approaches.

# New Greenhouse Gas Reduction Goals

**The actions of the CERTF in direct response to its charge led to the recommendation of the following new carbon emissions reduction goals for Penn State.**

**Goal 1:** Achieve 100% emissions reduction by 2035

- **Milestone 1:** 2022: Initiate action to advance New GHG Reduction Goals
- **Milestone 2:** By 2025: Achieve 55% net GHG emissions reduction
- **Milestone 3:** By 2030: Achieve 70% net GHG emissions reduction
- **Milestone 4:** By 2035: Achieve 100% net GHG emissions reduction

*Goal 1 and Milestones 1-4 are based on our existing inventory and 2005 baseline.*

**Goal 2:** Beyond 2035: Continue beyond 100% GHG emissions reduction, leading the way to a safe, healthy, and just future

Figure 9 displays the trajectory of emissions reductions to be achieved through these goals compared to Penn State's historical GHG emissions and our past emissions reduction goals. Achieving these goals will require Institutional commitment to Climate Action. In the next section we put forward a tractable roadmap to chart Penn State's pathway to a carbon positive future.

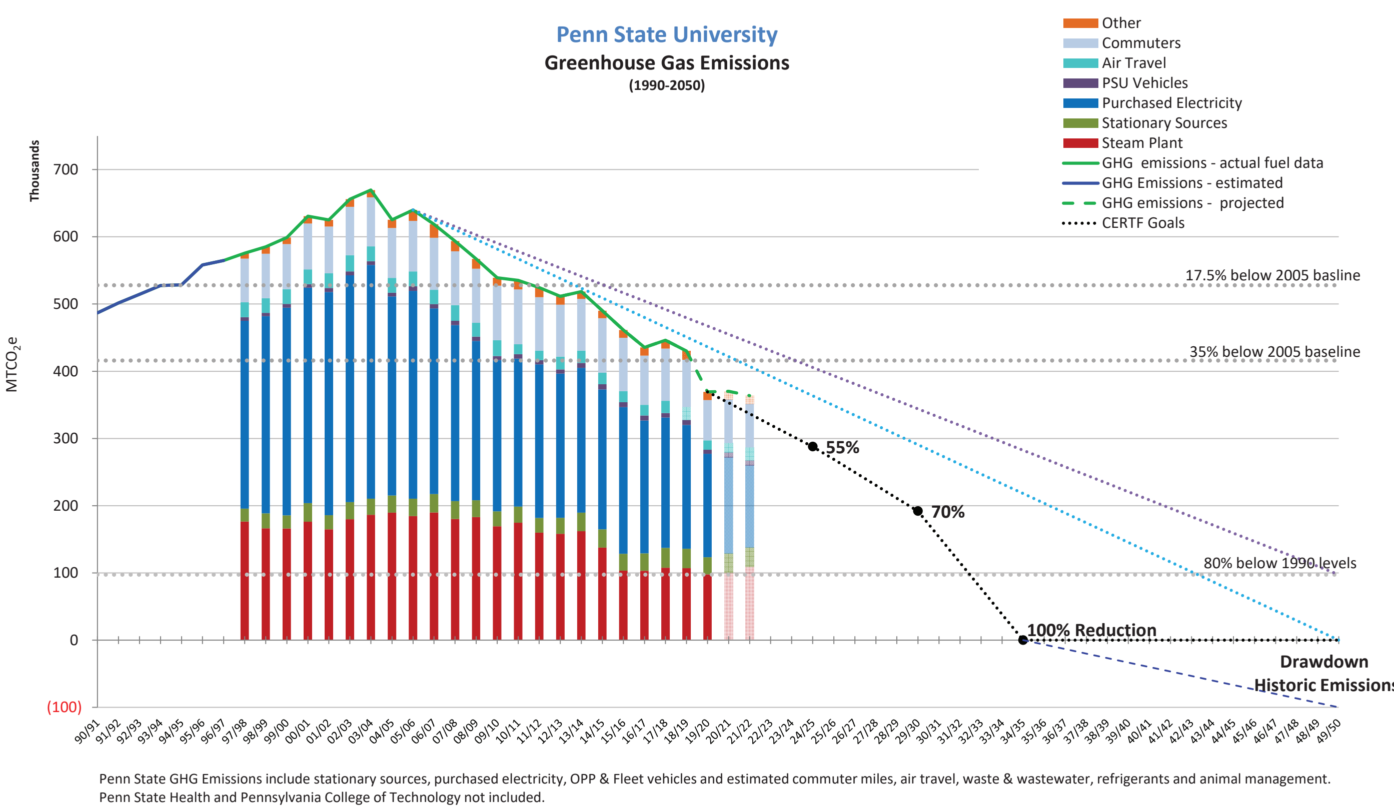


*Figure 9: Illustration of new GHG goals against historic reductions*

# Roadmap Recommendations

This section presents a simplified "road map" for achieving Penn State's new carbon emissions reduction goals, and a framework for understanding the more detailed accounting of subject matter background, rationale, and recommendations presented through the remainder of the report. The actions presented in the road map, and others not described here, are further detailed in the Emissions Reduction and Mitigations Strategies section of the report. Figure 10 is a graphical representation of Penn State achievements in energy savings and emissions reductions with future projections of new goals and milestones tied to the roadmap.

The colored wedge chart in Figure 10 illustrates how Penn State has achieved GHG reductions and how recommended future strategies will help us reach our new goals. The top of the wedges illustrates where emissions might be without any reduction strategies. The solid blue line indicates actual emissions. The black dots illustrate past goals of 17.5% by 2012 and 35% by 2020 and the new proposed goals for 2025, 2030 and 2035. Each of the different-colored wedges illustrate the reduction to be accomplished with a specific technology or strategy. For example, the rust colored wedge displays the reduction from installation of a Combustion Turbine at the East Campus Steam Plant (ECSP)

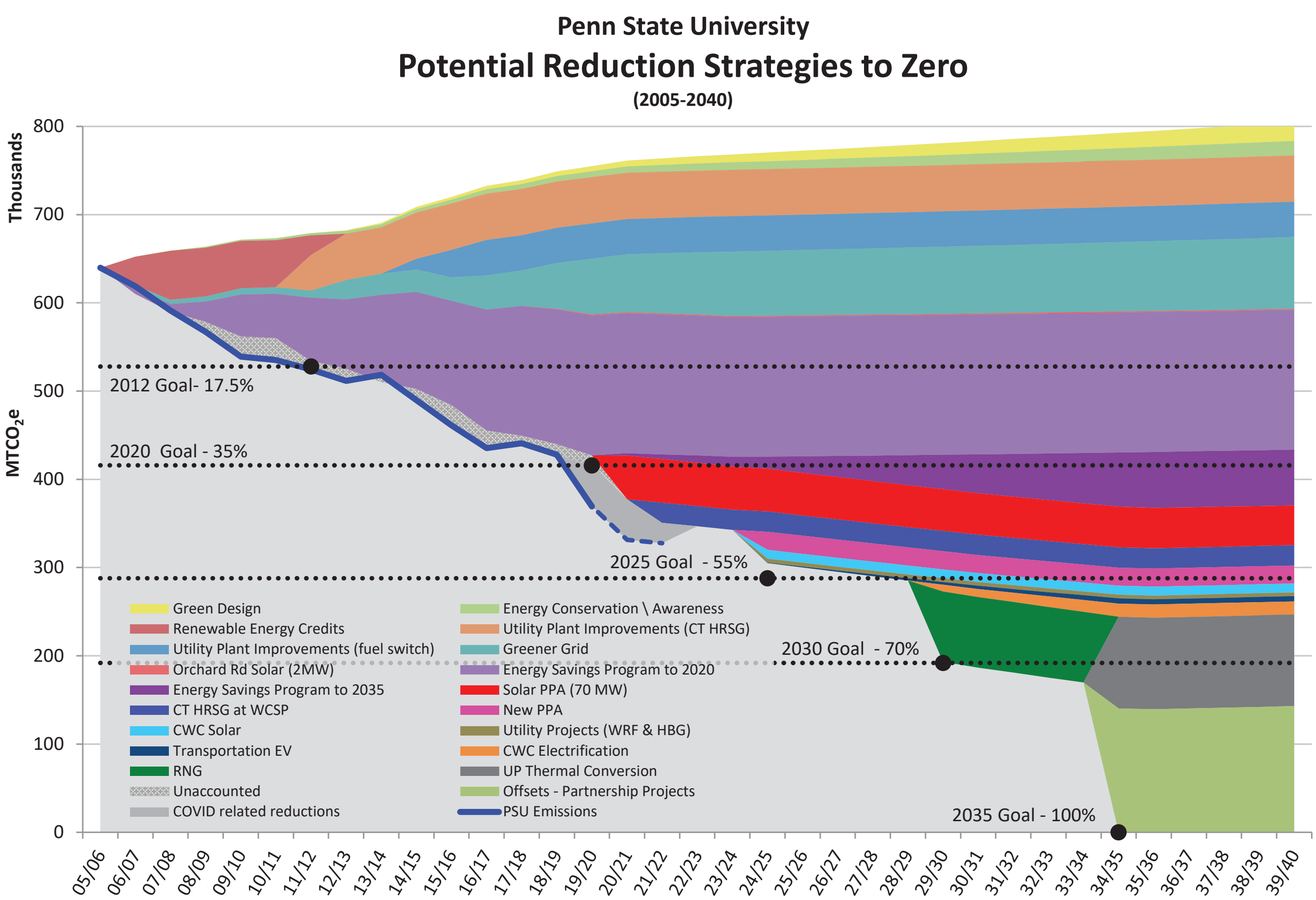


*Figure 10: Illustrates new and existing GHG reduction strategies needed to achieve new goals*

back in 2011, and the light blue wedge is the reduction from the coal to gas conversion project.

The large purple wedge in the center is the Energy Savings Program, the strategy that is responsible for most of the University's reductions to date. This program annually funds $12 million of building energy conservation projects and utility system efficiency improvements. Projects range from tuning up existing buildings to optimize their performance, building HVAC system upgrades, updating temperature controls, lighting fixture retrofits, installation of occupancy sensors, and envelope improvements. This program is highly recommended to continue.

The bright red wedge shows the contribution from a recent off-site solar energy purchase, and the dark blue wedge is the expected reductions from a project that installed a combustion turbine at the West Campus Steam Plant. The combustion turbine project was recently completed and will lower GHG emissions by 16,000 MTCO2e per year.

Moving to the strategies recommended to be implemented in 2025, the hot pink colored wedge shows the potential reductions from an additional off-site renewable electric purchase, and the very light blue shows the potential reductions from the installation of on-site solar at several Commonwealth Campus locations. The thin royal blue wedge shows the reductions from the decarbonization of University-owned vehicles. Projects recommended to be started in 2030 include the decarbonizing of the Commonwealth buildings indicated by the burned orange wedge and the purchase of Renewable Natural Gas (RNG) as indicated by the dark green wedge. Projects to be finished in 2035 include the decarbonizing of the UP heating system indicated by the dark gray wedge, and the purchase of offsets to mitigate any remaining Scope 3 emissions in 2035 as indicated by the light green wedge.

The following boxes outline the actions necessary to meet the goals and milestones.

## GOAL 1: ACHIEVE 100% EMISSIONS REDUCTION BY 2035

- Guiding Principle: Eliminate GHG emissions as rapidly as possible, and regularly reassess goals to increase ambition.

**Milestone 1: 2022: Initiate Action To Advance New GHG Reduction Goals**

- Develop a strategic communication plan about new GHG emissions reduction goals for Penn State.
- Increase visibility of and access to Penn State's GHG Inventory. Inventory details and progress will be made available on the 'Our Footprint' page on the Sustainability Institute's website.
- Increase the visibility and educational value to the campus and broader community. Include in University-wide communications (i.e., sustainability link on the main PSU website).
- Begin the creation of independent emission inventories and Carbon Emission Reduction Programs for Penn State Health and Penn College of Technology.
- Develop President-initiated fundraising campaign.
- Hire an outside consultant to develop a detailed feasibility/planning/preliminary design and costing study to decarbonize the UP heat and power infrastructure, based on preliminary technology recommendations included in this report. These include biomass, shallow geothermal heat exchange with heat pumps, deep well geothermal, micro-nuclear reactors, conversion of steam distribution system to medium temperature hot water, and the impact of additional Energy Savings Program projects. [$2M]
- Initiate study to evaluate/plan to decarbonize University-owned vehicles. [$60K]
- Begin purchasing hybrid and electric vehicles and equipment, and installing chargers. [$1.3M]

## GOAL 1: ACHIEVE 100% EMISSIONS REDUCTION BY 2035 (CONTINUED)

### Milestone 1: 2022: Initiate Action To Advance New GHG Reduction Goals

- Initiate another large renewable electric generation purchase. [$1M per year]
- Initiate project planning/design for near-term projects (Harrisburg Biomass, WRF Fuel Cell, Solar at CWC, decarbonizing CWC heating systems). [$1M]
- Maintain Energy Savings Program funding over the next 10 years to target a 25% reduction in energy use and include avoidable cost of carbon offsets in the justification. [$12M per year]
- Create a public facing Energy/Carbon Dashboard and start an educational effort. [$75K]
- Continue comprehensive annual reporting of carbon reductions to the Board of Trustees for their information.
- Clarify clear executive level responsibility and accountability for developing and implementing a carbon emissions reduction plan. Monitor, assess, and provide feedback on unit strategic plan reports, updates and overall progress regarding carbon emissions reduction.
- Refine GHG Inventory data inputs and estimation methods.
    - Engage and support the Commonwealth Campus communities to participate in updating the campus' inventory annually and use these data to develop reduction initiatives specific to each campus. These data could be used to inform campus strategic plan efforts focusing on reduction initiatives.
    - Engage University faculty and subject matter experts in emissions calculation methodologies, particularly in the land management (i.e., forestry, farms), animal management and synthetic chemicals sectors.
    - Update Commuters sections of the GHG inventory.
- Expand the assessment of the organizational climate impact. Continue the effort to establish processes and procedures to quantify additional Scope 3 emissions that are not included in the current inventory (especially procured goods and services, capital goods, leased spaces, and visitor transportation). Use the GHG Protocol for guidance.
- Continue developing guidance and best practices for engaging and prioritizing vendors and partners who are decarbonizing.
- Enhance Green Labs Program by adding additional staff to existing program to provide focus on ventilation. [$160K per year]
- Complete a space utilization study that includes the impacts of remote work. Desired result would be better utilization of existing space to defer construction of new space and associated operational and embodied carbon emissions. [$3M]
- Form a committee to explore the role of internal and partnership-based drawdown and offsets projects.
- Investigate opportunities to reduce emissions from Penn State farm operations.
- Initiate surveys of the greater Penn State community to identify target behaviors most likely to lead to emissions reductions – behaviors at least partially determined by some of the observations and recommendations in this report.
- Policy Development
    - Develop a net zero emissions infrastructure policy for new construction.
    - Create a vehicle purchasing policy to require that at a vehicle's purchase, the purchaser must evaluate the availability of hybrid, electric and/or lower carbon emitting versions. If a purchaser finds they cannot replace their vehicle with an alternative vehicle, then an exception must be requested and approved.
    - Create a policy/guidance document to determine when travel is necessary or acceptable.
    - Develop a policy that encourages remote work when possible to lower commuter emissions.
    - Create a policy on travel related offsets for consistency.

**Milestone 2: By 2025: Achieve 55% Net GHG Emissions Reduction**

- Renew or replace expiring Hydro PPA. [$1M per year]
- Continue Energy Savings Program projects. [$12M per year]
- Continue phased transition of University-owned vehicles to electric vehicles. [$1.3M per year]
- Begin 10-year project to decarbonize UP District Heating System. [$20M per year]
- Begin 10-year project to decarbonize Commonwealth Campus building heating/cooling systems. [$33M per year]
- Complete Harrisburg Biomass Project. [$3.9M]
- Complete Water Reclamation Facility Fuel Cell Project. [$1.9M]
- Complete installation of solar at CWCs. [$41.8M]
- Provide comprehensive 5-year report on progress made to the President and the Board of Trustees.
- Scope 3
  - Finish refining the data inputs and estimation methods for Scope 3 emissions data currently in inventory.
  - Finish establishing processes and procedures to capture additional Scope 3 emissions categories that are not included in the current inventory.
  - Implement guidance and best practices for engaging and prioritizing vendors and partners who are decarbonizing.

**Milestone 3: By 2030: Achieve 70% Net GHG Emissions Reduction**

- Continue Energy Savings Program Projects.
- Continue phased decarbonization of University-owned vehicles.
- Continue decarbonizing Commonwealth Campus building heating and cooling systems.
- Continue decarbonization of UP district heating system
- Initiate a renewable natural gas purchase.
- Provide comprehensive 10-year report on progress made to the President and the Board of Trustees.

**Milestone 4: By 2035: Achieve 100% Net GHG Emissions Reduction**

- Finish transition of Commonwealth Campus building heating and cooling systems to net zero.
- Finish phased decarbonization of University-owned vehicles.
- Finish project to decarbonize UP District Heating System
- Make another large renewable electric generation. purchase headed towards net zero for Scope 2 (purchased electricity).
- Expand internal and partnership GHG drawdown projects to match any remaining emissions.
- Offset remaining Scope 3 (University-sponsored travel and commuters).
- Provide comprehensive 15-year report on progress made to the President and the Board of Trustees.

## GOAL 2: BEYOND 2035: CONTINUE BEYOND 100% GHG EMISSIONS REDUCTION, LEADING THE WAY TO A SAFE, HEALTHY, AND JUST FUTURE

- Deploy technologies to reduce/eliminate remaining Scope 3 emissions sources.
- Continue GHG drawdown projects as research and innovation testbeds.
- Develop new net zero sources of energy and energy storage technologies.
- Increase community education and training on the sustainable energy transition through extension programs and partnerships.
- Final plan accomplishment report to the President, Board of Trustees, and the public.

# Value to Penn State

Penn State's visionary commitment to facilitate innovation, inclusion, sustainability, and positive and enduring achievement uniquely positions us to lead climate actions and build a more just and sustainable future. We are one of the largest research institutions in the U.S. We reside in a state that combines outstanding agricultural productivity, energy resources, and industrial infrastructure, with a track record of energy innovation that includes the first demonstrated commercial oil and nuclear power. Our strength and breadth in research, innovation, and partnerships in climate, energy, and agriculture is nearly unmatched.

Most of the changes we would need to make to decarbonize also bring multiple additional benefits: innovative research, a boost in reputation, rich education, increased health, community employment, operational savings, effective partnerships, and more beautiful campuses.

## BENEFITS OF BOLD CLIMATE ACTION TO PENN STATE

***It is in our mission.*** The Pennsylvania State University is the land-grant university of the Commonwealth of Pennsylvania with a global mission committed to research, teaching, community engagement, service, and operational excellence in all areas. Specifically, Penn State is already leading in the sustainability-related fields of low-carbon and renewable energy, carbon capture and sequestration, carbon cycle management, transportation, buildings and infrastructure, materials, food and agriculture, climate-related natural and social sciences, business, policy, law, the arts, humanities, and ethics with participation on local, state, national, and international climate-related research, teaching, and solution organizations. The University's legitimacy and enrollment reputation are tied to this mission.

***Carbon management is part of our Strategic Plan.*** Penn State is committed to empowering resilience to help individuals, our University community, and society to respond effectively to adversity and, even more impactfully, to "bounce forward," creating new solutions in response to complex challenges of the 21st Century including anthropogenic climate change.[37] In addition, we must lead with innovative and aggressive programs institutionally to reduce our impact on the environment by waste elimination and fostering resilient, equitable, thriving communities in Pennsylvania and around the globe.[38]

***We must be carbon competitive against peers.*** As previously stated, a growing number of peer organizations have committed to GHG reduction targets within the past few years. If Penn State does not act decisively now, we risk becoming less competitive for students with these competitors.

***We could reduce the impact of a carbon tax.*** Governor Wolf has been taking more action against climate change; this could entail joining the Regional Greenhouse Gas Initiative's (RGGI) cap and trade program or a possible carbon tax. If Penn State moves to carbon neutrality it can avoid these future costs and save money in the long term. Based on our current GHG inventory of 400,000 MTCO2e, possible carbon tax scenarios between $10 and $70 per ton would amount to $4 million to $28 million per year.

## BENEFITS TO PENNSYLVANIA

Reducing emissions prevents and reduces climate damage. The state of Pennsylvania (population of 13 million, 2020 GDP of $694 million) contributes approximately 1% of global GHG emissions,[39] which, according to the Commonwealth's Third Pennsylvania Climate Impacts Assessment,[40] negatively

[37] The Pennsylvania State University's Strategic Plan for 2016-2025 (https://strategicplan.psu.edu/plan/executive-summary/)
[38] See https://strategicplan.psu.edu/plan/foundations/ensuring-a-sustainable-future/
[39] Clean Air Council Climate Change Policy (https://cleanair.org/climate-change-policy/)
[40] Pennsylvania Climate Impacts Assessment Update (https://www.pennfuture.org/Files/Admin/Pennsylvania-Climate-Impacts-Assessment-Update—2700-BK-DEP4494.compressed.pdf)

affects agriculture, energy, human health, infrastructure, recreation, water quality, forests, and other ecosystems in Pennsylvania, and human health and ecological systems around the world.

The Constitution of the Commonwealth of Pennsylvania, Article 1, Section 27 guarantees that,

*"The people have a right to clean air, pure water, and to the preservation of natural, scenic, historic, and esthetic values of the environment. Pennsylvania's public natural resources are the common property of all the people, including generations yet to come. As trustees of these resources, the Commonwealth shall conserve and maintain them for the benefit of all the people; including generations yet to come."*[41]

As a land-grant university, Penn State has certain obligations to the Commonwealth (i.e., education, jobs, environment) with known direct 7-fold financial benefits for every dollar invested in Penn State. Thus, our leadership and actions in the emissions reduction sector stand to benefit large swaths of the Commonwealth. Pennsylvania boasts a proud heritage of energy innovation and production and seeks to be forward-looking and to continue to innovate in the changing energy landscape, another sector in which the University has and can play a major role.

## BENEFITS TO THE WORLD

Reducing emissions prevents and reduces climate damage, a topic described earlier in this report. In addition, wealth inequality among people, and nations highlights the need for climate justice; the disproportionate impact of climate related events falls on poorer people, communities, and countries. Countries and organizations committed to social justice as embodied in the U.N. Agenda 2030 and global sustainable development goals can fulfill their mandates through climate action.

Any delay in reducing GHG emissions makes the Paris Agreement's warming limit goals much more difficult and irreversible, if not impossible to achieve, and more expensive as existing GHG emissions levels are rapidly reducing the shrinking carbon budgets that must constrain total global GHG emissions to achieve said goals. Recent studies suggest that the rate of global warming during the next 25 years could be double what it was in the previous 50 years.[42]

Both the magnitude and speed needed to achieve reductions necessary to prevent dangerous human-induced warming urgently requires colleges and universities, all levels of government, the private sector, and civil society to rapidly develop strategies to achieve the Paris Agreement's warming limit goals.

## BUILDING ON THE MOMENTUM FROM STUDENTS, FACULTY, RESEARCH, AND OPERATIONS

Many climate initiatives have been occurring at Penn State by both students and faculty. Student organizations like the Penn State Climate Action Petition Coalition, Eco Action, UP Undergraduate Association (UPUA), and the Student Sustainability Advisory Council (SSAC) are actively calling on the University to do its part in mitigating the effects of climate change. Students want climate action: the Climate Action petition received over 2,100 signatures calling Penn State to rapidly move to net zero emissions, and a survey of more than 1,500 Penn State students indicated that the majority want more climate action from the University (Figure 7).[43] Then students held countless climate strikes hosted by Eco Action. Also, nearly as many people voted in favor of Penn State divesting from fossil fuels in the last UPUA election as voted for the UPUA presidential candidate. Students have also been creating specific recommendations for the University to move towards carbon neutrality.

[41] See page 2 of https://blogs.law.widener.edu/envirolawcenter/files/2010/03/PA_Citizens_Guide_to_Art_I_Sect_27.pdf

[42] James Hansen, et al., "Assessing "dangerous climate change": Required reduction of carbon emissions to protect young people, future generations and nature." PLoS ONE (2013), 8. https://doi.org/10.1371/journal.pone.0081648

[43] http://awakenstate.org/2020/01/30/what-do-psu-students-think-of-climate-change/

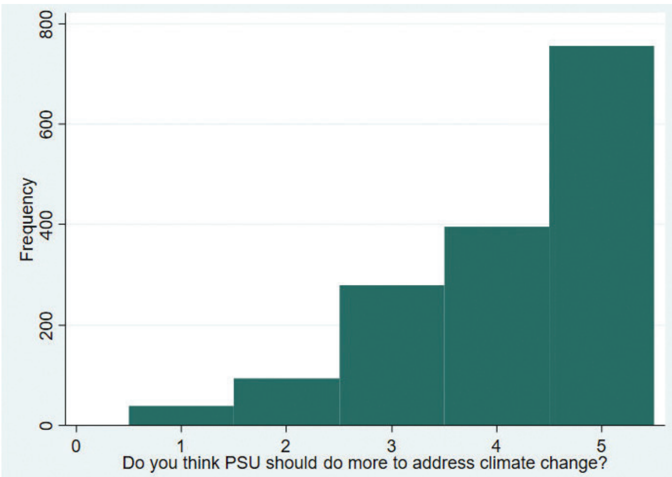


*Figure 7: Awaken State Survey of 1584 students.*[43]

The SSAC carbon neutrality group has worked on improving building efficiency standards, a community solar project, and increasing public transportation. The Council of Sustainable Leaders, a student affiliate organization of Penn State's Sustainability Institute (SI), organized climate speakers and discussions through 2019 and 2020.

On February 1, 2020, the Council of Commonwealth Student Governments (CCSG) created a Standing Sustainability Committee (CR 19-20.16) and in March 2020 hosted their first sustainability summit bringing together 120 student government representatives from 19 Commonwealth Campuses. Then on October 9th, CCSG passed a Climate Resolution in support of the Penn State Climate Action petition. This resolution was co-sponsored by student representatives from Behrend, Brandywine, Greater Allegheny, Abington, Lehigh Valley and Harrisburg campuses. Student governments from Abington, Brandywine, Greater Allegheny and Scranton campuses also put out statements demanding the administration take more aggressive action on climate change. These are just a few of the student initiatives that are in progress to help the students have a sustainable planet for themselves and future generations.

Faculty have been equally concerned about climate action. The Faculty Senate Committee on University Planning passed a Resolution in April 2020 recommending a task force on carbon reduction.[44] The Full Senate also passed the Climate Action Resolution on April 28, 2020, calling on the University's Senior Leadership to develop a University-wide Climate Action and Adaptation Plan. It also called for significantly increasing investment in academic, co-curricular, outreach, and research initiatives focused on climate science, solutions, and management. It suggested that the University engage peer institutions, government, the private sector, and civil society to raise awareness and identify courses of action to reduce the impacts of and embrace the opportunities created by anthropogenic climate change.

Penn State faculty started Climate Crossover, a teaching initiative to incorporate climate into classrooms, and build an interdisciplinary community of instructors to raise awareness of the intersections between climate and their work.

The pending Climate Consortium Initiative, to be hosted by the Institutes of Energy and the Environment in the Office of Senior Vice President of Research aims to coordinate and support centers, institutes, and initiatives related to climate science, risk, and solutions to accelerate research innovation and foster societal impact. Through University community engagement, future outcomes of the Consortium were recognized as: (1) Penn State will have cemented a set of priority partnerships in Commonwealth communities and beyond, focused on carbon mitigation, energy transition, adaptation and resilience, serving as an

[44] See Appendix C: Faculty Senate Climate Action Resolution from the PSU University Faculty Senate
See also Appendix H: Climate Action Task Force Recommendation from the PSU Senate Committee On University Planning

exemplar to other land-grant institutions; (2) Penn State will have transformed "who" is doing climate research, actively promoting and elevating Black, Indigenous, People of Color (BIPOC communities and prioritizing anti-racism, diversity, equity, and inclusion in all climate activities; (3 Penn State will be a leading scientific and cultural voice in informing public policy and community empowerment around climate change solutions; (4 Penn State will pioneer innovative partnerships and financial models, and secure external funding in support of net carbon negative emissions in our operations, research, education and outreach and inspire carbon solutions in partner communities; and, (5 Penn State will be recognized as an international powerhouse of climate research.

The rapid rate of reduction that is necessary requires a deep research and development investment in hard-to-decarbonize sectors such as industry and aviation. Penn State is poised to provide the research, technological innovation, and industry partnerships to lead this transition. In addition, our interdisciplinary research breadth and depth is top in the nation, positioning us to leverage increasing federal investment in climate research. Our capital investment in operations will be concomitant with establishing our research leadership in climate research, scholarship and creative accomplishments, pushing beyond our $1 billion portfolio in research expenditures.

## THE BUSINESS CASE FOR CLIMATE ACTION: WHY BUSINESSES ARE DOING IT, AND PENN STATE SHOULD TOO.

### *Business Resilience*

Businesses and industry have noted that weather disasters like forest fires, intense storms, floods and droughts are becoming more frequent, imposing real costs on companies and communities. They are acting to build resilience and ensure continuity of business, and to protect their facilities and operations, supply chains, and access to water and electric power. Nearly all companies in the Fortune 500, and Standard & Poor's Global 100 Index have identified physical risks of climate change, and they regularly plan for and report climate risks. Penn State would be well served by building resilience as a means of maintaining operational continuity and reducing the costs of business disruption.

### *Low-Carbon Innovation*

Companies understand the need for transition to a low-carbon economy. They are investing in renewable energy, setting and meeting carbon emissions targets, incorporating a price on carbon into their business plans, and greening their supply chains. Most of the Fortune 500 companies have set targets to reduce GHG emissions, improve energy efficiency, and/or increase the use of renewables. More than 80% of S&P 500 companies are measuring and managing their GHG emissions. It is becoming common practice in companies to set GHG emission reduction targets in line with climate science. Business groups such as the World Business Council for Sustainable Development and the World Economic Forum are encouraging transformation to 100% renewable energy and setting net-zero targets. The Glasgow Financial Alliance for Net Zero (GFANZ),[45] that represent 450 financial firms responsible for over $130 trillion in assets, announced at the 2021 U.N. Climate Change Conference (COP26) in Glasgow, Scotland, in November 2021 that they are

[45] https://www.gfanzero.com/about/

committed to decarbonization of the economy across 45 countries. In this transformation to low-carbon economies, innovation is a source of competitive advantage and creates new jobs. Business strategies around climate change create opportunities for companies to develop technologies, products, and services that mitigate climate change, and help customers adapt to the physical changes already underway. Advanced energy is a $238 billion industry in the U.S. and $1.6 trillion worldwide.[46] Revenue from advanced energy increased 11% in 2018, and the industry supports more than 3.5 million jobs across the nation. Globally, revenue from building energy efficiency products and services grew 9% in 2018, to a total of $298.5 billion. A Lazard energy analysis shows that in many cases it is more expensive to continue to use fossil fuels than it is to replace them with renewables.[47]

UCLA's Luskin Center for Innovation reported that by 2019, 33% of Americans will reside in a city or state committed to achieving 100% clean electricity. 67% of customer accounts are with utilities that have carbon emissions reduction goals. Despite the COVID-19 pandemic, renewable energy growth continued in 2020, accounting for nearly 90% of 'new' global power capacity. Penn State with its considerable research capabilities is well positioned to innovate in low-carbon economy and renewable energy sectors.

### *Risk Reducing Policy Stabilization*

Penn State can reduce its risks of operation by leading in carbon reduction ahead of global policy changes. Global and national climate policies are evolving because of the Paris Climate Accord and U.N. Agenda 2030, and emerging scientific consensus. In 2020, 47 major U.S. companies urged the Biden Administration and Congress to enact fair, durable, and bipartisan climate solutions. Effective climate policies reduce uncertainty and risks for businesses, for short- and long-term planning and investments and help them better anticipate regulatory risks and economic opportunities. A patchwork of state and regional policies, on the other hand, ends up being costlier for companies to manage. Penn State could work with companies and government at state and city levels on climate and emissions initiatives. These efforts will contribute to greater resilience, community upgrades, and stronger emergency planning.

### *Stronger Business Efforts*

Penn State has a considerable investment portfolio of its endowment fund that is subject to climate pressures in the investment sector. Investors and other stakeholders are motivating companies to take climate action. Shareholders have passed resolutions calling on companies to measure and report their carbon footprints and to demonstrate that climate-related risks and opportunities are identified, assessed, and adequately managed. A growing number of mutual funds, which manage many Americans' retirement investments, are voting in favor of climate change-related shareholder resolutions.

An industry-led task force in July 2017 recommended ways companies across multiple sectors can inform their lenders, investors, insurance underwriters, and other stakeholders about climate risks—and opportunities—for their businesses. More than 1,500 organizations, which represent a $12.6 trillion market capitalization and $150 trillion in assets, support these recommendations. State financial regulators as well as those in countries around the world are also encouraging companies to report climate change risks in their financial filings. Penn State should recognize these calls for and emerging trends in sustainable investing and apply them to our own investments.

[46] https://info.aee.net/hubfs/Market%20Report%202019/AEN%202019%202-pager.pdf

[47] https://www.lazard.com/media/451881/lazards-levelized-cost-of-energy-version-150-vf.pdf

# Emissions Reduction and Mitigation Strategies

## Thermal

### THERMAL ENERGY SYSTEMS

*Image 1: West Campus Steam Plant*

The single largest component of Penn State's carbon emissions footprint has been the UP-campus steam system. This system delivers steam to the major campus buildings through a network of underground pipes, with heat exchangers or radiators in the individual buildings to transfer the thermal energy in the steam to heat the building air with condensate recirculated back to the steam plant. The strategy of a central steam plant serving many individual buildings is called **district heating**. Although district heating is used at university campuses, government complexes, industrial parks, and even a few city neighborhoods in various locations in the U.S., district heating is far more common in Europe especially in northern regions with cold winters.

For decades, Penn State has produced steam by burning fossil fuels, initially with coal-fired boilers and more recently with natural gas. In addition to converting water to steam, the natural gas turbines on East and West Campus now also power electricity generators that capture more of the combustion energy, using an energy-efficient process called cogeneration. The electricity produced on campus through cogeneration supplied 25% of UP's electricity demand during 2020. It is estimated that the carbon emissions associated with the cogeneration facility are 96,000 MTCO2e during 2020 which is 34% of the total 282,482 tons emitted at UP.

Currently at Commonwealth Campuses, the typical heat source is fossil natural gas purchased from local utilities for individual buildings. In addition to being a viable substitute for fossil natural gas use at individual buildings, Renewable Natural Gas (RNG) can be a low- or negative-carbon option for district heating depending on the source of RNG. This section of the report will also review heat pumps, a very efficient low-carbon option for individual buildings that have their own heating systems. There may also be options to develop efficient, low-carbon district heating systems at some Commonwealth Campuses in the future.

### SYSTEM LEVEL CONSIDERATIONS

#### *University Park*

Because the campus steam system is such an integral part of Penn State's energy program, OPP has evaluated alternatives over the years, which this Task Force was able to leverage for the present analysis. The primary objective of the UP-steam system is simple: it must be capable of meeting the campus heating demand. However, projecting the future demand is challenging, as it will vary depending on both individual building and distribution system considerations. And some of these demand and distribution system decisions will interact with potentially constraining decisions about low-carbon thermal sources to supply that demand. *At the simplest level, the choices are to eliminate the steam system entirely and replace it with an electric heating system for each individual building or commit to maintaining the district heating network and install a source of thermal heat with dramatically reduced carbon emissions*.

Converting all the campus buildings to electric heat would require a massive investment to renovate all the buildings, as they were designed for an external supply of district heat. Switching from district heat to individual building heat would also cause a substantial increase in electricity demand. This option would require decades to accomplish and would disrupt campus infrastructure including classrooms, laboratories, offices, and residence halls during the upgrades. Given the economies of scale and proven efficiency of district heating, and the diverse portfolio of practical and scalable low-carbon thermal sources available, there are strong reasons to continue maintaining a district heating system at UP. However, for new buildings and those undergoing deep renovation, it may make sense to switch to electric heat on a case-by-case basis.

*The Task Force did consider one other variation related to maintaining the district network, which is to convert the steam system to a hot water system operated at a lower temperature and pressure that requires different gauge pipes*. This conversion would also cause years of disruption, including to vehicles and foot traffic as roads and paths are closed for pipeline replacement. However, this option does offer the benefits of reducing the thermal load and thus the overall cost of producing thermal heat, as well as long-term maintenance costs. Converting from steam to hot water would also expand the range of possible alternative sources of thermal heat for the district heating network.

For buildings that are being built or renovated and are projected to remain part of our district heating network, future flexibility would be enhanced by installing heat exchangers and terminal equipment that are compatible with medium temperature hot water as well as steam.

Assuming the district heating network is maintained, reducing the temperature of the circulating steam to hot water at a lower temperature offers multiple advantages. A new hot water district heating system would be better insulated, which in combination with the lower operating temperature would reduce heat losses in the distribution system. The new system would have much lower maintenance costs, both initially because it would be new but also in the longer term because it would operate at lower pressure. While switching the steam system to a hot water system would be a major financial undertaking, it is an important investment to consider. The efficiencies, reduced thermal demand, and reduced maintenance expenses translate to significant cost savings overall.

Although it is only a partial solution, by far the most cost-effective way to reduce the district heating systems' thermal demand is *by investing in aggressive energy efficiency improvements during new construction and deep building renovation*. Penn State's ESP program already funds building energy efficiency, and the ESP has been shown to reduce energy demand. While investing heavily in energy efficiency during renovation is the best way to reduce both heating costs and carbon emissions, it becomes much more expensive if done separately from other building renovations. The UP campus includes hundreds of buildings, and a normal schedule for building renovation will take several decades and billions of dollars to complete. Accelerating this schedule for deep building renovation should be carefully evaluated, but renovating too quickly would be costly as well as wasteful, especially for building components that still have a substantial useful life. However, over the coming decades aligning these changes with necessary work within the Capital Plan budget could have substantial economic and climate-related co-benefits.

These system-level considerations, with a logic for major investments in distribution and demand that will require years and even decades of sustained effort, calls for a multi-pronged and staged approach. In response, the Task Force evaluated short to medium-term as well as long-term strategies to address Penn State's thermal heating needs. These short-term strategies start with a strong recommendation to continue the ESP funded at $12 million per year to achieve a 25% reduction from current energy use. The building ESP offers real savings, with each individual project paid off by its energy savings in ten to fifteen years. Switching the distribution system to hot water instead of steam also appears to offer long-term financial advantages, although the payback from these investments will not be as rapid.

### *Commonwealth Campuses*

While the primary focus of the Task Force thermal analysis has been to reduce carbon emissions from the UP-steam system, it is important to note that several of the Commonwealth Campuses may also be good candidates for a district heating system or alternative thermal strategy. Electrification with heat pumps for individual buildings is one option, but shallow-well geothermal or smaller biomass boilers may also make sense at some sites. Our modeling of alternative thermal options includes cost and carbon reduction estimates for shallow-well geothermal across the Commonwealth Campus system, and for a biomass boiler district heating system for the Harrisburg campus.

A clear roadmap for determining the best combination of strategies to reduce the overall thermal load is important for sizing any thermal system, whether at UP or a Commonwealth Campus. Some sizing complexities include the seasonal and diurnal fluctuation in heating demand. While some thermal sources can be readily ramped up and down to meet demand, others run most efficiently under a constant load. For these reasons it is important to consider the complementarities among different alternative thermal sources.

### *Low (to no, or even negative) Carbon District Heating System Thermal Sources*

The Task Force evaluated a wide range of alternative low-carbon strategies that could produce either steam or hot water as thermal energy and could be sized at scales relevant to Penn State UP and some Commonwealth Campuses. Some of these alternatives are easily coupled with electricity cogeneration (e.g., micro-nuclear or biomass), while other thermal sources could supply the thermal load on campus but would not include electricity cogeneration (e.g., geothermal or solar thermal). Geothermal and solar thermal systems can provide a thermal source for heat pumps. At the expected temperatures, these systems are most compatible with hot water district heat, although the water temperature could be boosted with electric boilers to continue to operate with steam.

In the near term, **Renewable Natural Gas** is an alternative that can provide rapid and significant reductions in our current University carbon footprint. RNG is the methane released during anaerobic decomposition (Figure 11) of organic material.[48] Currently available from landfills, wastewater treatment plants, and farm-based anaerobic digesters, many of the RNG suppliers are not only producing a zero-carbon or negative-carbon substitute for fossil natural gas, but also eliminating the methane emissions from conventional waste management. Although Penn State currently operates two anaerobic digesters, one at the

[48] https://www.epa.gov/agstar/how-does-anaerobic-digestion-work

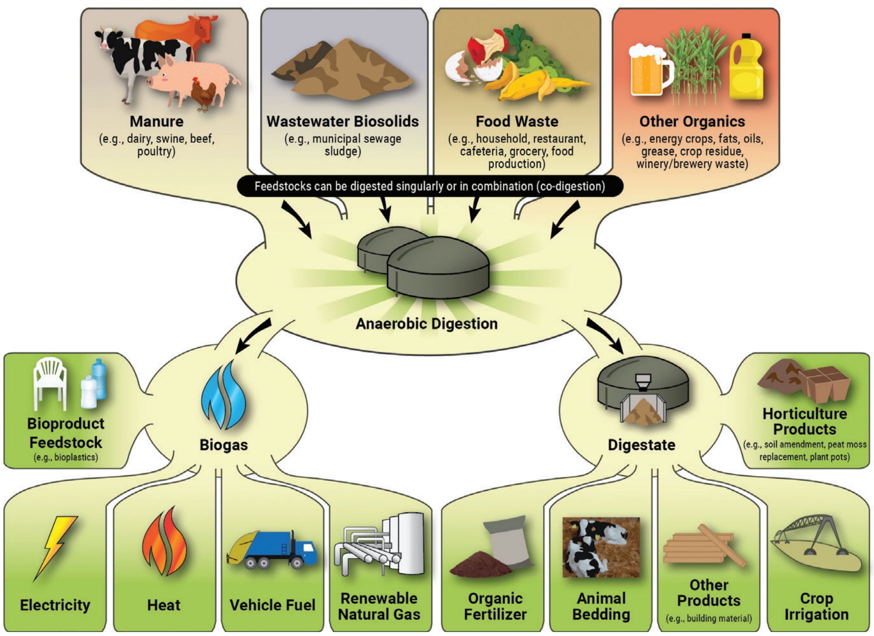


*Figure 11: Diagram showing the process of Anaerobic digestion.*[48]

wastewater recovery facility and a new one at the dairy barns, the quantities of gas produced at these existing facilities is far from sufficient to meet Penn State's demand. Instead, RNG would be purchased from off-site commercial producers, delivered through the existing pipeline network, and because it is 100% compatible with our existing steam power plants there would be no construction disruptions on campus.

RNG is already commercially available, although as to minimize costs and maximize offsets, including assuring additionality, it would be best if Penn State contracts required that new RNG facilities be built. Methane has extremely high global warming potential, more than 80 times that of $CO_2$ over the next twenty years, and although methane decays rapidly in the atmosphere, it is still more than 30 times as powerful as $CO_2$ over the next hundred years. In Pennsylvania, a few dozen livestock farms have anaerobic digesters, but most farms are storing their manure in lagoons, tanks, and manure piles where the methane is uncontained and currently being released to the atmosphere. By providing a purchase contract that helps finance new anaerobic digesters to capture methane, Penn State could earn an offset for eliminating the previous methane emissions from that source. As an example, if the RNG were sourced from new anaerobic digesters at dairy farms in Pennsylvania, purchasing RNG for just 20% of our total natural gas demand could offset the emissions from the remaining 80% fossil natural gas. Contracting for RNG with the required offsets would allow Penn State to meet a net-zero goal for the UP-thermal system in just a few years. In the longer term, RNG may make sense as a flexible supplement for peak thermal loads, as it would complement other thermal strategies that work best as baseload.[49]

For the mid- to long-term, some of the new, **advanced micro-nuclear** reactor technologies look especially attractive. Several companies are packaging recent developments in advanced nuclear reactor designs at a micro-reactor scale (e.g., small enough to fit in a shipping container). Some companies have systems that they anticipate will be available for sale as soon as 2026, although construction and installation may take longer. Other companies, including the least cost option analyzed are farther away from commercialization. These smaller reactors could provide both heat (at steam temperatures if needed) and electricity, and reduce the budget uncertainties of variable fuel prices. Contracts would include disposal (and potentially processing, as opposed to storage) of spent fuel. The largest challenges to adoption

[49] See Appendix: I.13: Renewable Natural Gas

remain the initial capital costs (therefore working best for continuous base-load operation), the maturity of the technology, and public perception regarding the presence of a commercial-grade reactor on campus.[50]

Another promising alternative is **deep well geothermal**. Deep well geothermal takes advantage of the constant heat found a mile or so below the ground surface to heat water that is then brought to the surface for use. For local geology near the UP campus, a single well geothermal system may prove more practical and cost effective than the more common dual-well system such as what Cornell University recently selected. A single well system circulates water in one well by centering a smaller thermally insulated pipe inside a larger outer pipe, creating an inner tube and outer annulus. The upfront capital costs are high, though with minimal environmental impact. This system would require conversion of steam to a hot water distribution system or could be used to pre-heat water to increase efficiency of conventional or electric boiler systems for steam distribution. The Ohio State University has already implemented a geothermal well network that currently provides 100% of cooling and 90% of heating for five high-rise dormitories on campus, and the University of Michigan consultancy report recommends geothermal exchange as the most effective strategy (see Appendix D: Benchmarking).[51]

**Solar thermal** is a technology that has only recently been scaled-up to serve district heating needs but is now proven in countries like Denmark with a cold climate and less sunshine than Pennsylvania.[52] These systems often use flat plate collectors to transfer heat from solar radiation to internal collector fluid loops that in our climate would contain an antifreeze mixture, and then transfer that heat to water in a secondary loop. The panels can be installed on roof-tops or in open land, and while an UP-scale installation would cover many acres, solar thermal at smaller Commonwealth Campuses would cover the area of a parking lot. Large solar thermal systems in cooler climates also need seasonal storage, either insulated tanks or ponds at the surface, or subsurface aquifer or borehole systems. This system can either be used for stand-alone hot water distribution systems or used to pre-heat water for steam distribution as previously described.

Solar thermal and geothermal (shallow and deep well) technologies may produce water at temperatures that are too low for district heating. Heat pumps can be used to upgrade that thermal energy for district heating for smaller campuses or for individual buildings. Heat pumps use electricity to transfer heat that already exists in the natural environment. The three main types are air-source, water-source, and near-surface geothermal heat pumps. Coupled to a stable thermal energy source like geothermal, heat pumps can use renewable electricity to upgrade that thermal energy to hot water. Heat pumps are an energy efficient and low-carbon alternative to furnaces and air conditioners that can also be implemented at any buildings not connected to a district heating system.

**Biomass** is another low-carbon alternative, with the potential to be carbon negative depending on the biomass source, which in our region would be wood chips from thinning, logging, and salvage operations. Biomass power plants could be built at the scale of a Commonwealth Campus as well as UP and could produce either steam or hot water. The major challenges associated with biomass power include fuel procurement and logistics, as large volumes would need to be brought to campuses by truck, and particulate emissions from combustion, which even at regulated emission levels, would remain a human health hazard and will raise community concerns.[53]

[50] See Appendix: I.12: Micro-Nuclear Reactors
[51] See Appendix I.4: Deep Earth Source Geothermal Heating
[52] Furbo, Dragsted 2018 https://doi.org/10.1016/j.solener.2017.10.067
[53] See Appendix I.1: Biomass Boilers

**Hydrogen** is extremely attractive as a fuel because the on-site combustion product is simply water. However, depending on the source of the hydrogen there may be substantial carbon emissions off-site. Hydrogen made from coal or natural gas can be very carbon intensive, whereas hydrogen made from water using electrolysis powered by renewable electricity can be carbon free. The Task Force focused our analysis on the latter: **Green Hydrogen**, where hydrogen is produced using electrolysis powered by renewable energy sources to produce a clean and sustainable fuel. A campus scaled system would then use that fuel in specialized high-temperature hydrogen boilers. This technology is capital intensive, energy intensive and water intensive but is clean, quiet and does not require any conversion of the existing steam system.[54]

The Task Force also considered on-site **Carbon Capture and Storage (CCS)**, which could be applied to any fossil or bio-based fuel combustion system. CCS would be necessary to achieve significant carbon emission reductions using fossil natural gas and could allow it to become near-carbon neutral. Capturing $CO_2$ in the exhaust from burning RNG in existing gas turbines or solid biomass boilers would result in carbon-negative energy, allowing the University to offset other challenging emissions such as those from commuter transportation or other Scope 3 sources. However, on a cost per ton of $CO_2$ removed basis, CCS is currently expensive for smaller on-site combustion sources. These costs are primarily driven by capture technology, and there are several promising innovative technologies under development. There is also uncertainty about whether the geology underlying UP is suitable for carbon sequestration.[55] Research and innovation could reduce these uncertainties and will drive these costs down in time, and there are several large commercial projects now underway in the U.S.

## THERMAL SYSTEM RECOMMENDATIONS

- Given the economies of scale and proven efficiency of district heating, and the diverse portfolio of practical and scalable low-carbon thermal sources available, there are strong reasons to continue maintaining a district heating system at UP. However, for new buildings and those undergoing deep renovation that are not connected to the district heating system, it may make sense to switch to electric heat on a case-by-case basis.
- Maintain ESP funding at $12 million per year over the next 10 years to target a 25% reduction in energy use and include avoidable cost of carbon offsets in the justification.
- Initiate Requests for Information, Qualifications, and then Proposals for Renewable Natural Gas sufficient to offset emissions from the current fossil natural gas-powered steam system.
- Commission a more detailed analysis of the costs and savings as well as timelines and constraints of switching from steam to hot water for the campus distribution system.
- Begin a detailed feasibility/planning/preliminary design and costing study by an outside consultant to decarbonize the UP Heat and Power Infrastructure. Technologies to include in the study: biomass, shallow geothermal heat exchange with heat pumps, deep well geothermal, micro-nuclear reactors, conversion of steam distribution system to medium temperature hot water, and the impact of additional ESP. [$2M]
- Consider sizing one or more of these thermal sources to provide baseload during the heating season, with RNG powered turbines continuing to provide peaking load.
- For individual buildings and campuses not connected to the district heat system, consider heat pumps powered by renewable electricity to meet existing and future thermal demand.
- Continue to evaluate Hydrogen production and Carbon Capture and Storage for potential future integration into the thermal system.

[54] See Appendix I.10: Green Hydrogen
[55] See Appendix I.3: Carbon Capture and Sequestration

# Electric

## INTRODUCTION

Electricity is a highly valued energy source and is the driver of many of the everyday activities at Penn State, from the lights that shine on the Nittany Lion Shrine to the freezers at the Berkey Creamery to classrooms across the Commonwealth, to lab equipment in our world-renowned research facilities. Much of this electricity, whether generated on campus or purchased from the grid, releases carbon and other GHG emissions, which is the second largest component of Penn State's GHG inventory. Our emissions associated with electricity use are represented in all three GHG scopes, though the majority lies within Scope 2 which represents purchased electricity. Scope 1 emissions are related to on-campus electricity generation that utilizes carbon-based fuels. And Scope 3 emissions are related to the transmission and distribution losses associated with purchased electricity.

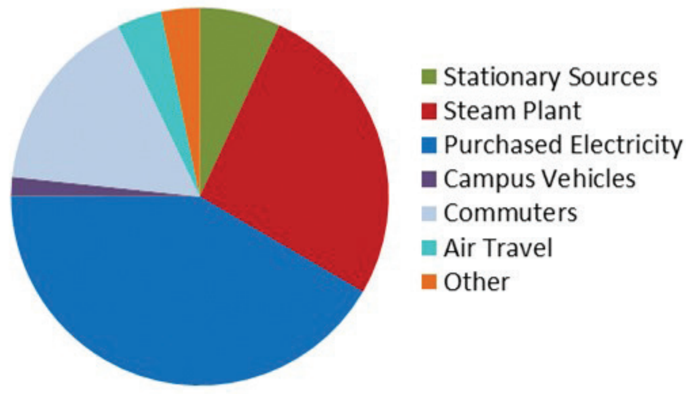


*Figure 12: Penn State's Emissions Breakdown by Sector for FY 19/20*

Penn State has made significant progress in lowering the carbon emissions associated with electricity use since 2005, by 1) lowering consumption through ESP investments, 2) additional on-site cogeneration, and 3) purchased electricity from carbon-free sources such as solar and hydro. Through such activities, Penn State exceeded its 2020 carbon reduction goal to reduce emissions by 35% from 2005 levels – and reached a reduction of 40% or 270,000 MTCO2e.

## SOURCES OF SUPPLY

Most of the University's electricity supply is purchased from the grid where the specific source of the generation is unknown, though generation in Pennsylvania typically uses a mix of resources including coal, natural gas, nuclear, hydro and other renewables. Seventeen percent of Penn State's electricity use is met through on-site cogeneration at UP as a by-product of producing steam at our two steam plants. This process simultaneously produces electricity and heat for buildings at a carbon intensity that is lower than an equivalent combination of grid-based electricity and natural gas-fired boilers for heat. This process increases Scope 1 emissions while lowering Scope 2 emissions, at the current carbon intensity of the grid.

Penn State purchases some of its electricity through Power Purchase Agreements that are specific to certain renewable energy generators. The PPAs currently in effect serving our campuses are:

- A solar PPA with Lightsource BP provides 25% of Penn State's state-wide electricity use. Lightsource BP owns and operates a large 3-site Solar Photovoltaic project in Franklin County, Pennsylvania that is contracted to Penn State, the largest solar project in Pennsylvania to date. Penn State purchases all of the output from this 500-acre project which consists of over 170,000 panels, is rated at 70 MWdc, provides 53.5 MWac to the grid, and generates approximately 100,000 MWh per year.

*Image 2: One of three solar farms that make up the 70-megawatt solar array in Franklin County, PA. Credit: Mark Chambers/Lightsource bp*

- A hydro PPA with Mahoning Creek Hydroelectric Company, provides 9% of Penn State's state-wide electricity use. Mahoning Creek owns and operates a site in western Pennsylvania that is rated at 6 MW and was added to an existing U.S. Army Corps of Engineers dam as a result of the contract with Penn State.
- Another solar PPA with the Alternative Energy Development Group (AEDG) provides 1% of Penn State's state-wide electricity use. AEDG owns and operates a 2 MWdc Solar Photovoltaic project located on a leased location at the UP campus.
- These solar PPAs are additionally being used as living labs for educational field trips, pollinator research, and energy outreach.

## CARBON-FREE ELECTRIC SUPPLY

The U.S. Department of Energy (DOE) is working toward a carbon-free electricity grid by 2035, an exciting and challenging goal, but it is subject to changes in leadership and public policy at the national level. As a result of public policy and incentives, carbon emissions from electric generators have reduced significantly over the past decade. For example, the DOE Emissions & Generation Resource Integrated Database (eGRID) published emission factors show emission factors in Western Pennsylvania dropping by 23% and in Eastern Pennsylvania by 16% over the past 5 years.

While lower eGRID emission factors reduce Penn State's carbon emissions by reducing the number of emissions associated with purchased power, additional reductions can be obtained by expanding our purchases of renewable energy from sources such as solar, wind, and hydro.

*Image 3: Hydro-power dam in Western PA. Credit: U.S. Army Corps of Engineers*

## RENEWABLE PPAS

*Image 4: Student volunteers prepare a solar panel for mounting outside OPP offices.*
*Credit: Penn State. Creative Commons*

Solar PPAs such as the Lightsource BP and AEDG agreement referenced above are the most cost-effective and timely way to convert purchased energy to carbon-free renewables. These Solar PPAs differ in scale and location which drives materially different pricing. Lightsource BP is an off-site utility-scale PPA located on land outside of our campus footprint. As such the generation must be delivered to campus in much the same way as traditional grid purchased electricity. The AEDG PPA is "behind-the-meter" which means it reduces our need to purchase power from the grid (including off-site renewable purchases). An overview of the risks and benefits associated with each PPA type is provided below.

## OFF-SITE UTILITY-SCALE SOLAR PPAS

Off-site utility-scale PPAs have many benefits over traditional grid purchases and behind-the-meter PPAs including:

- The upfront capital is provided by the project owner, which may be a large energy company, bank, or equity fund. This capital may cost more than if it was provided by Penn State; however, certain other benefits can accrue to Penn State if the project is owned by a third-party.
- The federal tax incentives provided by the Investment Tax Credit (ITC) and accelerated depreciation can only be realized by an entity with a large federal tax liability. As a tax-exempt entity, Penn State can only realize these incentives if a third-party owns the solar project.
- All project costs and risks are the responsibility of the project owner which protects Penn State from performance and financial risks such as the risk of lower-than-expected generation, system damage, maintenance costs and land lease obligations.
- Project generated environmental attributes, such as the renewable energy credits (RECs), can be passed to Penn State for retirement as part of our carbon reduction plan. This can increase the PPA price but provides direct access to RECs without having to purchase them separately on the open market at higher prices.
- The pricing structure of a PPA can protect Penn State from market risk over the term of the PPA which is typically 20 to 25 years. With the market price of electricity rising over time, a fixed stable price protects our operating budget against future cost increases.
- Solar generation is largely aligned with the broader grid's peak use hours of the day and provides electricity to our use profile during the highest priced hours. By reducing our need to purchase electricity during high priced hours, a solar PPA can reduce the cost of purchased electricity.

- The economy of scale associated with a large solar project purchased with a PPA is substantial. By utilizing land outside our campus footprint, it is more likely that solar PPA pricing can be equivalent to current market prices and be added to our energy portfolio very quickly.
- The pursuit of a renewable PPA often supports the development of additional generating capacity which supports the preference in our carbon plan for additionality. This style of agreement is however fixed in capacity and the resulting annual production. Balancing the volume of electricity purchased from PPAs with Penn State's consumption needs is challenging and must be deeply considered. Modeling results have shown great differences in the volume of electricity used by the University depending on projects and other transactions. For example, the Energy Savings Program and On-site Solar lower our electricity use profile, while other carbon reduction strategies such as vehicle electrification, building electrification, and shallow well geothermal systems raise electricity use. These carbon reduction strategies can cause an imbalance between our need for purchased electricity and the PPA volumes.
- Large renewable PPAs are often hosted on agricultural land, which engenders mixed reactions from local communities. Solar projects are less visible than wind projects but use far more land. Wind projects can avoid agricultural land by being sited on ridgelines which makes them highly visible to local government constituents. Currently, the development of renewable generation on distressed land such as old coal mines and landfills is more expensive and does not have special incentives to compete with agricultural land.

*Image 5: Solar array. Credit: The Center for Pollinators in Energy at Fresh Energy.*

## ON-SITE BEHIND-THE-METER SOLAR PPAS

Behind-the-meter PPAs also have a place in a prudent and diversified carbon reduction plan. There are several benefits that behind-the-meter PPAs can deliver that off-site utility-scale PPAs cannot:

- By providing generation at the point of use, the cost of transmitting and distributing the generation can be avoided. Pennsylvania net metering rules currently require the local electric utility to purchase all generation at the full retail tariff rate and credit such purchase on their monthly bills. In addition, since the generation is not delivered to the local utility, PJM[56] transmission costs are directly avoided (not credited).
- On-campus solar projects are more visible to students and faculty and are more accessible for education and research.
- All projects meet the preference for additionality as they are new projects reducing grid-based fossil fuel generation.
- Project ownership can be transferred to Penn State at the end of the PPA but may require capital at the end of the agreement or a higher PPA rate. This provides access to the RECs in addition to the physical asset.

[56] PJM is a regional transmission organization (RTO) that coordinates the movement of wholesale electricity in all or parts of 13 states and Washington D.C.

As with the off-site utility-scale PPA, a behind-the-meter PPA has similar risks plus the following additional concerns:

- At a smaller scale, the cost per watt is much higher resulting in a higher PPA rate and fairly equivalent value when compared to the purchase of market-based grid electricity.
- On-site projects sited on the ground occupy land that could be used otherwise now or in the future and the cost of removing the project can be substantial.
- On-site projects sited on a rooftop complicate roof maintenance and replacement and will likely require structural modifications prior to installation. Furthermore, roof penetrations required for some installations can increase the risk of leakage over time.
- Third-party ownership can tap into the tax incentives but introduces development and operational risk on campus property. Additionally, the cost of the project RECs will be factored into the PPA price which may offset the value obtained from tax incentives.

## ON-SITE BEHIND-THE-METER SOLAR DIRECT PURCHASE

A behind-the-meter Solar Direct Purchase is like behind-the-meter PPAs but is directly funded and has several financial differences. These benefits can be delivered with a behind-the-meter Direct Purchase:

- By providing generation at the point of use, the cost of transmitting and distributing the generation can be avoided. Pennsylvania net metering rules currently require the local electric utility to purchase all generation at the full retail tariff rate and credit such purchase on their monthly bills. In addition, since the generation is not delivered to the local utility, PJM transmission costs are directly avoided (not credited).

*Image 6: Students set 255 W solar panels on array outside of OPP.*
*Credit: Penn State. Creative Commons*

- On-campus solar projects are more visible to students and faculty and are more accessible for education and research.
- All projects meet the preference for additionality as they are new projects reducing grid-based fossil fuel generation.
- Direct Purchase provides ownership of the electrical output and the RECs for the life of the project.

As with the off-site utility-scale PPA, a behind-the-meter PPA has similar risks plus the following additional concerns:

- At a smaller scale, the cost per watt is much higher resulting in a higher levelized cost of electricity (LCOE) rate and equivalent value when compared to the purchase of market-based grid electricity.
- Direct Purchase On-site projects require maintenance and operation by Penn State. All loss of generation events such as weather or equipment failures would fall to Penn State.
- On-site projects sited on the ground occupy land that could be used otherwise now or in the future and the cost of removing the project can be substantial.

- On-site projects sited on a rooftop complicate roof maintenance and replacement and will likely require structural modifications prior to installation. Furthermore, roof penetrations required for some installations can increase the risk of leakage over time.
- A project owned by Penn State will eliminate access to the federal ITC and depreciation tax incentives.

*Image 7: Hydro-power dam. Credit: Unknown*

## OFF-SITE UTILITY-SCALE WIND PPAS

Wind generation can have an important role in a balanced portfolio and carbon reduction plan and can deliver the following benefits beyond a solar PPA:

- Wind generation can be averaged in with solar generation to provide a flatter and more stable generation profile that also tends to complement solar by supplying more power at night. The combined generation profile fits better with our electricity use profile and reduces the exposure to risk as described in the first bullet of the risk section in Off-Site Utility-Scale Solar PPAs above.
- Wind generation has largely been priced lower than solar generation due to a lower cost per watt cost for installation coupled with the Production Tax Credit (PTC) it receives.

While wind generation may appear more attractive on a cost/kWh basis, the risks associated with wind PPAs compare quite negatively to a solar option. Wind PPAs come with risks that are more difficult to manage:

- While the price of off-site wind generation can be lower than solar, the generation profile concentrates less during costly peak hours and offsets lower price grid purchases during off-peaks and overnight.
- None of our campuses, except for Behrend, have a wind profile necessary to make on-site wind generation feasible.
- Off-site wind projects face far more public scrutiny due to their visibility and environmental challenges (e.g., bird endangerment).

## OFF-SITE HYDRO PPAS

Similar to the wind generation profile, hydro generation operates at all times of the day yet at an even more predictable and constant hourly profile with some exceptions depending on the season and environmental limitations required for some projects. A hydro PPA has the following benefits:

- Similar to wind generation, hydro can be a complimentary fit with other renewable resources that minimizes hourly mismatches between generation and use.
- Existing hydro generation can be purchased at competitive prices but does not address additionality.

The disadvantages of hydro pose the following risks:

- There are no hydro resources on campus land making it only possible access this renewable resource through an off-site PPA.

- Hydro technology has been commercialized for many years and new projects are difficult to identify making additionality difficult to achieve.
- Hydro resources tend to vary across seasons, peaking in the spring when campus electricity use is lower.
- Environmental concerns far exceed other renewable assets including protection of fish migration and spawning, reservoir levels, drought conditions, and extended winter freezes.

## CONSIDERATIONS

Additional renewable purchases will face more financial and operating considerations than the existing Lightsource BP and AEDG solar PPAs. The current PPAs provide generation that in total does not exceed the use profile during any hour of the day; however, the next PPAs will likely pose challenges matching generation to use. PPA terms typically exceed 20 years and commitments made in the near term must factor in decisions anticipated during the PPA term. There are a number of considerations that will impact the next PPA purchase such as:

- Future impacts on usage from carbon reduction activities that may lower (or increase) the amount of electricity used by campuses including:
    - ESP projects targeting electricity reduction and energy efficiency.
    - The amount of on-site solar generation at UP or Commonwealth Campuses.
    - Conversion of thermal and distribution systems that increase or decrease electric generation capacity.
    - The electrification of building heating systems to eliminate Penn State's use of natural gas will increase electricity use.
    - Changes in campus master plans and anticipated additions to the building stock and conditioned space.
    - Conversion of University-owned vehicles to electric and associated increase in electricity use.
- Given the considerations above, the size of the next PPA will target expected future energy use during the term or need to be structured with adequate volume flexibility to allow for changes to the commitment.
- The potential financial risk associated with the size of the PPA and the hourly mismatches between a renewable purchase and the use profile need to be considered. The mismatch will be settled in traded markets with exposure to price volatility and sectoral trends. One such trend being the anticipated large-scale increase in intermittent renewable generation and the retirement of dispatchable resources.
- The treatment of RECs in any PPA structure will need to be considered:
    - Pennsylvania REC prices have been increasing and may face further upward pressure as legislation designed to motivate a transition to renewables increases. The PPA price may be higher than grid-based electricity purchased at market and the premium will need to be evaluated and minimized.
    - Could non-PA based RECs be substituted and meet our needs providing a lower PPA price?
    - Is Penn State inclined to sell PA-based RECs to generate cashflow for other carbon reduction activities?
- Regulatory and market changes affecting the application and cost of environmental attributes such as RECs and offsets including the potential for a carbon tax or other carbon disincentive.
- The cost and value of bundling battery storage into a renewables project.

## ELECTRIC RECOMMENDATIONS

- Initiate Requests for Information, Requests for Qualifications, and then Requests for Proposals for additional off-site Renewable Electricity Generation purchases.
  - Consider the impact of the following on the size, timing and term of the purchase:
    - Reductions from ESP Program.
    - Additional on-site electricity generation associated with the low-carbon thermal option selected.
    - Additional requirements associated with the electrification of buildings and vehicles.
    - Size of any on-site and behind-the-meter solar or fuel cell projects.
  - Structure the RFP to identify:
    - Optimum blend of wind, hydro and solar.
    - Value associated with batteries.
    - Price premium associated with a project on reclaimed land.
    - Portfolio value of PPA.
  - Standard provisions:
    - Require a bundled energy and REC purchase.
    - Require co-benefits like Franklin County project.
- Initiate Commonwealth Campus On-site Solar Renewable Electricity Generation projects.
  - Convene a Stakeholder group to oversee project development and delivery.
  - Determine preferred delivery method and secure funding.
  - Implement on-site Solar projects at most workable sites up to a total size of 20MWdc.
  - Consider the impact of the following on the size, timing and term of the purchase
    - Reductions from ESP Program.
    - Additional on-site electricity generation or consumption associated with the low-carbon thermal option selected.
    - Additional requirements associated with the electrification of buildings and vehicles.
  - Structure the project to identify:
    - Optimum source of funding, from internal or external sources.
    - Value associated with batteries.
    - Portfolio value of Direct Purchase or PPA.
  - Standard provisions:
    - Require RECs and system ownership to Penn State upon direct purchase or at end of PPA if used.
    - Require co-benefits similar to Franklin County project.
- Evaluate the ability of all campus electricity services to support the electrification of building heating systems and vehicles.
- Maintain ESP funding at $12 million per year over the next 10 years to target a 25% reduction in energy use (some of it electricity) and include avoidable cost of carbon offsets in the justification.

# Transportation

## OVERVIEW

On a national scale, as of 2019, transportation accounted for 29% of the U.S. GHG emissions, making it the largest emissions sector for the country.[57] Over half is attributed to "passenger cars, medium- and heavy-duty trucks, and light-duty trucks, including sport utility vehicles, pickup trucks, and minivans." In the FY 18/19 Penn State GHG emissions inventory, the transportation sector accounted for approximately 23%, with commuter emissions across all campuses by themselves accounting for 16%. At many Commonwealth Campuses, commuting emissions are the largest sector of its inventory. As Penn State's energy sector is decarbonized, the University's travel emissions will increase as a relative percentage in the overall inventory. Thus, reducing transportation-related emissions is an opportunity for Penn State to lead and engage its stakeholders. Since it is also the largest contributor to national emissions, it is an opportunity to have great impact.

The transportation-related emissions accounted for in the current Penn State GHG Inventory are split between Scope 1 and Scope 3. Scope 1 emissions are from vehicles owned by the University and Scope 3 are emissions from vehicles the University does not own but related to University operations. Details about the inventory can be found in Appendix E: Transportation. The Task Force investigated strategies to reduce the GHG emissions associated with University-owned vehicles and commuters, and strategies other universities have used to reduce transportation-related emissions.

## UNIVERSITY-OWNED VEHICLES

The University owns well over 2000 vehicles and other motorized equipment of all different shapes and sizes (from lawn mowers to cranes and sedans to busses). We assessed the feasibility of *converting the University's fleet of vehicles over to electric vehicles (EVs)* by examining what costs and infrastructure upgrades would be required to transition vehicles managed by Transportation Services and the OPP Garage. This analysis included approximately 900 vehicles (sedans, SUVs, pickup trucks, cargo vans, minivans and box trucks). Information was available for electric versions of these vehicle types for estimated battery performance, gas mileage, and purchase prices. Although some rebate and grant funding may be available for purchasing non-fossil fuel based vehicles, these financial incentives were not included in this analysis. The modeling effort is described in detail in the Appendix I.7: Electric Vehicles.

Overall, the switch from internal combustion engine (ICE) vehicles to EVs has many benefits, including eliminating the need to use fossil fuels for our transportation needs. This change reduces maintenance needs (no more oil changes, radiator leaks, fuel pump issues, etc), improves working conditions for those working on and in the vehicles (reducing exposure to fumes and noise), and reduces the impact of the vehicles on the environment (less noise and less air pollution where the vehicles are operated). Electric vehicles also reduce total emissions over their usable lives even when charged from Pennsylvania's current electricity sources, which are primarily fossil fuel-based. But fully decarbonizing our electricity at the same time will lower emissions even more significantly. The risks associated with EVs are the health and environmental impacts of battery materials and manufacturing. The University's research in battery materials, technology and recycling could be an important part of the solution to this uncertainty.

[57] https://www.epa.gov/ghgemissions/sources-greenhouse-gas-emissions

There are other vehicle technologies that are being developed, including biofuel and fuel cell vehicles. These have not taken to the larger market as EVs have, though there are some start-ups working to change that (i.e., Nikola trucks).[58] This should be considered as we look to decarbonize our entire fleet of vehicles. We recommend a consultant be hired to do a decarbonization study for the entire University fleet using this focused analysis as a starting point but expanding it to consider all low/no-emissions vehicle technologies.

*Image 8: PSU's West Deck. Credit: PSU Transportation Services*

Limited information was available on the University-owned aircraft. The committee recommends that the emissions associated with flying the university-owned aircraft be included in the annual GHG inventory.

## COMMUTING

Many Penn State students and almost all faculty and staff reside off campus. Some may live within walking or biking distance of their campuses, but many more reside outside of a reasonable distance to walk or bike to campus. Some students and faculty/staff take public transportation. The commuting sector evaluation used parking pass information, campus population data from the COVID-19 dashboard, and availability of information on campus websites regarding parking costs and public transportation availability to evaluate the commuting landscape.

One method to encourage changes in behavior is through *creating a disincentive for single occupancy vehicle usage* through charging even a nominal fee for parking. Website reviews showed that fourteen campuses had free parking for students (with a subset having free parking for faculty and staff), two campuses had no information available, and only four campuses charged for parking permits on a tiered structure with student permits substantially less expensive than faculty and staff. These campuses are Altoona, Erie, Harrisburg, and UP. Another method is re-visit how personal vehicles interact with the campus. Street calming methods, hub-and-spoke designs with peripheral parking for all but handicapped individuals with internal bus transport around the campus, creation of one-way roads with bicycle lanes, all have the potential to reduce the movement of personal vehicles on campus, which will increase student safety.

The goal would be to encourage those faculty, staff and students who can take public transportation to use it regularly. A first step could be to *provide better information on public transportation options* to campus commuters through websites, onboarding, social media, etc. For many campuses, the 'Visit Us' webpages typically focused on

[58] https://nikolamotor.com/press_releases/nikola-details-north-american-fuel-cell-vehicle-program-112

directions for driving and public transit information, typically bus transit, required several clicks away from the main visiting and parking pages. Seven campuses list that they have designated bus stops on campus, while 6 campuses list public transportation nearby but without a bus stop on campus. If bus passes are subsidized, that information was not readily available on most campus websites. This review highlighted that individual commuting is not discouraged and most campuses have readily available and free parking, while finding information on public transit is much more difficult.

*Image 9: Blue Loop Cata Bus. Credit: Sean M. Flynn*

A strategy for reducing commuter emissions that was modeled was to *support Penn State's Remote Work policy and to create Carbon-Reduction Days* built into the Academic Calendar (like Wellness Days). We estimate that an emissions reduction from commuting of 16%, or 9,000 MTCO2e annually, could be realized using these strategies. This does not include any savings from a reduction in heating/cooling loads due to spaces being unoccupied during remote workdays. The full analysis is included in Appendix E, and the assumptions used are:

- All faculty and staff could NOT commute 1 day per week (which would likely balance out those who could do more remote work and those who must be on campus to perform their jobs).
- 4 – 6 remote teaching or Carbon-Reduction Days are built into the calendar (approximately 15% of the class time), which would still meet accreditation requirements that no more than 24% of in-person classes be offered in another format and leave flexibility for weather-related changes.
- An estimate of 150,000,000 miles of commuting and 60,000 tons of carbon emissions from the FY 19/20 emissions inventory.

The cost of having remote working days would be negligible due to the amount of infrastructure already in place through adaptation to the covid pandemic. However, ensuring everyone has access to stable internet and for students to have appropriate technology readily available would be important, so some costs may be incurred to provide students, faculty, and/or staff with appropriate technology based on their needs. A co-benefit of this strategy is that if Remote Workdays are coordinated throughout the University, some building spaces could be left in unoccupied mode during the absence of users. This would result in savings in building energy usage and costs.

## BUSINESS TRAVEL – UNIVERSITY-FUNDED AIR TRAVEL

*Image 10: Aerial view of the University Park Airport*

In the current GHG inventory, air travel mileage is calculated using spending data from each business unit of the University and dividing by The Bureau of Transportation's estimate for the average fare of a domestic flight at 13.7 cents/mile. For FY 19/20, the total cost of air travel throughout the University was approximately $1,150,000. Using the 13.7 cents/mile conversion factor of dollars spent to miles flown, this was estimated at approximately 87,000,000 miles and 14,425 MTCO2e. Because FY 19/20 includes 3 months of the pandemic, this likely reflects travel for only 9 months. Therefore, simply scaling up by 1.33, the annual carbon emissions for travel can be estimated as 20,000 MTCO2e.

This method is limited because it is based on air travel cost as reported by each business unit, rather than actual flight mileage. To compare, one UP college completed a unit-level GHG inventory and analyzed air travel data for both FY 18/19 and 19/20. In this process, the unit was able to acquire detailed flight information and actual mileage traveled from the SAP Concur Reimbursement System. Based on this analysis, the University-level GHG inventory overestimated the miles traveled and emissions for that college by approximately 50%. This highlighted the need to improve how travel data is available and incorporated into the inventory.

This category should include all air travel that faculty, staff, and students take to support the University's mission that are not completed using a University-owned airplane. This also does not include ancillary transportation costs associated with University-related travel such as subways, taxis/ride-shares, etc.

## TRANSPORTATION OUTSIDE SCOPE OF THE CHARGE AND/OR CURRENT GHG INVENTORY

There are travel-related emissions sources that are not currently included in the University GHG inventory. It is recommended that an inventory of these sectors begin, to understand their contributions to the overall emissions footprint of the University.

For example, the only sector of business travel currently inventoried is air travel reimbursed through Concur; however, the use of rental cars, personal cars, and other public transportation methods could be a substantial part of the University's transportation-related emissions. The systems in place to fund those transportation methods vary, thus the data are not easily available. In addition, some faculty likely do not pursue reimbursement for travel between campuses because of the paperwork. For scale, rental spending through Enterprise is roughly $5 million/year. Enterprise does provide regular reporting of Penn State's rental business, so this is a possible source of data for inventorying travel emissions. Charter buses are also not included in the GHG emissions inventory. All of these methods of travel are related to Penn State business and should be examined for measuring and reducing their footprint.

## TRANSPORTATION RECOMMENDATIONS

- Improve data collection and tracking systems to ensure transportation-related reduction activities can be measured and tracked.
- Ensure all transportation-related activities are included in the University inventory, including University-owned aircraft and University-sponsored educational trips (e.g., study abroad).
- Plan and execute a full decarbonization of the entire University fleet. A right-sizing analysis should be completed and followed by a professional study that includes determining the right technologies for all vehicle types, infrastructure required, and phasing recommendations. The use of plug-in hybrids to address range issues should be considered if necessary, as should investigating newer technologies such as biofuels and fuel cells.
- Continue increasing the fleet fuel efficiency and/or switching to hybrid and EVs where available and reasonable in the short term. An investment of approximately $1.23 million would fund EV or hybrid replacements for some sedans, minivans, and box trucks and completion of the electrification of lawnmowers.
- A vehicle purchasing policy should be created/modified to require that at a vehicle's purchase, the purchaser must evaluate the availability of hybrid, electric and/or lower carbon emitting versions. If a purchaser finds they cannot replace their vehicle with an alternative vehicle, then an exception must be requested and approved.
- For faculty and staff, a policy/guidance or rubric for when travel is necessary or acceptable should be created. This is a place where the soft power of Penn State, given its size and travel dollars, could be used to continue to promote the productivity of virtual and hybrid options and normalize the purchase of travel offsets. The goal is not to stop air travel since our experts' participation in off-campus events raises our profile and reputation, but to consider whether all travel is necessary.
- Remote work should be supported and implemented considering the emissions impacts. Carbon Reduction Days could be built into the academic calendar, similar to Wellness Days.
- To reduce commuting emissions, lower emission modes of transportation need to be available and convenient to all campuses. We recommend a group be convened to examine the availability of public and shared transportation options and information across all Penn State campuses and recommend updates. This will include working with our community partners to increase safe routes for bicycles and walking from the community to and through campuses. It also will include a review on how campus transportation infrastructure, especially for personal vehicles, is sited, designed, and built.
- Create a system-wide guidance or policy on travel-related offsets. Offsets are available to be purchased through many travel agencies, however guidance about purchasing them is currently managed unit by unit.

# Farms

## AGRICULTURE AND CLIMATE CHANGE MITIGATION

*Image 11: Aerial view of cover crop project in 2017. Credit: Mark Horse*

Atmospheric warming and associated climate change are due to absorption and emission of thermal radiation in the atmosphere by GHGs emitted from fossil fuel combustion, agriculture, and land use change, in particular deforestation. In the last decade, it is estimated that agriculture and land use change contributed ~23% of the total anthropogenic emission of GHG or 12+/-3 Gt $CO_2$ equivalent per year, specifically accounting for 13%, 44%, and 82% of the total emissions of carbon dioxide, methane, and nitrous oxide ($N_2O$) respectively.[59] Thus, agriculture can have a primary role in controlling $CO_2$ equivalent emissions globally by slowing or halting the conversion of tropical and subtropical forestlands to agriculture, and critically by controlling methane and nitrous oxide emissions associated with agriculture (see Appendix F: Farms). Widespread shifts towards energy sources with a lower carbon footprint and reduced emission of $CO_2$ will make controlling methane and nitrous oxide progressively more important in the coming decades.[60]

Terrestrial ecosystems currently recapture an estimated 29% of the total anthropogenic GHG emissions, a formidable figure and an indirect indicator of the potential of terrestrial systems including agriculture to be carbon sinks. Therefore, efforts on the agricultural front should aim at reducing current direct emissions from agriculture, with the simpler steps taken immediately, and second at developing and deploying increasingly more complex interventions that reduce emissions and increase the capture of carbon (or energy) in agricultural systems. This is important beyond Penn State's agricultural land because our operations can be a living demonstration program. Penn State Extension developed over decades of engagement an invaluable asset with stakeholders across the state: trust – that can be a springboard for successful practices at Penn State to be amplified through extension programs that reach local communities throughout the Commonwealth. Operationally in the Penn State and greater Commonwealth agricultural sector, GHG emissions reductions will be achieved through *reductions in methane and nitrous oxide emissions, storage of soil carbon, and combined approaches that displace fossil fuel usage and store carbon*.

**Reduction in methane emissions** is associated with a reduction in emissions from animal production. In developed economies with a large agricultural base like the U.S., sources of agricultural methane are enteric fermentation, typically from beef and dairy cattle, and manure management. In lesser developed economies with

[59] IPCC 2021 Sixth Assessment Report (https://www.ipcc.ch/assessment-report/ar6/)
[60] Andy Reisinger, et. al., "How necessary and feasible are reductions of methane emissions from livestock to support stringent temperature goals?" *Philosophical Transactions of the Royal Society* (2021) A, 379(2210), p.20200452. https://royalsocietypublishing.org/doi/pdf/10.1098/rsta.2020.0452

large livestock inventories, livestock is the primary source of methane emission. Manure management in dairy systems results in most of the manure-related GHG emissions in the U.S., whereas beef systems are the largest source of enteric methane. There is great potential to reduce emissions based on diet manipulation and feed supplements, an area of active research.

**Reductions in the emissions of nitrous oxide** from agriculture are a primary concern and relate to the fate of reactive nitrogen additions to the biosphere through biological nitrogen fixation and synthetic fertilizers. Nitrous oxide emissions occur mostly from incomplete denitrification and during nitrification. Synthetic fertilizers have an intrinsic carbon footprint associated with the energy consumed in making it. This footprint can drop if renewable energy is used for synthesis of ammoniacal fertilizer. However, unlike nitrogen fixation or nitrogen recycling through manure applications, the amount of fertilizer applied can be accurately controlled and tailored to the crops needs. As a reference, a baseline nitrous emission of 2% of the fertilizer nitrogen addition renders a carbon footprint of 9.7 kg $CO_2$ eq per kg of nitrogen, much higher than the emission associated with the synthesis of the fertilizer. Globally, more efficient fertilizer use needs to be regulated to reduce agricultural GHG emissions. Reducing $N_2O$ emission by denitrification requires a) tampering down denitrification and, b) if denitrification is active, forcing it to full reduction of nitrogen to dinitrogen. The first approach is most practical in agricultural fields through specific management practices, the details of which exceed the demands of this report and include practices already in place at Penn State, and new practices that can be expanded by residue management, cover crops, precision nitrogen application, and use of denitrification inhibitors which also reduce emissions through nitrification. Even if partially successful, nitrification inhibitors are one of the simplest and least controversial means of reducing nitrous oxide emissions.

**Increasing carbon capture in soils** has also been proposed as a mechanism to drawdown atmospheric $CO_2$. Soil organic matter results mostly from decomposition of fresh plant residues. Microorganisms decompose organic residues thereby releasing $CO_2$. About 20% of the carbon in crop and root residues is retained as soil organic matter that is also decomposed by microorganisms. Therefore, the soil organic carbon pool can be conceptualized as a bank account with deposits taxed heavily by microbes, and with an additional large operating fee. The only nearly permanent storage of carbon is through biochar. For this reason, the enthusiasm for storing carbon in soils has dampened in academic circles and narrowed to specific and still valuable options. Management that favors soil carbon storage tends to be beneficial, e.g., no-till agriculture can increase soil carbon, and result in numerous additional benefits in soil quality.

There are a few key changes with the potential to contribute to more carbon neutral agriculture. First, *perennialization* of the system can lead to increases in soil organic matter on the order of perhaps 2 Mg $CO_2$ eq per ha per year, which compares favorably with emissions of nitrous oxide just from nitrogen fertilizer synthesis (~1 Mg $CO_2$ eq per ha per year for annual crop fertilized with 200 kg/ha of nitrogen) and is similar or less than emissions associated with moderate nitrous oxide emission rates. However, a tradeoff exists: perennialization that reduces grain output by reducing the area of annual crops in a region may simply elicit land use change elsewhere. Second, *addition of biochar to soils* is likely one of the most direct ways of increasing (pyrogenic) soil organic carbon, as about 2/3 of the carbon added as biochar will remain the soil. Third, *transition* *from high-tillage to no-till* systems, when that transition has not happened and is economically and agronomically viable. Fourth, cover crops can have carbon benefits, but these are of lower magnitude if cash crops dominate the rotation (for more detail on this paragraph, and the next, see Appendix F: Farms).

*Image 12: PSU student obtaining soil cores.*

**Combined approaches that displace fossil fuel usage and increase soil carbon and possibly geological carbon storage** also deserve attention, encompassing the biochar amendment and referring generally to using biomass crops or crop residues as combustion sources. In addition, the technology to produce biogas from land fields or biodigesters is mature, and if manure is available, capturing and using biogas is viable. *Radiation management*, e.g., by integrating photovoltaics in farms as an innovative way to reduce the agricultural carbon footprint by generating energy in areas with limited productivity, or, in some cases, during dry spells. An oft-ignored component of climate smart agriculture is to increase yield without changing the use of resources and without altering GHG emissions, i.e., *reducing the carbon intensity of agricultural outputs*.

## AGRICULTURAL MANAGEMENT AT PENN STATE

Penn State manages 2190 acres of farmland for grain and forage production. Farm Services manages about 1720 acres to produce feed for animal research and to manage their manure. The remainder of the area is mostly at Rock Springs and is dedicated to research. The dominant crops are corn and soybean mostly managed with no-till.

The living filter, although occupying small acreage, offers a particular set of challenges for wastewater management, as crops must withstand excess irrigation year-round. A small portion of the living filter (< 2 acres) already includes irrigated shrub willow, and 35 acres of a field adjacent to I-99 and 4 acres at Rock Springs include rainfed shrub willow, a dedicated biomass crop with high carbon storage capacity.

## AGRICULTURAL GHG INVENTORY

The most recent animal inventory, fuel usage, nitrogen fertilizer usage, and lime usage as a soil amendment is reported in Table 6, alongside emission factors from SIMAP (Sustainability Indicator Management & Analysis Platform) for agile calculations, and with other appropriate emission factors as needed. It is important to note that Farm Services fuel usage includes that used by student buses during field trips and heating of some facilities, not just that to produce crops.

*Table 6: Farm operations and agricultural research inventory of GHG emissions. The inventory includes fuel used by buses and for heating some facilities*

| GHG Inventory Categories | Total -- | Emission Factor SIMAP ($MT\ CO_2$/unit) | Emission Factor Other ($lb\ CO_2$/unit) | Estimated Emissions (MTCO2e) |
|---|---|---|---|---|
| Fuel diesel & heating oil, gal | 42,996 | | 22.4 | 437 |
| Gasoline, gal | 7,390 | | 19.6 | 66 |
| N Fertilizer, lb | 151,085 | 0.0025 | | 378 |
| Lime, lb | $1.1 \times 10^6$ | 0.0002 | | 220 |
| Livestock* | | | | 3,811 |
| Total | | | | **4,912** |

The factor for fertilizer approximates the sum of emissions from nitrogen fertilizer synthesis plus about 2.5% emissions from nitrous oxide derived from the fertilizer use in the field.

## OPPORTUNITIES FOR GREENHOUSE GAS EMISSION ABATEMENT AND GENERATION OF INTERNAL OFFSETS

Penn State farms are mostly managed with no-till agriculture and a relatively tight nitrogen budget. Because of the already adjusted management, opportunities for quick adjustment are limited, but available.

The first target is the reduction in nitrous oxide emission from nitrification and denitrification. The recommendation is to support financially the purchase and use of nitrification inhibitors. The most optimistic local impact would be a reduction in emissions of ~125 MTCO2e per year. This assumes that today emissions are 2.5% of the applied nitrogen, and the nitrification inhibitor suppresses 50% of that emission, (i.e., 0.5 x [151,085 lbs. fertilizer x 0.32 lbs. N/lbs fertilizer x 0.454/1000 (lbs to kg to ton conversion) x 0.025 x 44/28 (N to $N_2O$ conversion) x 310 ($N_2O$ to $CO_2$e]). It is important to note that these emission rates are estimated, and it is likely that actual emission rates are higher, perhaps by 2 times, which changes the GHG inventory and the opportunities to control emissions.

The second direct intervention is the reduction of emissions from animal production. Clearly, they comprise the bulk of agricultural emissions, while at the same time, precise allocation of the emissions contain some uncertainty.[61] The main reduction in emissions, and offsets, would come from manure management in a *digester to produce biogas*. It is plausible that reduction comparable to that expected from nitrous oxide emissions reductions described previously will come from nitrous oxide emissions reduction through manure management. This requires monitoring, as today the emission is all bulked in the emission factor per animal.

[61] Hristov, A.N., Harper, M., Meinen, R., Day, R., Lopes, J., Ott, T., Venkatesh, A. and Randles, C.A., 2017. Discrepancies and uncertainties in bottom-up gridded inventories of livestock methane emissions for the contiguous United States. Environmental science & technology, 51(23), pp.13668-13677.

## OTHER CLIMATE FRIENDLY INTERVENTIONS

Other management practices have potential to reduce emissions, but as importantly, may serve as examples for the agricultural community.

*Image 13: PSU Farms*

### *Precision Nitrogen Management*

A full-fledged implementation of precision nitrogen management that is tailored to each field's square yard can have large impacts in nitrogen management. Developing a more detailed map of yield potential for each crop in each field, and tailored application of nitrogen and other fertilizers can significantly reduce nitrogen fertilizer application rates. Investment in this strategy pertains mostly to equipment for monitoring crops, licenses to acquire imagery and processing software, and resources to validate these technologies. If these technologies are deployed in all of Pennsylvania cropland, the benefits would be enormous in terms of GHGs and for water quality.

### *Manure Management*

Manure management, from the use of the digester to the application of manure or digestate to fields, is fraught with uncertainty because manure composition varies significantly and is not known at the time of application. It is easy to overapply manure to avoid nitrogen shortages. Management also adds costs, as estimating nitrogen side dressing rates is challenging. Interested faculty could work to develop sensing techniques to estimate manure composition at low cost. Manure injection into soil has also been proposed as a way of avoiding nitrogen volatilization as ammonia. The challenge of this approach is the potential increase in nitrous oxide emissions as demonstrated in our own fields. This option should be managed with caution, perhaps only in well drained areas, if at all, when considering GHG.

[62] de León, M.A.P., Dell, C.J. and Karsten, H.D., 2021. Nitrous oxide emissions from manured, no-till corn systems. Nutrient Cycling in Agroecosystems, 119(3), pp.405-421.

### *Cover Crops*

Where they fit in the production system, cover crops come with multiple benefits.[63] Among them is the addition of carbon to the soil and concomitant nitrogen retention.[64] A potential drawback is that legume cover crops, touted for their capacity to supply nitrogen to the system and replace synthetic fertilizer, can easily elicit large emissions of nitrous oxide.[65] While research is underway in this important area, the use of grass cover crops that can be killed by winter cold temperatures like oats (fall services) and some broad leaves mixed with cold-tolerant grasses (spring services) and with a lesser proportion of legumes in the mix, can bring multiple benefits. The exposure of Penn State fields to I99 makes some of those fields particularly valuable as demonstration sites.

*Image 14: Cover crops at Rock Springs*

### *Living Filter*

An expansion of the area of perennial warm season or woody crops like shrub willow at the living filter should be considered. Both crops thrive in wet environments, produce substantial amounts of biomass when nourished and irrigated through the summer, and enable year-round application of water. For shrub willow, we have documented carbon storage rates of minimally 3 Mg $CO_2$ per hectare per year even without accounting for the aerial biomass or fossil fuel displacement if the wood chips are burned. The 35 ac of shrub willow at Penn State's Rockview field may have stored 14.5 ha x 3 Mg $CO_2$ / ha = 43.5 Mg $CO_2$e year, offsetting e.g., 25% of the emission from lime additions in all Penn State fields. Irrigated willow is about twice as productive, helps solve the water and nutrient excesses challenge, and produces wood chips that can be used to produce biochar or other soil amendments without the need to develop any new technology. Switchgrass biomass could be used by Penn State in the biomass digester to produce biogas. Internal offsets from the production of biomass from perennials can be significant and provide multiple additional benefits if they do not displace much of the grain production area.[66]

[63] Schipanski, M.E., Barbercheck, M., Douglas, M.R., Finney, D.M., Haider, K., Kaye, J.P., Kemanian, A.R., Mortensen, D.A., Ryan, M.R., Tooker, J. and White, C., 2014. A framework for evaluating ecosystem services provided by cover crops in agroecosystems. Agricultural Systems, 125, pp.12-22.

[64] Finney, D.M., White, C.M. and Kaye, J.P., 2016. Biomass production and carbon/nitrogen ratio influence ecosystem services from cover crop mixtures. Agronomy Journal, 108(1), pp.39-52

[65] Saha, D., Kaye, J.P., Bhowmik, A., Bruns, M.A., Wallace, J.M. and Kemanian, A.R., 2021. Organic fertility inputs synergistically increase denitrification-derived nitrous oxide emissions in agroecosystems. Ecological Applications, 31(7), p.e02403.

[66] Montes, F., Fabio, E.S., Smart, L.B., Richard, T.L., Añó, R.M. and Kemanian, A.R., 2021. A semi-commercial case study of willow biomass production in the northeastern United States. Agronomy Journal, 113(2), pp.1287-1302.

### *Residue Management*

When large amounts of residues are leftover in, e.g., corn, wheat or barley fields, they decompose, and most of the carbon formerly in residues returns to the atmosphere. This is particularly true for no-till agriculture, where the lack of mixing of surface residues with the soil reduces the opportunity for carbon storage. In fact, several researchers have shown that roots have a disproportionate effect on soil carbon storage.[67] It follows that a fraction of the residues could be used for other purposes without altering the soil carbon balance, e.g., to produce biogas in a digester. Subfields with high productivity could be considered for harvest of straw or stover and bailing for other uses. In short, we should task the soil microbiome to share its meals to reduce GHG. Penn State could promote research in this area, possibly combined with the production of perennial crops for a holistic and impactful management of agricultural landscapes.

## FARMS RECOMMENDATIONS

- Reduce nitrous oxide emission from nitrification and denitrification by supporting the purchase and use of nitrification inhibitors.
- Reduce emissions from animal production primarily through manure management in a digester to produce biogas, and secondarily by develop sensing techniques to estimate manure composition for more effective and targeted manure application (related to 3 below).
- Implement precision nitrogen management tailored to each agricultural field's square yard primarily by investments in equipment for monitoring crops, licenses to acquire imagery and processing software, and resources to validate these technologies.
- Strategically plant cover crops to add carbon to the soil and better retain nitrogen.
- Expand the area of perennial warm season or woody crops like shrub willow at the living filter to store more carbon and produce energy sources from biomass for digestion and combustion.
- Manage a small fraction of crop residues for other purposes without altering the soil carbon balance, e.g., to produce biogas in a digester or to harvest straw or stover to bail for other uses.
- Utilize existing infrastructure and organizational framework, e.g., public exposure of Penn State fields including Rock Springs, Agriculture Extension Services, to broaden the impact of University agricultural science and land management strategies to the greater agricultural community of the Commonwealth and beyond.

[67] Mazzilli, S.R., Kemanian, A.R., Ernst, O.R., Jackson, R.B. and Pineiro, G., 2015. Greater humification of belowground than aboveground biomass carbon into particulate soil organic matter in no-till corn and soybean crops. Soil Biology and Biochemistry, 85, pp.22-30.

## Behavioral

### BACKGROUND

Significant carbon reduction can be achieved via behavior change, e.g., one source states that 28% of global GHG emissions derive from the global food system.[68] This figure could be reduced by half through change in food consumption. However, the behavior change path is different from other options contained in this report for at least 2 reasons. One is that there are many behaviors associated with carbon yet few single behaviors that are likely to produce a large effect by themselves. "Change in food consumption" could include reducing food waste, eating less meat, eating more plants, purchasing food from local sources, reducing plastic packaging, growing one's own produce, and so on. However, many small actions, especially those that are repeated over time, can cumulate into significant impact.

A second difference concerns the causes of behavior. There are numerous underlying determinants of human action. These forces may align with one another, or they may conflict. People may value emissions reduction as an abstract principle but find that it conflicts with their preferences in particular cases, when asked to forgo hamburgers, for example. The situation is further complicated by the fact that causes of behavior can align in one group of people, but be in conflict in another group. Furthermore, the arrangement of forces can change over time. Fortunately, there is a (small) natural tendency among the determinants of behavior toward alignment.[69] The appropriate behavior change strategies can create a sort of snowball effect in which seemingly minor changes can provide the foundation for broader changes.

It is important to note that factors that bring about behavior change exist at 2 levels. At the individual level, people make decisions consciously, based on facts and feelings. But decisions always take place within some context that structures their options. For instance, a hungry person may wish to choose a low-carbon meal but be unable to do so because there are no low-carbon options available. Conversely, when options consist of primarily low-carbon choices, people will, in the aggregate, incline toward those choices. Efforts to produce behavior change must consider individual and contextual influences on behavior. Doing so requires knowledge of existing behaviors, implementation of multiple behavior change strategies, ongoing monitoring of behavior (and its causes), and strategy adaptation as needed.

In addition to contextual-level issues, we focus on four causes of behavior all of which can increase or decrease the likelihood of engaging in some action:

1. Personal consequences, including time and money. Individuals contemplate the costs and benefits of their actions. Reduced costs and heightened benefits increase the likelihood of change, but if costs are seen as high or benefits as low those perceptions serve as barriers to change.

2. Personal values, including caring for others, fairness, and personal freedom. Caring for others can be extended to caring for future generations, which is sometimes the premise of messages that seek pro-environmental behavior change. Such messages may be seen by some as an infringement on their personal freedoms.

3. Norms, that is, the actions and perceptions of other people, including what we see others doing and what others tell us we should be doing. When that information comes from members of their own group, people

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[68] www.klimato.co

[69] Heider, F. (1946). Attitudes and cognitive organization. Journal of Psychology, 21, 107-112.

generally conform to the recommended action. When it flows from members of an outgroup, they may react against it. In-group leaders can be especially effective at legitimizing new behaviors and reinforcing existing ones.

4. Habits are routinized behaviors that are performed repeatedly in each context. Although they begin as conscious choices, with sufficient repetition conscious choice fades and the behavior becomes automatic, that is, habitual. This automaticity can be advantageous if the behavior reduces carbon emissions. Old habits, which may need to be displaced, can act as barriers to acquiring a new habit.

Research is sorely needed to determine how to effectively tap the potential of behavioral change in solving the climate change issue. Penn State could lead such an effort and the campus could be a living lab to figure it out. The first step in such an effort would begin with a determination of behaviors to change, probably most effectively identified through surveys of the greater Penn State community that targeted behaviors most likely to lead to emissions reductions – behaviors at least partially determined by some of the observations and recommendations in this report. This information would subsequently be applied to the design of outreach, policy development, and incentives to elicit the needed behavioral changes.

## TOPICAL DISCUSSIONS

***Build behavioral infrastructure for values change.***

Values are deep-seated judgments that are changeable, but often slowly. Doing so requires repeated exposure to value-relevant issues and repeated evaluation of those issues. Universities are institutions whose purpose is, among others, to teach students to value knowledge, critical thinking, ethics, and civic responsibility. It is increasingly important that universities encourage students toward a comprehensive understanding of climate-related issues, including the reduction of carbon emissions, and the competencies necessary to live in a climate-altered world. Such work is currently being carried out at UP through the leadership of Sustainability Councils, and at least the College of Earth and Mineral Sciences, Eberly College of Science, the College of Engineering, and the College of Arts & Architecture. However, we suggest a thorough review that summarizes climate-relevant coursework across all units at all campuses and development of a plan to incentivize the creation of more environmentally-oriented courses and majors. Greater abundance and variety of such courses structures the decision space to encourage low-carbon choices. We emphasize that coursework alone will not be enough. Large-scale institutional change (e.g., creation of a Climate College), guided by the highest levels of administration is needed to produce University-level adaptation to climate change.

***Promote the United Nations' platform "A World in support of ActNow campaign."***

This professional mobile application (www.aworld.org is designed to assist users in changing a large range of individual-level behaviors, most of which have implications for carbon emissions reduction. It presents users with a set of habitual behaviors, each of which is coded for its link to carbon reduction. Users identify habits that they already possess and are given the opportunity to choose new ones that they wish to implement (thereby mitigating against perceived infringement on personal freedom. They receive immediate quantitative feedback with respect to the decrease in carbon emissions that is the result of their behavior/change (thereby allowing them to assess impact. The app also automatically provides a means for sharing their decision/action via social media (a means of communicating norms. Because the app includes such a wide range of behaviors – transportation choices, energy use, food consumption, other consumer choices – it represents an opportunity for behavior change in a variety of domains (which increases its likely impact). *Use of the app should be promoted via multi-media campaign or during orientation that involves endorsement by formal and informal campus leaders among faculty, staff, and students, and in coordination with Strategic Communications*. Early fall semester is an ideal time for such a campaign because it is a time in which students and faculty are forming the habits that will carry them through the rest of the semester and academic year.

***Collaborate with relevant faculty and private organization(s) to provide individuals with information on the carbon footprint of their dietary choices.***

Members of the PSU community who are already positively oriented to carbon reduction will act on their values to the extent that they have relevant information and the opportunity to act. Food consumption is an activity that provides just such an opportunity. Recent research finds that consumers who were provided with information concerning the carbon impact of their meat choices made choices that reduced their carbon impact by as much as 32% (vs. those who were not given that information).[70] As an example, Klimato is a company whose mission is to provide consumers with information concerning the carbon footprint of their food.[70] As currently formulated, they collaborate with restaurants to calculate the carbon footprint of their recipes, which is then provided to customers via the menus (similar to nutrition labeling, which has proven to be effective at promoting healthier food choices). Such companies are well positioned to provide carbon-relevant data to the many commercial food vendors that populate campuses. This idea could be extended to dormitories and other campus food service operations with help from either private companies or Penn State faculty and students. Doing so would provide individuals with the knowledge they need to reduce food-related carbon emissions via individual choice. It would have the added benefits of keeping carbon emissions top-of-mind by repeatedly exposing everyone who eats on campus to the concept of incorporating climate impact into food-related decisions. During the Spring and Summer of 2021, several students worked to calculate the GHG emissions associated with menu ingredients for the UP dining halls. This could be a basis for inclusion in customer-facing communications. We note the presence of faculty on the UP campus whose expertise lies at the intersection of food consumption and GHG emissions.[71]

***Monitor carbon-related behaviors and their causes.***

Assessing progress towards emissions reduction goals requires measurement of the behaviors in question. Knowledge of the causes of those behaviors is necessary as well for understanding why the hoped-for changes are or are not occurring. Evidence that the hoped-for changes are not occurring is abundant: The world is currently living beyond its carbon capacities. In 2019 Americans emitted the equivalent of 75 tons of $CO_2$ per person (75 $tCO_2e$/cap) versus the global average of 28 tons of $CO_2$ equivalent per person.[72] We suggest a long-term research effort that monitors carbon-related behaviors and their causes. Although a comprehensive approach is needed, it should also be tailored to the different target audiences: students, staff, faculty, and visitors. For example, it might be sensible to monitor and, perhaps, attempt to change composting behavior among faculty and staff. This makes less sense among students living in dorms or other housing

[70] Anna Kristina Edenbrandt, et. al., "Interested, indifferent, or active information avoiders of carbon levels: Cognitive dissonance and ascription of responsibility as motivating factors." *Food Policy*, 101, 102036.
[71] Garcia-Herrero, L., Costello, C., De Manna, F., & Schreiber, L. (2021). Eating away at sustainability: Food consumptions and waste patterns in a U.S. school canteen. *Journal of Cleaner Production*, 279,123571.
[72] https://ceo-na.com/news/us-per-capita-carbon-footprint-looms-large/

that does not include the ability to compost (although offering composting opportunities to dorm residents would be an effective means of changing the context-level decision space). In contrast, it would be valuable to assess change in environmental inclinations in the undergraduate population before and after having taken an environmentally-oriented course, whereas this would be less applicable to staff and faculty (unless we can make climate education part of the onboarding process). One crucial piece of the monitoring function would be to measure the impact of planned change efforts, which occur at both levels. Some change efforts are focused on specific behaviors such as food consumption as a function of carbon footprint labeling (see #3). Transportation-related behaviors constitute another area that is ripe with opportunities for behavior change, a topic described in the Transportation section of this report and the related appendices.[73] Other efforts are broader and more varied, such as the (hoped for) activities of Strategic Communications and the Division of Outreach, both of which involve many forms of messaging over a long period of time. Attempts to understand either specific or broader, ongoing efforts will require measures of both. Hence, it will be important to include representatives from both units on any committee whose goal is to monitor and change carbon-related behavior. Equally important will be the presence of persons with expertise in the science of behavior change (e.g., faculty). From an organizational perspective, this research effort should operate as an interlocking set of ongoing projects, each of which focuses on a specific problem *and* its relationship to the other relevant behavior change issues.

## BEHAVIORAL RECOMMENDATIONS

- Initiate surveys of the greater Penn State community that target behaviors most likely to lead to emissions reductions – behaviors at least partially determined by some of the observations and recommendations in this report.
- Complete a thorough review that summarizes climate-relevant coursework across all units at all campuses and development of a plan to incentivize the creation of more environmentally-oriented courses and majors and develop a plan.
- Use of the AWorld app should be promoted.
- Collaborate with Klimato (or a similar organization) to provide individuals with information on the carbon footprint of their dietary choices.
- Complete a long-term research effort that monitors carbon-related behaviors, with special attention to food and transportation.

[73] See Appendix E: Transportation. See also Appendix I.7: Electric Vehicles.

## Carbon Offsets


*Image 15: Tree planting initiative in Hershey*

As climate change is a global issue and GHGs mix throughout the atmosphere, reducing emissions anywhere benefits the planet. A carbon offset is a reduction of GHG emissions or an increase in carbon removal, compared to a preset business-as-usual reference, that occurs in one location and is used to balance emissions elsewhere to achieve net zero carbon emissions to the atmosphere. One carbon offset credit is the equivalent of one MTCO2e. Carbon offset credits are transferable units certified by a third party that represent carbon offsets. The purchaser of an offset credit can claim the atmospheric carbon reduction and include it in their GHG balance as a negative emission that therefore fulfills reduction goals. Offset programs and organizations (e.g., American Carbon Registry, California Compliance Offsets Program, Gold Standard Registry) have been created to set standards for carbon offsets, verify projects against these standards and operate registries to track and manage carbon offset credits. Although there are regulatory and voluntary carbon markets, Penn State does not currently have a regulatory requirement for offsets, thus could participate in the voluntary space. There are many types of offset projects, and costs vary currently from ~$4 to $20/ton based on the type of project, location, vintage, perceived quality and co-benefits. As Penn State works to reduce its GHG pollution as rapidly as possible, some consideration should be made for an offsets program and strategy that adheres to a strict set of standards to ensure that carbon is removed from the atmosphere to offset our institutional emissions.

High-quality carbon offset programs are founded on a common set of principles: permanence, additionality, verifiability, and over time, a preference for removal of carbon over prevention. One good example of such an approach is Rutgers University's PAVER (Permanent, Additional, Verifiable, Enforceable, Real) requirements.[74] Recently, carbon offset programs are being scrutinized for their additionality and whether they truly remove carbon from the atmosphere. If Penn State explores third-party carbon offsets as part of an emissions reductions strategy it is essential that we rigorously evaluate offset programs to ensure that they are genuinely removing newly emitted carbon from the atmosphere.

Ultimately, the most reliable means to reduce our GHG footprint is to focus on reducing emissions. As we work to reduce our emissions, we may consider the development

[74] https://climatetaskforce.rutgers.edu/wp-content/uploads/sites/332/2021/01/WG5_Phase2Report.pdf

of a high-quality offset program that ensures carbon uptake while providing economic, environmental, educational, and cultural benefits to the Penn State community and Commonwealth through the development of external, internal, and hybrid offsets, examples of which we describe further below. We define **external carbon offsets** as those produced by and purchased from third parties, most likely through a voluntary carbon registry. **Internal carbon offsets** are those produced by Penn State by deploying technology on or managing land that is owned and controlled by the University. **Hybrid** refers to strategies which involve partnering with other landowners to develop offsets whereby offset credits from these projects are granted to Penn State through legal agreement and incorporated into the University emissions reduction strategy.

Penn State's GHG reduction strategy has been based on a foundation of energy conservation, increased efficiency, increased levels of combined heat and power, targeted renewable purchases, awareness, and programs in transportation efficiency and waste reduction. To date, Penn State has focused on direct emissions reductions and has not invested in carbon offset purchases. However, the emissions reduction strategies have limitations and as the University progresses towards carbon neutrality, some sectors will be more difficult or impossible to reduce to zero emissions. Some direct reduction strategies, especially for thermal and electricity, are not fully developed, are not mature nor commercially available, will require a large capital investment and could take many years to implement fully (e.g., see Thermal and Electric sections of this report). As we further develop the strategies for direct emissions reductions, offsets can bridge the gap to meet a near term carbon neutrality goal. For sectors of Penn State's inventory where emissions are not under our direct control, particularly Scope 3 emissions (e.g., travel-related purchases described in Transportation section), offsets may be the only option to zero out these emissions in the foreseeable future (for some information on peer institution strategies see Appendix D: Benchmarking.

Unlike direct emissions reduction projects that will reduce emissions in Scope 1, or renewable energy credits (either unbundled or bundled with a PPA) that reduce Scope 2 emissions, offsets do not reduce emissions in a particular Scope category. Emissions are calculated and reported for each Scope and carbon offsets are applied as a net adjustment to the GHG inventory. *Although carbon offsets can be utilized as part of a comprehensive approach to achieve carbon neutrality, they should not replace or impede action for direct reduction strategies*.

**Permanence** means that the source of the carbon offsets being produced is permanent and viable, ensuring that carbon is removed from the atmosphere for a specified period, typically ranging from 40 to 100 years.

**Additionality** demonstrates that carbon offsets are the results of actions that are above-and-beyond business as usual, and thereby remove carbon from the atmosphere that otherwise would remain.

Offsets are **verifiable** when they can be measured and confirmed by a third party. Verification programs are the gatekeepers that evaluate offset protocols used to calculate carbon offset credits.

## POTENTIAL CARBON OFFSET STRATEGIES

In this section, we outline the development of external, internal, and hybrid offset programs and provide examples of each. A decision tree (Figure 13) was initially constructed to help understand the advantages and disadvantages of each approach. For a particular project, as well as for an overall offset portfolio, the decision tree can help us understand the matrix of possible offset strategies and guide Penn State to develop projects that align with our emissions reduction philosophy and goals. For benchmarking purposes, please visit Appendix D: Benchmarking for information gathered regarding various offset strategies developed by peer institutions.

The decision tree informs choices relating to the type, timeline, and geographical location of different offset projects. The first decision is the most fundamental – should Penn State consider purchasing third party offsets from the voluntary market? From an informal poll of the CERTF, 82% of respondents supported the purchase of third-party offsets. Other options include internally developed and hybrid projects as described previously.

The timeline and location of a particular project as part of our emissions reduction strategy must also be considered. Here, timeline relates to how long a particular project will be part of Penn State's emissions reduction strategy: a long-term strategy will involve managing the project for decades, whereas a short-term strategy will be employed for the immediate future, likely until more long-term projects are developed and implemented. As for location, we consider local projects as those within Pennsylvania, whereas regional projects are those in the northeast and mid-Atlantic U.S. A more detailed analysis of each of these strategies follows (also see Appendix G: Offsets).

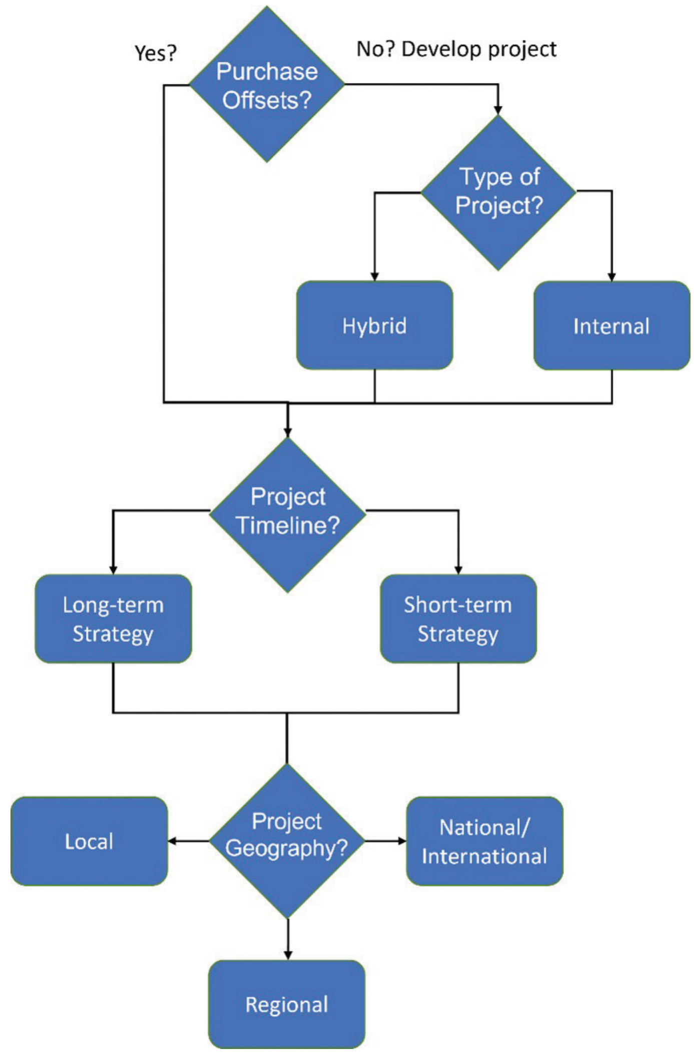



*Figure 13: Carbon offsets decision tree*

### *External Offsets*

Carbon offsets available for third party purchase are produced by organizations that remove $CO_2$ from the atmosphere that would otherwise not have been removed. The following table displays a variety of offset options currently available for purchase and demonstrates the range in project type, location, vintage, price, and availability in carbon registries. The evaluation of offsets to be purchased should be guided by a set of evaluation criteria and principles (like Rutgers' PAVER that could be developed by a committee of Penn State experts from the natural and social sciences, finance, legal, and operational realms. The requirements could be used to, e.g., guide a Request for Proposals to offset developers whose offsets would only be purchased, or developed through partnerships with the University (see hybrid approach below), if their offsets met our required criteria.

*Table 7: Examples of the variety of offset options currently available for 3rd party purchase through voluntary carbon markets*

| Project Type | Location | Vintage | Indicative Price/Tonne | Availability (400,000 tonnes) | Notes |
|---|---|---|---|---|---|
| Hydro, Wind, Solar, Industrial Emissions | China, India, Turkey | Older 2007-2013 | $4 | Volumes are currently available. Hard to say what available volumes will be mid-2022 | |
| $N_2O$ Abatement | USA | 2021 | $6 | Volume available, may be vintage 2022 | Requires new verification standards, but a powerful target. |
| Reduction in nitrogen fertilizer use | USA | | | | Requires definition of baseline fertilizer sales are available. |
| Forestry | USA, possibly PA | Newer 2013-2021 | $15-$20 | US Forestry may not be available for entire volume needed | |
| Reforestation | USA | 2023 | $15 | Available | For future emission mitigation only |
| Mine CH4 | East Coast, possibly PA | 2018-2021 | $10-$15 | Project is issuing soon, should be available | |
| Forestry | International | 2013-2021 | $10 | International volume should be available | |

A third-party carbon offset purchase offers certain advantages, not the least of which is the immediate ability to manage and impact the University's GHG emissions and do so in a rapid manner. Doing so could start momentum towards a University goal of carbon neutrality or negativity, demonstrate the seriousness with which the University views this issue, and set the University on a pathway to continue to reduce emissions through the purchase of carbon offsets. There is an opportunity here for Penn State to assist in carbon reduction projects in Pennsylvania and/or the world with positive environmental impact while supporting economic development and the livelihoods of PA citizens and beyond. An additional advantage of a third party offset strategy is that the purchases could be temporary while the University focuses on direct reduction of emissions. Further, third-party offset strategies can be flexible, changed year to year, to support emerging new technologies and management approaches and be responsive to the changing needs of the University community. Please refer to Appendix G: Offsets for a discussion of disadvantages of third-party offsets and temporal and geographic considerations of third-party offset purchases.

*Image 16: PSU students measuring trees to assess carbon stock.*

### *Internal (Penn State) Offsets*

As part of its land-grant mission, Penn State owns and manages extensive areas of land that can contribute to our emissions reductions. Land-use strategies such as improved forest and agricultural management can lead to carbon uptake and storage in biological systems.

For example, Stone Valley Forest near UP includes 2700+ hectares of forestland that is managed by the Forestland Management Office in the College of Agricultural Sciences. These forests currently hold approximately 100 tons of carbon per hectare and absorb approximately 1 ton of carbon per hectare per year in their aboveground biomass. For Penn State to include carbon offsets from these forestlands, we would have to implement forest management strategies that achieve additionality above current business-as-usual management. This could include tactics such as selective tree thinning that produces timber to be used in long-lived wood products (buildings, furniture) and promotes carbon uptake in residual trees. The additional carbon uptake resulting from improved forest management could be included in our carbon accounting as an internal offset to emissions. It should be noted that

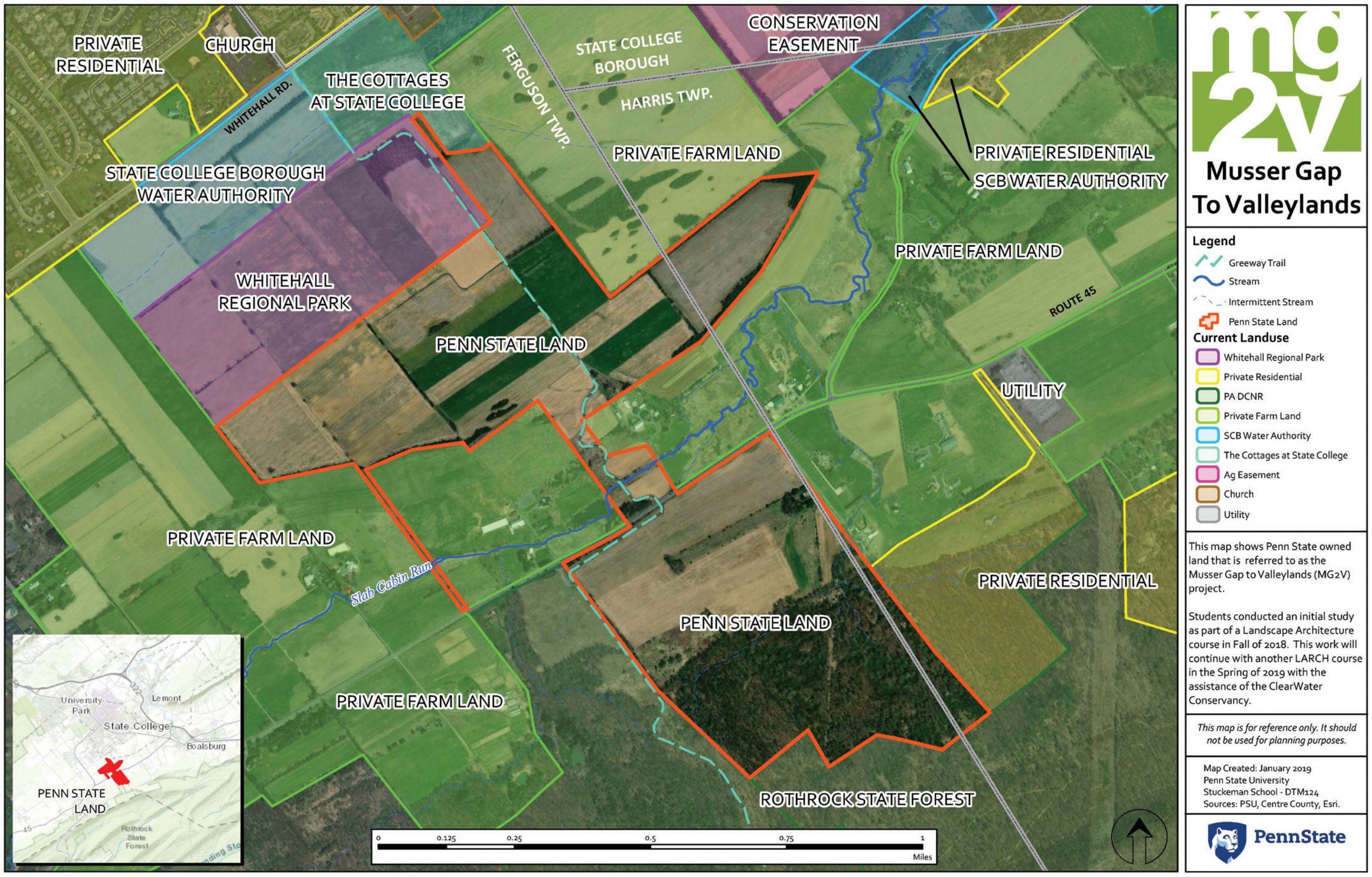



*Image 17: The Musser Gap to Valleylands (MG2V) project is an effort to conserve land the University owns.*

this strategy could only contribute a relatively small offset, perhaps at the order of hundreds of tons of $CO_2$ equivalents per year and could include costs for personnel and forest harvesting operations. However, as the Commonwealth's land-grant University we could educate stakeholders such as the over half-a-million private landowners in Pennsylvania about forest management for carbon offsets. Other examples include a relatively recent evaluation of all Penn State properties for the purpose of deploying solar arrays that determined we have ~242 acres that could be available for that purpose or dedicated to some other land use or management strategy that removes and/or stores carbon from the atmosphere. Further, the Musser Gap land purchase in Centre County near UP (MG2V) includes at least 64 acres of agricultural land currently slated for natural forest restoration, and this Task Force has actively engaged the leaders of that project to develop a carbon sequestration approach to that plan.[75] Climate-smart agriculture can also have positive impacts on the institutional GHG balance, as well as a multiplicative impact through Penn State by showcasing these technologies and practices (see Farms section of this report). Deploying new technologies and strategies on campuses may also lead to the production of offsets that can be applied to those emissions sectors that have not been eliminated (e.g. using RNG as described in the Thermal section of this report).

[75] https://www.psu.edu/news/campus-life/story/community-event-seeks-input-musser-gap-valleylands-project/

Penn State-developed offsets have potentially transformative implications, but this strategy should not be divorced from efforts to reduce carbon emissions through methods other than offset production. Realistically, Penn State likely cannot produce sufficient offsets needed to offset our current emissions, and thus this approach should be considered as part of a portfolio of offset solutions. Nonetheless, the development of Penn State offsets could be effective and could certainly help with branding, visibility, building pride and the development of partnerships among the greater University community. First and foremost, Penn State-developed offsets could build from existing assets of land and infrastructure, faculty expertise, and technology transfer pathways. They could help to improve research, hedge against increased carbon offset purchasing cost in the future, improve local communities, and leverage our strengths as an institution in many productive ways, such as engagement and educational opportunities for faculty, staff, students, and community members. Given that Penn State's geographic footprint is large, we may also be able to create an internal offset strategy that is broader than most other Universities in the U.S. We could have control over the budget and guide resource allocation using scientifically grounded data, as well as have no limits on the data we collect, which could help improve research and potentially improve technology development through a variety of external funding sources. Further, we could better control the transferability of research/technology development and build stronger links to existing educational activities and opportunities. Finally, an internal strategy should be revisited regularly and guided by accurate data that comprehensively portrays carbon emissions goals. As the inventory of Penn State's carbon emissions gets more accurate over time, we may see an increase in our reported emissions, and this offset strategy should be placed in that context.

If carbon offsets were produced in a local context by Penn State, there are many ways in which the University could lead. First, this would be an investment in Pennsylvania from the University, actualizing our mission as Pennsylvania's land-grant institution. By working with our local communities, we could increase the impact of our offset production by also helping those communities in which Penn State is present – and transfer our knowledge to such communities to support their growth and resilience. Local offset production also allows for education of students, faculty, staff, and community members – and allows for some degree of ease and control of resource allocation and verification of the validity and viability of the offsets produced. If carbon offsets were produced in a regional context by Penn State, beyond the advantages listed in the local section – our potential for impact of our carbon reduction efforts increases. We could activate the Commonwealth Campuses and our extension network to expand engagement, visibility, and provide resources to our region and communities. The production of Penn State carbon offsets would also increase our marketing and branding for Penn State. Depending on the region outlined, this could also affect those students who might enroll from outside of Pennsylvania availing of Discover Penn State Awards who are interested in universities being transparent about their carbon emissions reduction efforts.

### *Hybrid Offsets*

We consider a hybrid approach to be any carbon offset project or program developed under the auspices of Penn State, availing of finances, expertise, equipment, or technology, but not occurring on Penn State-owned lands. An advantage to the hybrid partnership approach is it allows us to combine the advantages of the external and internal approaches while using, selecting and validating viable projects using our parameters of offset verification.

We could build on the work we have already done internally to reduce carbon emissions at Penn State and build on the specific areas in which we could make more rapid progress by purchasing third party offsets and applying technology or approaches that our expertise could inform. We could activate current, and develop new, partnerships in a strategic way to maximize our resource investment (time, money, and expertise). Guided by a leadership entity, a hybrid approach may allow a greater degree of flexibility, but also allow for data driven direction and speed toward emission reduction both in the immediate and long term. We would also be able to leverage outside expertise (guided by our internal leadership entity) to ensure things like verification were embedded in our purchasing and production of offsets. This would also be a tangible way in which we could get the University community involved in a trajectory that builds over time, supported by third party carbon offsets, then moving towards carbon emissions reduction and internal offset (or external offset) production in a sustainable manner. We could also potentially maximize and expand our impact by using both an internal and external approach to offset purchasing and production, assisting communities in multiple ways, but also providing opportunities for yet unrealized partnerships.

*Image 18: Abandoned gas wells leak methane and other GHGs to the atmosphere and a program to identify and plug them with resulting offsets is being developed. Credit: Susan Phillips / StateImpact Pennsylvania*

A variety of possible hybrid approaches can be imagined, and we describe a few briefly below and provide more detail for each of these in the appendices. A common thread in these examples is that they draw on existing Penn State expertise and/or focus on addressing issues of long-term environmental degradation in Pennsylvania. For example, capturing methane from existing orphaned oil and gas wells (Well Done Foundation and coal mines (CNX would help to address statewide problems and may be deployable on a small subset of our Commonwealth Campuses on which these features are known to exist. Similarly, the presence of inadequately reclaimed and abandoned mine lands throughout the state represents an excellent opportunity to sequester carbon in soils by soil restoration and reforestation in partnership with GreenForestsWork and the PA Department of Environmental Protection. Conversations with the Centre County Planning and Development Office indicate a strong interest in partnering with the University to develop regional programs of agricultural land management to increase carbon sequestration in farm soils while helping to protect water quality. Lastly, Plant Village, led by PSU faculty member D. Hughes, is a USAID-funded program to engage small farms in Africa including an effort to plant trees, sequester carbon, and develop an offsets program – PSU investment in and overall support of this program could be far reaching in climate action impact and in broadening the Penn State brand internationally. Plant Village was foundational to a $39 million investment for the establishment of the Feed the Future Innovation Lab for Current and Emerging Threats to Crops, a program announced by USAID administrator S. Power at the COP26 meeting. This award highlights the opportunity for Penn State to leverage its research-education-outreach enterprise alongside offset strategies.

## CARBON OFFSET RECOMMENDATIONS

- Since eliminating our GHG emissions is technologically and financially challenging in the short term, the University should develop an innovative carbon offsets program as a component of its emission reduction strategy that provides solutions to the intractable problem of carbon cycle management for society at large.
- The carbon offsets program should investigate both internal and hybrid approaches. Offsets developed internally on Penn State land may offset some of our emissions, acknowledging that it will not be sufficient to offset the entirety of our emissions but can provide important educational, outreach, research, economic, and community development opportunities. A hybrid approach, by partnering with landowners and other entities but deploying Penn State's unique resources, expertise, labor, and technology, should also be developed.
- Third-party carbon credits on the voluntary market could be purchased in the short term (years) to build momentum toward achieving a carbon neutrality or negative goal, to demonstrate the seriousness with which the University views the problem of global warming, and to establish the University as a leader in solving the climate crisis.
- An Offset management committee should be formed, comprised of appropriate natural and social scientific, legal, operational, and financial expertise, to guide the University through the development of an offset strategy that is revisited annually and improved over time in a rigorous manner. Consideration of educational and societal co-benefits and development of core criteria and principles for investment decisions should be part of this committee's charge.

## Modeling of Emissions Reduction Strategies

### EXPLANATION

The Integrated Energy (& Emissions) Portfolio (IEP) model is a long-term cost and GHG projection model used to evaluate the cost, risk, and carbon impacts of existing and potential campus energy systems and procurement plans. The IEP modeling process establishes a 35-year baseline reflecting business-as-usual (BAU) based on the existing utility systems and contract commitments. The BAU baseline forms a point of reference and comparison for the evaluation of potential changes to the portfolio including:

- Capital investments to reduce energy use or shift to cleaner fuels.
- Purchases of utilities such as renewable electricity, natural gas, water, and/or clean energy credits.
- Regulatory evolution promoting clean energy purchases and the transition away from fossil fuels.
- Market evolution and the associated uncertainty of future price trends.

The IEP, and its valuation process, provides the CERTF with an objective, empirical, and standardized approach to comparing the cost, risk, and carbon impact of various pathways that lead to carbon neutrality.

OPP has built the IEP with the help of an outside consultant over the last seven years and has applied it to develop strategies that optimize capital allocation, meet sustainability goals, and reduce cost, risk, and carbon emissions. For example, the IEP model was used during OPP's pursuit of its 2020 GHG goals, which ultimately led to the execution of the large-scale solar purchase in Franklin County.

The IEP model receives inputs for projected usage of carbon emitting sources, invested capital, operating costs, purchases, and market prices and calculates an integrated, portfolio-wide projection of cost, risk, and carbon emissions over the thirty five-year modeling horizon. The output includes detailed cost, usage, and carbon metrics and quantifies portfolio risks inherent in open (un-contracted) positions that are subject to the uncertainty of future energy markets.

### CERTF APPLICATION & PROCESS

The CERTF mission is to identify, evaluate, and optimize opportunities that reduce or eliminate carbon emissions from Penn State operations. Recognizing there are numerous and competing paths to achieving carbon reduction and neutrality, the CERTF used the IEP to define, value, and rank opportunities. Four approaches were used to frame the benefits and risks of the various carbon reduction opportunities identified by the Subcommittees:

- **Stand-Alone Strategies** – each opportunity was analyzed against a baseline on its own merits.
- **Combined Scenarios** – a combination of strategies was used to maximize the carbon reduction potential.
- **Carbon Neutral Scenarios** – combined scenarios were also modeled with carbon offsets and REC purchases sufficient to achieve annual carbon neutrality across the entire portfolio and model horizon.
- **Goal-Oriented Combined Scenarios** – combined scenarios targeting the recommended carbon reduction milestones.

These approaches were used to rank options on a cost, capital, and carbon reduction basis which forms the foundation for recommendations provided in this report. The key metrics used to rank scenarios are:

- **Total Portfolio Cost (TPC) ($NPV)** – this metric, expressed as a Net Present Value (NPV), provides the net cost impact of a scenario on the portfolio over the modeling horizon compared to the BAU baseline. For example, Penn State's approximately $30 million annual portfolio cost in the BAU baseline results in a TPC of $737 million. A scenario that results in a TPC of $750 million would have a +$13 million TPC NPV metric interpreted as adding $13 million to the total portfolio cost on a net present value basis.
- **Total Carbon Reduction ($MTCO_2e$)** – this metric measures the total amount of carbon reduced in MTCO2e by a scenario compared to the BAU baseline over the model horizon.
- **Unit Cost of Carbon ($NPV/MTCO2e)** – this metric provides a ratio between the TPC of the scenario and the Total Carbon Reduction achieved by the scenario. For example, a scenario that increased the portfolio cost on a Net Present Value basis by $1 million and reduced 50,000 MTCO2e, would result in a Unit Cost of Carbon of $20/MTCO2e.
- **Capital Requirement (CapEx)** – this metric measures the amount of capital in total dollars that would be required to implement the strategies within the scenario. For example, a scenario including the purchase of solar generation under a PPA like Franklin County will have no CapEx; however, CapEx would be required in a scenario where Penn State owns the solar asset.

The primary ranking metric is the Unit Cost of Carbon. However, recommendations are guided by consideration of each metric listed above against key objectives and goals such as:

- **Carbon Reduction Timing** – is the timing consistent with the goals.
- **Capital Availability** – a strong Unit Cost of Carbon metric may require a large capital investment which is not currently available.
- **Credit Purchases** – credit purchases should be minimized as they do not directly reduce Penn State's carbon emissions, but they can allow for early claims of carbon neutrality without a large up front capital investment.
- **Commercial Viability** – a technology that looks attractive may not be commercially viable today, and its economics could improve or degrade as it continues to be developed.

The IEP allowed the CERTF to view each stand-alone strategy and combined scenario within a common framework and to manage the sizing of strategies in combined scenarios to avoid over-building energy equipment and/or over-purchasing clean energy.

## MODELED SCENARIOS

The combined scenarios modeled include various mixes of clean energy purchases, carbon credit purchases, and electrical and thermal technologies. As shown below, combined scenarios include various combinations of stand-alone strategies (Purchases and Projects) with the mix changing over time.

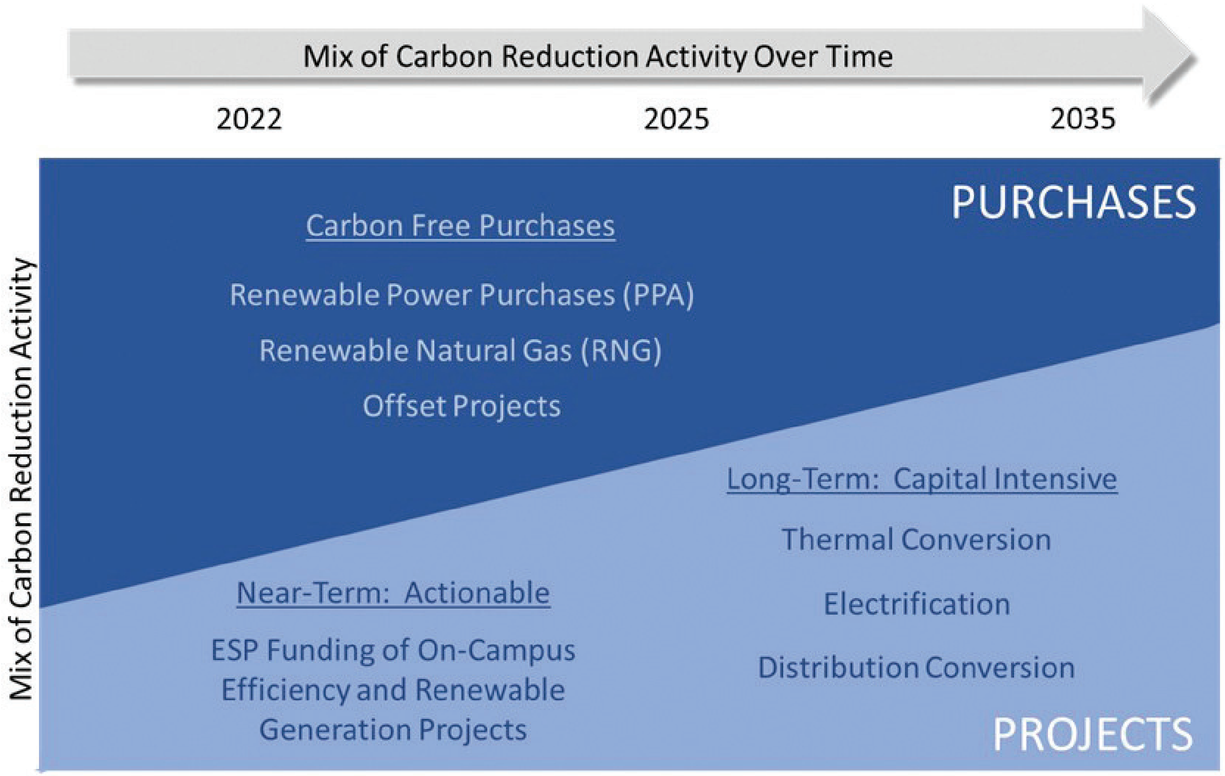



*Figure 14: Illustrative Mix of GHG Mitigation Strategies Over Time*

Combined scenarios value the mix of 1) projects that require capital to convert the energy systems to emit less (or no) carbon, and 2) purchases that eliminate carbon emissions with no up-front capital requirement. As shown below, the combination of projects and purchases requires iteration to avoid conflicts between the two.

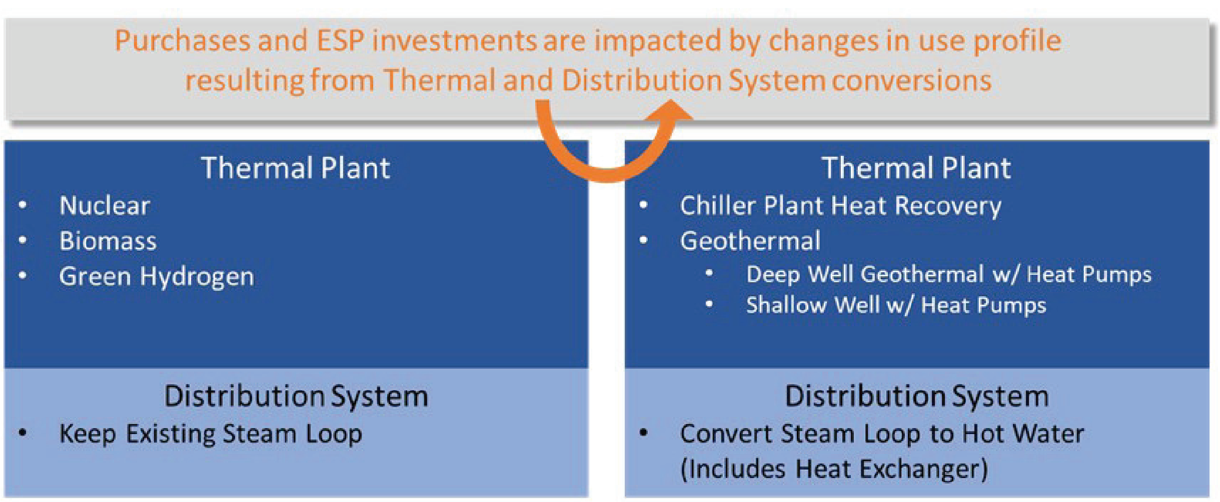



*Figure 15: Interaction Between Project and Purchase Mitigation*

To avoid strategy conflicts in combined scenarios, each scenario is constructed to ensure all aspects of the scenario work together and do not create conditions where energy purchases exceed the eventual use profile following implementation of large-scale projects. Currently, Penn State is not able to account for energy resale, storage, or conversion; however, if that changes in the future, larger renewable transactions could be pursued.

For example, in the graph below showing projected electricity usage over time, conversion of the UP thermal system to nuclear technology will reduce electricity purchases (through increased on-site electric generation as indicated by the projects section of the chart) and limit the amount available to purchase under a long-term renewable PPA purchase (as shown in the green section of the chart). Additionally, credit purchases (shown in blue) must be sized to offset only the carbon emissions not otherwise attenuated by the projects and purchases. If a clean energy purchase is contracted early in the time horizon without consideration of the impact of the eventual project implementation, the purchase will need to be renegotiated or sold into the market with exposure to potential financial losses.

To the right is a list of the stand-alone strategies analyzed to date and used in the combined scenarios contained in this report.

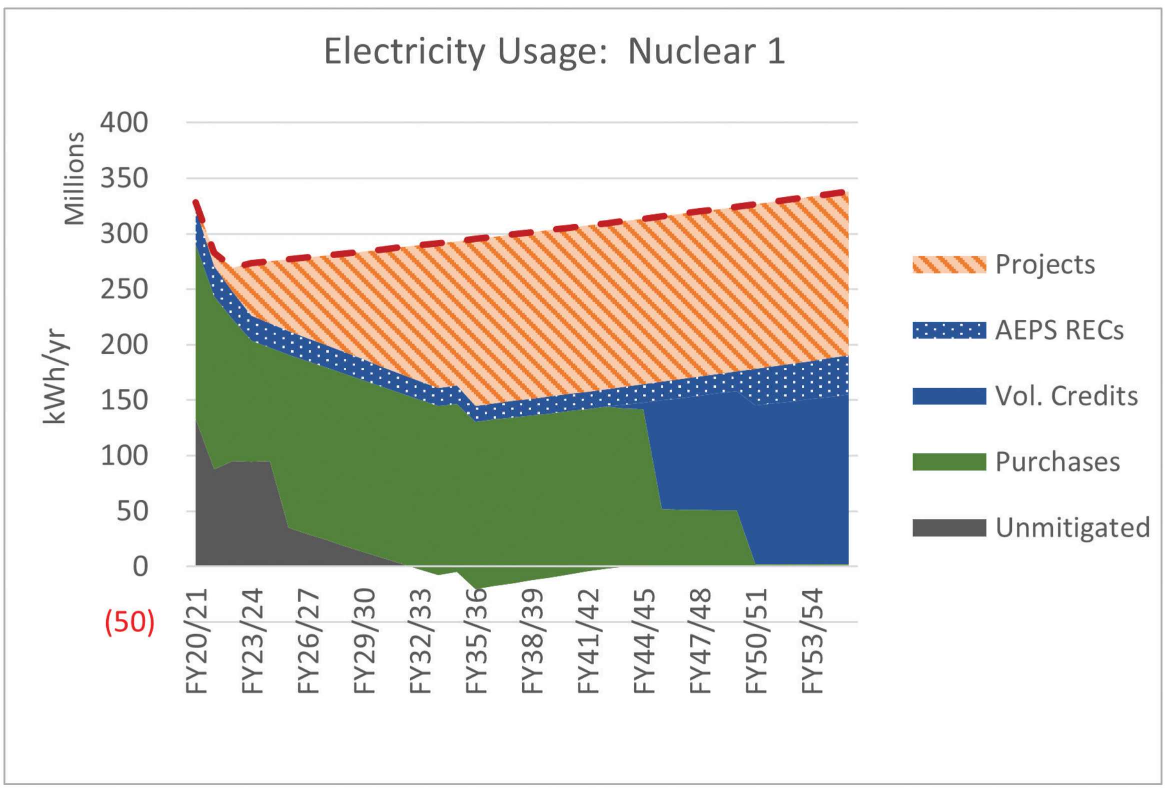



*Figure 16: Electricity Use and GHG Mitigation by Strategy Type*

*Table 8: Stand-Alone Strategy Descriptions*

| Name | Description |
|---|---|
| All Credits | Purchase of Offsets (RGGI priced) and RECs (Green-e priced) to cover 100% of Scope 1 & 2 emissions. |
| Bio Max Econ | Add Biomass boilers and associated equipment to UP Steam Plant and dispatch for maximum economic benefit. |
| Bio Max GHG | Add Biomass boilers and associated equipment to UP Steam Plant and dispatch to maximize carbon reduction. |
| Bio WCSP Only | Add Biomass boilers and associated equipment to UP Steam Plant using only the West Campus Steam Plant (WCSP) to feed peaking requirements. |
| Carbon DAC | Install direct air capture (DAC) equipment to remove carbon directly from the atmosphere. |
| CCS | Install Carbon Capture and Sequestration (CCS) at the East Campus Steam Plant (ECSP) with a pipeline transporting sequestered carbon to local sink. |
| CWC Solar | Install solar on Commonwealth Campuses (CWC) based on recent internal study of available land. |
| CWC SW Geo | Conversion of all buildings on Commonwealth Campuses to electric using shallow well geothermal and electric heat pumps. |
| ESP Existing | The current ESP program with existing financial justification for 10-year payback projects considering energy savings only. |
| ESP Revised | Revise the ESP program funding energy efficiency projects to allow for longer paybacks consistent with the alternative cost of credit purchases. |
| EV Transition | Transition Fleet and OPP vehicles to Electric Vehicles (EVs) during the existing 5-year vehicle rotation and installing charging equipment and electrical upgrades. |
| Elec Boilers ST | Converting natural gas boilers to electric boilers to feed thermal resources into the existing steam distribution system. |
| GR Hydrogen | Convert UP Steam Plant to green hydrogen including a large long-term solar power purchase agreement (PPA) to support the generation of hydrogen. |
| HBG Bio | Add Biomass boiler and equipment to displace use of natural gas at the Harrisburg Campus. |
| HW CHWX | Convert steam distribution system to hot water and install building heat exchangers and a heat pump at the planned chiller plant. |
| HW DW Geo | Convert steam distribution system to hot water and add HW CHWX plus a deep well geothermal system with heat pumps. |
| HW SW Geo | Convert steam distribution system to hot water and add HW CHWX plus a shallow well geothermal system with heat pumps. |
| Nuclear 1 | Convert UP Steam Plant to modular nuclear using a molten salt core technology (or similar). |
| Nuclear 2 | Convert UP Steam Plant to modular nuclear using a solid core technology (or similar). |
| PPA2 | Purchase a second large scale 25-year solar PPA similar to Franklin County at current market economics (higher cost). |
| RNG | Purchase Renewable Natural Gas (RNG) from local PA project similar to an offer from Marvel Power to acquire clean gas and offset credits. |
| ST to HW | Convert steam distribution system to hot water by replacing old underground steam infrastructure with low temperature equipment. |
| WRF FC | Install a fuel cell at the Water Reclamation Facility to generate electricity with currently flared biogas. |

These strategies were evaluated individually and within scenarios that combine multiple strategies to maximize the carbon reduction potential. The table below provides the key metrics for each strategy including:

- **Strategy** – the strategy short name.
- **Scope Impact** – the scope of carbon the strategy impacts.
- **Unit Cost of Carbon Reduction** – the TPC of the strategy (in $NPV compared to the BAU baseline) divided by the amount of carbon reduced through the end of the analysis term.
- **Net Cost** – The TPC of the energy and emissions portfolio inclusive of the strategy and compared to the BAU baseline.
- **Total Carbon Impact** – The expected total amount of carbon removed from the portfolio due to implementation of the strategy.
- **Total Capital Requirement** – the amount of capital required to implement the strategy.
- **Annual Operating Cost** – the annual cost increase/ decrease compared to the BAU baseline following implementation of the strategy.
- **Remaining Social Cost of Carbon** – representing the societal costs of unmitigated carbon emissions using $75/MTCO2e as provide by the U.S. Environmental Protection Agency (EPA).

*Table 9: Key Performance Metrics for IEP Modeled Stand-Alone Strategies*

| Strategy | Unit Cost of Carbon Reduction *($/MTCO2e)* | Net Cost *Negative = Savings ($NPV)* | Total Carbon Impact *(MTCO2e)* | Total Capital Requirement *($)* | Annual Operating Cost *($NPV)* | Remaining Social Cost of Carbon *(Total $MM)* |
|---|---|---|---|---|---|---|
| ESP Existing | (53.66) | (40,719,866) | (758,805) | 45,000,000 | 0 | 543 |
| WRF FC | (40.83) | (2,975,528) | (72,880) | 1,900,000 | 1,105,536 | 595 |
| HBG Biomass | (3.22) | (166,854) | (51,852) | 1,800,000 | 522,145 | 596 |
| PPA2 | 4.37 | 5,365,815 | (1,227,937) | 0 | 0 | 508 |
| CWC Solar | 8.10 | 1,834,221 | (226,444) | 41,837,133 | 3,275,262 | 583 |
| ESP Revised | 15.37 | 11,663,891 | (758,805) | 120,000,000 | 0 | 543 |
| Nuclear 1 | 19.35 | 56,258,389 | (2,907,861) | 192,000,000 | 41,513,079 | 382 |
| All Credits | 19.81 | 158,235,172 | (8,000,000) | 0 | 0 | 0 |
| RNG | 34.93 | 60,915,895 | (1,743,710) | 0 | 0 | 469 |
| HW CHWX | 78.30 | 76,383,410 | (975,468) | 139,760,000 | (25,901,601) | 527 |
| HW SW Geo | 80.20 | 118,218,512 | (1,473,966) | 169,760,000 | (22,781,666) | 489 |
| Bio WCSP Only | 82.12 | 172,380,902 | (2,099,236) | 140,000,000 | 31,168,439 | 443 |
| Bio Max Econ | 85.09 | 147,283,196 | (1,730,981) | 140,000,000 | 31,168,439 | 470 |
| ST to HW | 96.51 | 60,768,600 | (629,681) | 130,760,000 | (25,901,601) | 553 |
| EV Transition | 97.07 | 6,593,333 | (67,925) | 28,502,867 | (1,151,999) | 595 |
| Bio Max GHG | 100.83 | 211,785,998 | (2,100,420) | 140,000,000 | 31,168,439 | 442 |
| HW DW Geo | 116.72 | 232,635,434 | (1,993,071) | 258,760,000 | 0 | 451 |
| Nuclear 2 | 170.06 | 144,337,440 | (848,730) | 222,000,000 | 20,603,344 | 536 |
| Gr Hydrogen | 198.18 | 729,569,683 | (3,681,346) | 300,000,000 | 96,461,621 | 324 |
| Elec Boilers ST | 226.43 | 511,285,434 | (2,258,010) | 155,000,000 | 0 | 431 |
| CCS | 453.25 | 297,434,530 | (656,228) | 225,000,000 | 69,671,498 | 551 |
| CWC SW Geo | 462.01 | 240,139,401 | (519,767) | 333,000,000 | 0 | 561 |
| Carbon DAC | 5,669.59 | 1,900,496,254 | (335,209) | 1,627,000,000 | 422,355,446 | 575 |

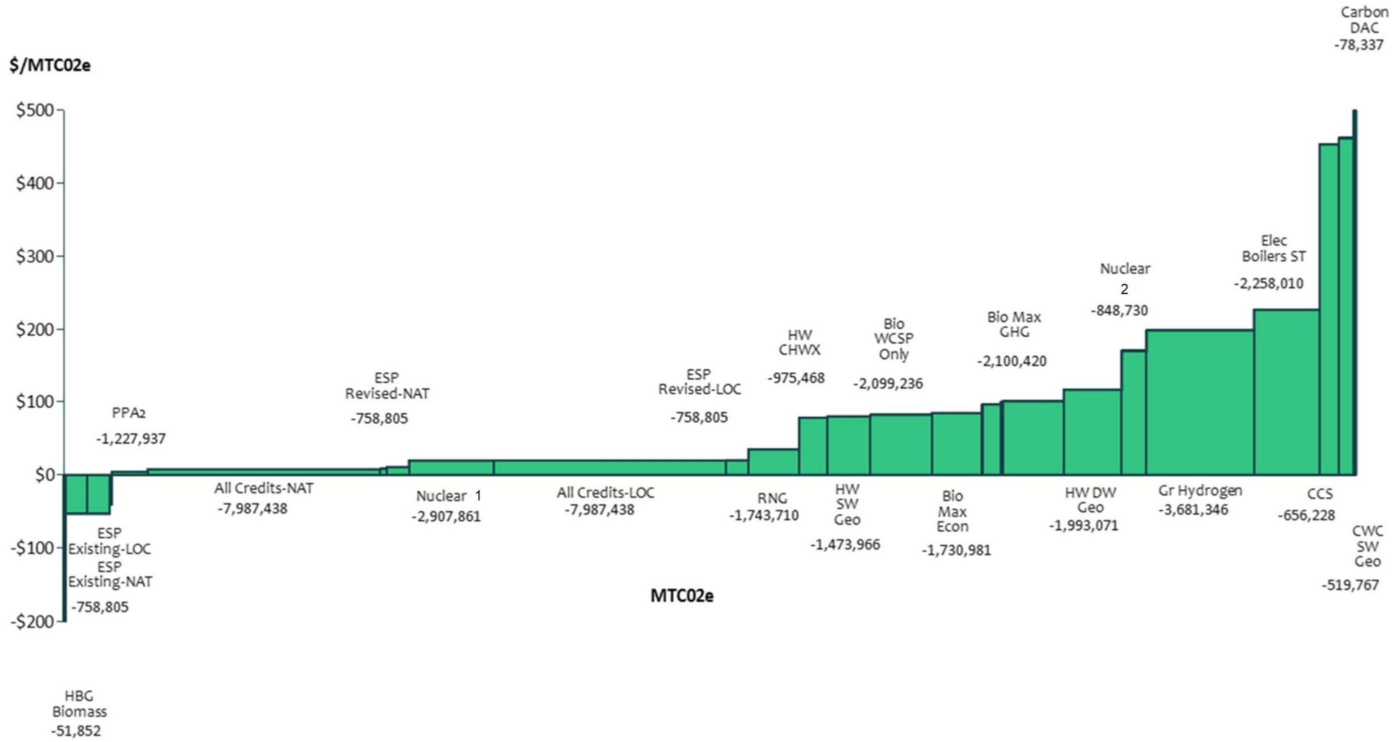



*Figure 17: Rank Order of Stand-Alone Strategies Based on Unit Cost of Carbon Reduction in $/MTCO2e*

While Table 9 and Figure 17 above rank stand-alone strategies using the Unit Cost of Carbon Reduction metric, Figures 18-19 below provide additional key insights into the effectiveness of each strategy.

First, in Figure 18, each strategy is plotted along an x-axis representing cumulative carbon reduction through the end of the modeling term (FY 55/56) and a y-axis representing the annual cost savings excluding capital and financing costs. The size of the bubble reflects the capital cost required to implement the strategy. As shown, capital has the highest impact in the top right quadrant of the graph, and capital deployment that creates negative cost savings are on the bottom half of the graph. Strategies targeted for recommendation and further consideration are in the top portion of the graph where the capital creates annual savings ***AND*** reduces carbon emissions.

The second plot, Figure 19 below, illustrates the return on capital by plotting an x-axis with the same cost savings and a y-axis with capital cost (the same as the size of the dots above). Strategies with a higher ratio between cost savings and capital provide a viable return on capital (ROC) and are located on the right side of the graph, whereas strategies that provide a low (or no) return on capital are located on the left side of the graph. The right side of the graph is broken into two likely capital sources: Grant/Donation Capital and Financeable Capital. Grant/Donation Capital would target projects that are financially viable (over 0% ROC) but do not provide the level of return needed to obtain typical financing. As such, these projects would be sourced from public/private grants and/or private donors such as alumni. Projects with at least a 5% ROC may be financeable in the debt or bond markets.

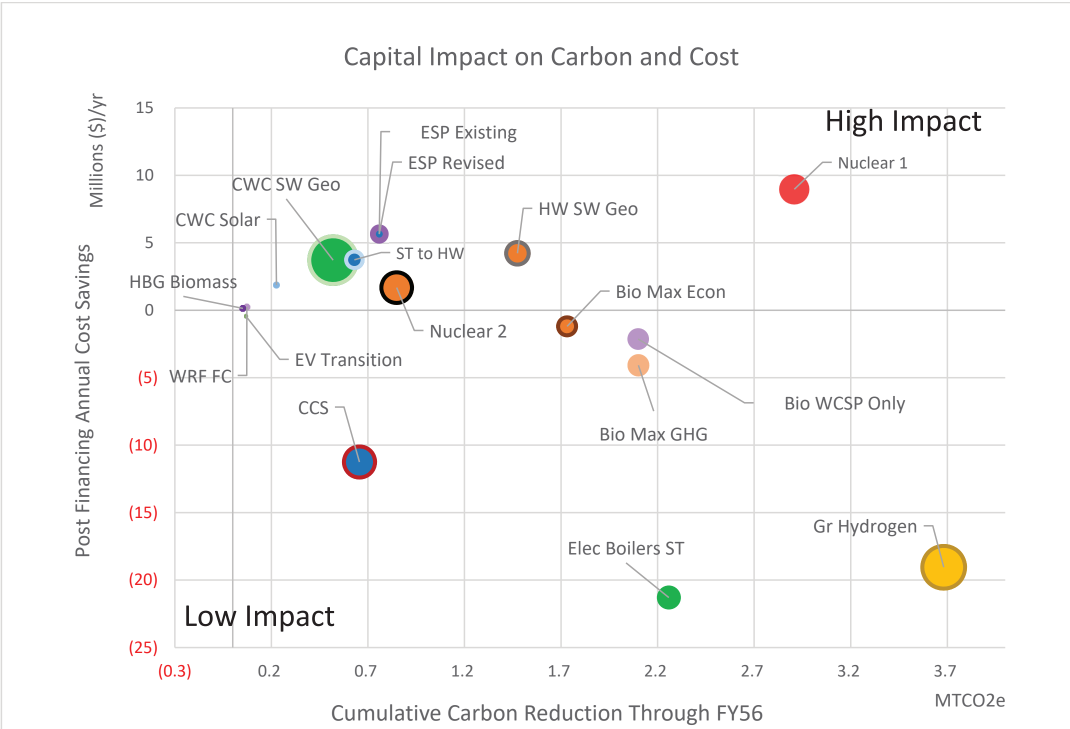



*Figure 18: Capital Impact on Carbon Reduction and Annual Costs*
*Note: Negative Cost Savings in the chart denotes an increase in cost compared to the baseline*

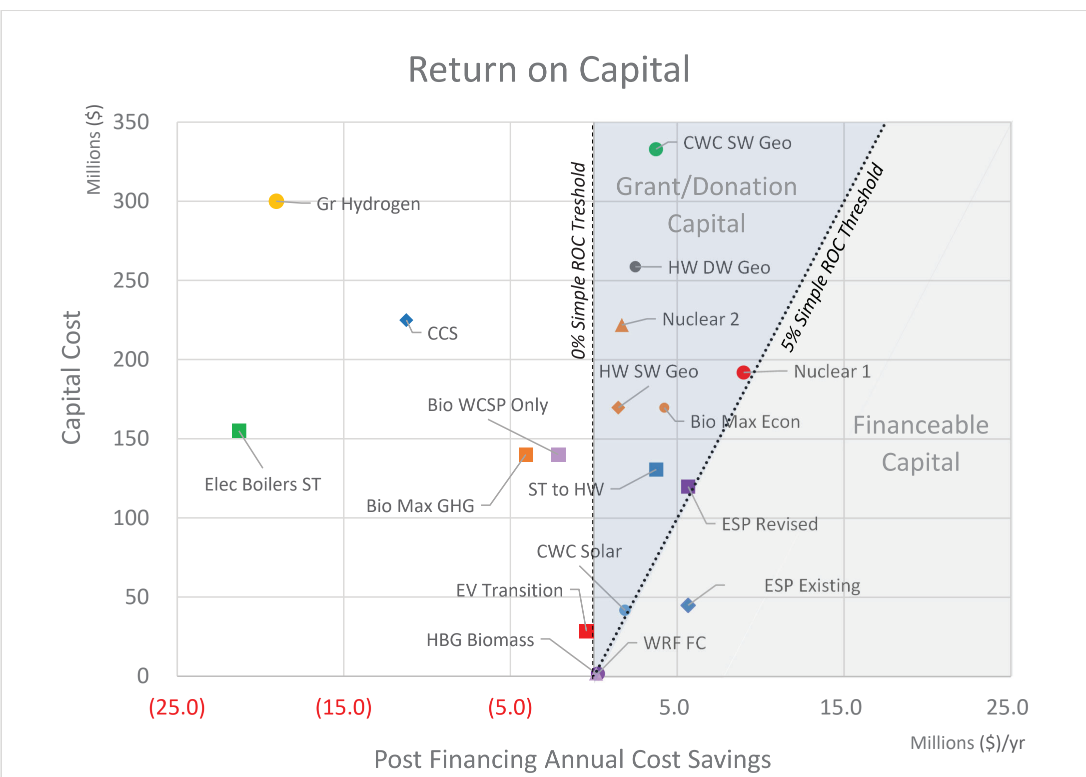



*Figure 19: Expected Return on Capital*

As expected, both graphs indicate the same set of strategies have positive impact; however, only a few fit the likely requirements for financing whether through debt and bond markets or other third-parties such as equipment providers. To further understand the financial and cost impacts, combined scenarios were designed to determine the total cost and carbon reduction that can be achieved by implementing multiple strategies within the portfolio.

The scenarios evaluated for this report are listed in Table 10 below as combinations of select stand-alone strategies described above and in accordance with the recommended milestones and associated actions under Goal #1.

To reduce credit purchases and fully decarbonize Scopes 1 and 2 of the portfolio, a transformation of the thermal, electrical and distribution systems will be required. Table 11 below provides the key metrics for the scenarios listed in Table 10.

*Table 10: Combined Scenario Descriptions*

| Name | Description |
|---|---|
| Nuclear 1 | All Milestone actions plus a conversion of the UP steam plants to molten salt core nuclear technology connected to existing steam infrastructure |
| Nuclear 2 | All Milestone actions plus a conversion of the UP steam plants to solid core nuclear technology connected to existing steam infrastructure |
| HW SW Geo | All Milestone actions plus a conversion of the UP steam plants to electric heat pumps supported by shallow well (SW) geothermal AND the conversion of the UP distribution system from Steam to How Water (HW) |
| HW DW Geo | All Milestone actions plus a conversion of the UP steam plants to electric heat pumps supported by deep well (DW) geothermal AND the conversion of the UP distribution system from Steam to How Water (HW) |
| UP Biomass | All Milestone actions plus a conversion of the UP steam plants to biomass boilers connected to the existing steam infrastructure |

*Table 11: Key Performance Metrics for IEP Modeled Combined Scenarios Targeting Recommended Milestones*

| Scenario | Unit Cost of Carbon Reduction *($/MTCO2e)* | Net Cost *Negative = Savings* *($NPV)* | Total Carbon Impact *(MTCO2e)* | Total Capital Requirement *($)* | Annual Operating Cost *($NPV)* | Remaining Social Cost of Carbon *(Total $MM)* |
|---|---|---|---|---|---|---|
| Nuclear 1 | 43.15 | 384,651,300 | (8,914,420) | 719,040,000 | 30,063,935 | 0 |
| UP Biomass | 49.91 | 442,969,058 | (8,876,093) | 667,040,000 | 17,403,230 | 0 |
| Nuclear 2 | 52.93 | 469,841,861 | (8,877,407) | 749,040,000 | 16,210,945 | 0 |
| HW SW Geo | 73.48 | 624,178,081 | (8,494,232) | 696,800,000 | (15,789,021) | 0 |
| HW DW Geo | 83.45 | 710,402,186 | (8,513,010) | 785,800,000 | (11,713,449) | 0 |

In addition to the metrics above, each scenario was rendered with the following graphs (using the Nuclear 1 scenario as an example):

- GHG Emission – is a condensed version of the wedge chart showing only future carbon reduction activity and the size and term of such reduction.
- Annual Cashflow – the expected annual change in cashflow (compared to the business-as-usual baseline) including changes in operating expenses, financing costs (capital and interest), and purchase premiums (the cost of a renewable purchase relative to a non-renewable purchase at market-based rates).
- Capital Expenditure – the estimated capital requirements by year and in total for the nuclear scenario.

The graphical results and a summary of key take-aways for each Combined Scenario are provided in the Modeling Appendix.

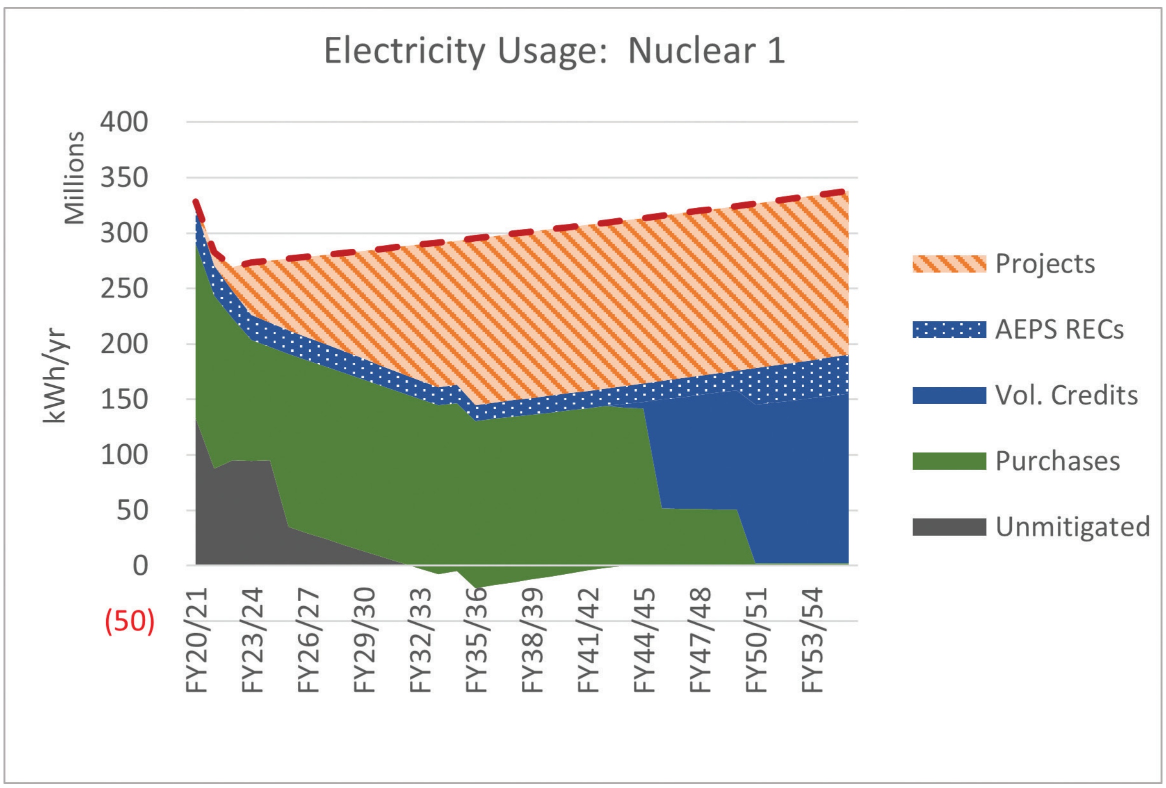



*Figure 20: GHG Reduction Scenario Using Nuclear 1 Strategy for the Thermal Conversion*

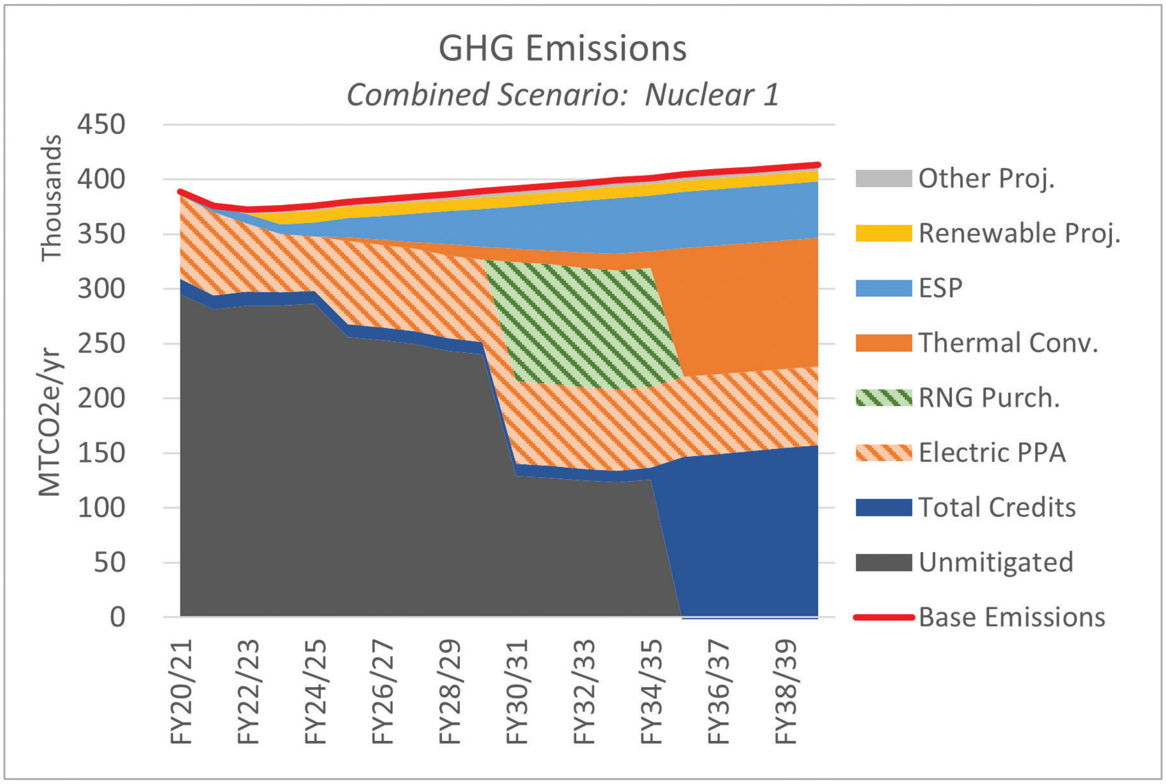



*Figure 21: Annual Cashflow Expectations for the Nuclear 1 Scenario*

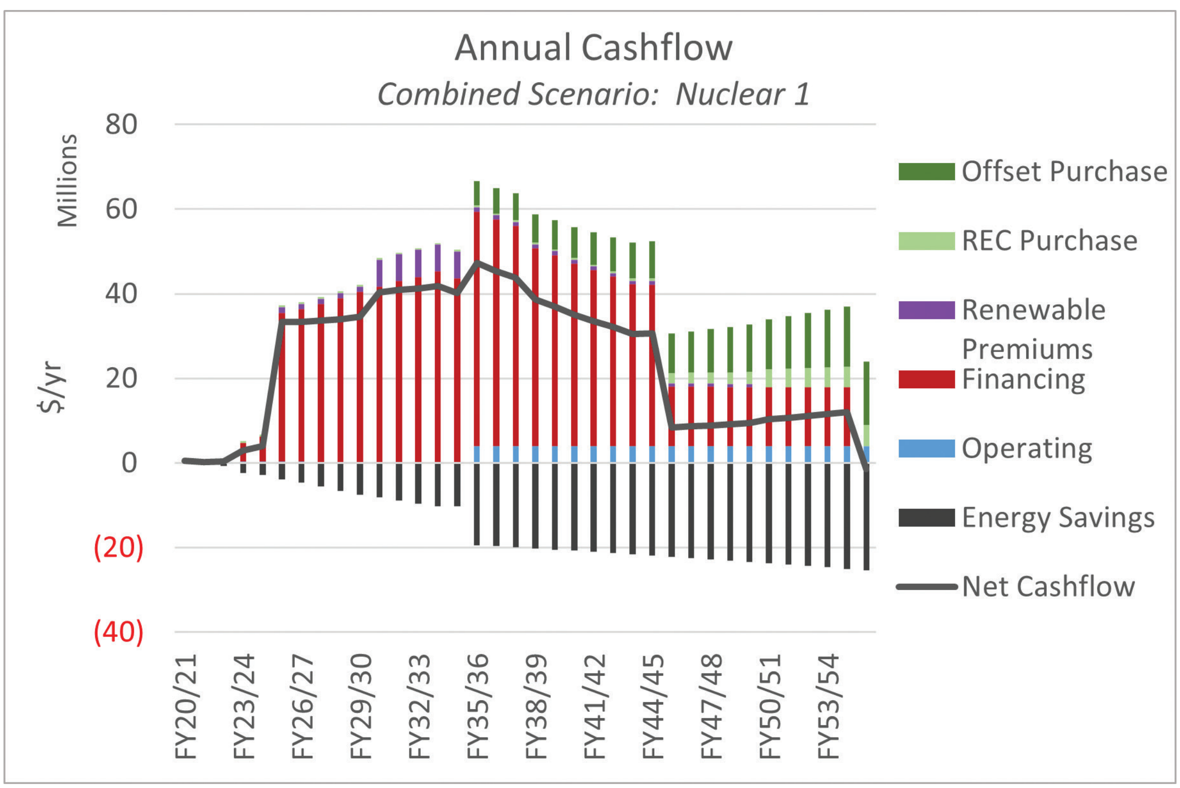



*Figure 22: Capital Expenditure Estimates for the Nuclear 1 Scenario*

## MODELING OBSERVATIONS

The quantitative analysis using the Integrated Energy/ Emissions Portfolio model influences the recommendations contained in this report through the following observations:

- All milestone scenarios include substantial capital investments ranging from $600 to $800 million with the major electrification and thermal conversion portions of the scenarios being 70% or more of the total capital required.
- The cost of carbon emissions that would be emitted without the capital investment, calculated using the EPA social cost of carbon at $75/MTCO2e over the term of the IEP analysis (through FY 55/56), is $600 million.
- Comparing the social cost of carbon of Penn State's carbon emission inventory and the capital required to eliminate carbon emissions gives important context to the capital requirements. *The capital investment in carbon reduction essentially shifts responsibility for the social cost of carbon from society back to Penn State where it belongs.* In other words, investing $750 million in actions that ultimately decarbonize Penn State's operations reduces the societal cost of carbon emissions by $600 million allowing Penn State to retake responsibility for these costs rather than imposing them on society.
- Annual cashflows, when viewed after the capital investment and financing costs are paid, range from cost neutral (Nuclear 1) to a $30 million annual cost increase (see Appendix H: Modeling of Emission Reduction Strategies).
- The amount of renewable energy purchases or REC/ offsets required to meet the final milestone ranges from 100,000 MTCO2e for mitigating Scope 3 under the Nuclear 1 strategy to 300,000 MTCO2e for mitigating Scope 3 emissions plus additional electric use required under electrification strategies such as HW SW Geo and HW DW Geo (see Appendix H: Modeling of Emission Reduction Strategies).
- Renewable purchases should be sized consistent with expected usage to avoid periods of oversupply following the implementation of large capital projects eliminating use or converting it from natural gas to electric. Given expected changes in energy use during the decarbonization process, a large scale, long-term renewable purchase will be difficult to properly size. Renewable purchases with shorter terms and volume flexibilities should be considered and any associated premiums may add to the annual cashflow estimates.

## MODELING RECOMMENDATIONS

- Recommit to the ESP program for another 10 years and allow for consideration of the value of carbon offsets in the payback analysis.
- Identify and execute renewable energy transactions for electricity (solar PPA) and renewable natural gas based on expected needs with consideration of more dynamic volume and cost environment.
- Commit to the purchase of carbon offsets and RECs over time to milestone targets that are not fully addressed by the actions above.
- Further study the effectiveness of large-scale thermal conversions to identify the right technology and timing to eliminate offset and REC purchase requirements needed to achieve the milestones.

# Funding Bold Climate Action

*The large cost of achieving the proposed carbon reduction goals is not lost on the Task Force.*

## A GENERATIONAL PHILANTHROPIC OPPORTUNITY

We believe a fundamental shift is needed from seeing the funding of climate action as a facilities and operations requirement to a University leadership priority aligned with our history, identity, and goals as a land-grant institution.

The Pennsylvania State University is a $7.8 billion institution of higher education facing a difficult economic climate due to declining or flat state appropriations, a tuition ceiling, and a recent past where already limited reserves were used to weather a global pandemic — which continues. In this context, how will we pay for robust climate action?

When the University embraces a leadership opportunity of this size and importance, new funding strategies are critical. By marshaling all its financial resources, moving beyond tuition and appropriation dollars to include private philanthropy and corporate sponsorships, Penn State can attract the investments needed to achieve these carbon emissions reduction goals.

## ATTRACTING THE NEW "CLIMATE DONOR"

Positioning bold Penn State climate action as a major philanthropic opportunity opens avenues to attract what has been called the new "climate donor." These are high net worth individuals who want to use their wealth to address climate change. There are tens of billions of dollars represented by this community of donors, many of whom may rank among our Penn State alumni, and there are few climate investments that can offer them the transparency, credibility, and societal impact that Penn State's carbon emissions reduction roadmap can.

For the donor, this represents a generational opportunity to impact the lives of students, faculty, alumni, and communities around the world — while bolstering Penn State's ability to be among the leading research institutions producing solutions to the climate crisis. According to Globe News Wire, there is a $283 billion clean tech market in 2020 which is expected to grow to $423.7 billion by 2026. If we include the markets for carbon capture, carbon offsets, energy storage and energy efficiency (subsets of the five major energy research areas where Penn State ranks in the top five nationally), the total market is over a trillion dollars.

Penn State will miss this leadership opportunity without philanthropic support. The Development and Alumni Relations Office was clear that such a philanthropic priority would require 100% clear support and championing by the University president. Presidential passion about the arts and food security — to pick two recent examples — are indicators that the chief executive's priorities make all the difference. For example, as a champion for the new Palmer Arts Museum, President Barron was able to catalyze $20 million in gifts in just 11 months. While more gifts are forthcoming to reach the $84 million target, his inescapable and undeniable passion and focus on this funding priority is what made it possible.

The President must make climate action a top priority and communicate this in compelling and consistent ways to University alumni. The establishment and branding of something like a Penn State Climate Endowment could provide a mechanism for donors to fund carbon emissions reduction projects, some of which may involve students in living lab experiences. When this happens, we are confident donors will emerge that perhaps have never contributed to their alma mater — or have never contributed for climate action.

When this power of executive support has been shown elsewhere, climate donors have responded. Below are examples from the past two years in higher education and the nonprofit sector. The emergence of the "climate donor" is a recent phenomenon that Penn State would be wise to capitalize on.

- $11.1 million: a gift from Dan and Sheryl Tishman to the University of Michigan to expand climate justice efforts.
- $750 million: a gift from Lynda and Stewart Resnick to the California Institute of Technology, the largest gift geared towards combating climate change ever to a university.
- $3.5 billion: a 10-year commitment by Laurene Powell Jobs to address the climate crisis specifically focused on climate-equity issues in housing, transportation, food security and health; where the funding is going hasn't been disclosed but nonprofits and universities are likely recipients.
- $2.5 billion: a pledge from Atlassian's Co-Founder and CEO Mike Cannon-Brookes for climate action, mostly as gifts to nonprofits; similarly, where the funding is going hasn't been disclosed but nonprofits and universities are likely recipients.
- $300 million: a pledge from Salesforce's co-founder and co-CEO Marc Benioff for climate action.
- $10 billion: the "Earth Pledge" was the largest donation of 2020 to climate action from Jeff Bezos and is beginning to be invested this year in environmental conservation, climate justice and clean energy projects.

The point here is that billions of dollars are now flowing into climate action. A bold, public commitment from Penn State would further strengthen our position as a credible recipient and steward of these dollars.

## CORPORATE PARTNERSHIPS FOR CLIMATE ACTION

When we see the funding of climate action as a leadership opportunity, not only a facilities requirement, we can use philanthropy to fund initiatives that enhance student experiences, climate bonds to fund large capital projects, and we can also engage another powerful part of the institution: corporate engagement.

Penn State's renewed Corporate Engagement Center plus the institution's wide-ranging existing connections with companies and start-ups in the energy and climate space, require only a strong external signal of bold climate action to rally around Penn State's goals. The public announcement of a bold, measurable carbon emissions reduction goal and a plan to get there will signal to these partners that Penn State is sincere in its commitment and "open for business" regarding strategic partnerships for climate action.

The University currently partners with many companies who have already set public, bold and measurable climate goals including:

- Amazon
- Microsoft
- PepsiCo
- Verizon
- Google

The nature of these partnerships has not yet included robust discussions of mutual support for extending their impact while advancing Penn State's climate research, action and education. However, since these are existing relationships, such discussions would be feasible and may well represent win-win opportunities for these companies as well as Penn State.

# Next Steps

This report provides a roadmap for Penn State carbon emissions reduction. Penn State is well positioned to achieve the proposed goals, but it is important to recognize there will be an immense amount of effort and investment required to implement these recommendations. Significant resources will be needed, both human and financial. But as this report makes clear, the benefits will also be great: for our University, the Commonwealth, and the world.

While this investment will reap important dividends for Penn State, those dividends will multiply manyfold if we leverage our expertise in energy innovation and climate solutions for education, research, and outreach. To maximize these benefits, the CERTF recommends an expanded effort to evaluate additional opportunities outside the scope of the original charge. These additional considerations will require ongoing attention by the various units across the University responsible for education, research, outreach, and financial management.

The following considerations, observations, and recommendations illustrate opportunities to multiply the power of Penn State for positive climate solutions.

1. **Create a Climate & Sustainability advisory board** of faculty, staff and students tasked with regularly evaluating, assessing and iterating upon Penn State's progress toward carbon neutrality, finding strategies to draw down emissions more rapidly, and identifying opportunities to amplify our impact through education, research, and engagement with our partners, communities, and government representatives. This Task Force demonstrated the power of engaging diverse perspectives from across the University in this effort.

2. **Encourage innovative, climate-smart courses and curriculum**. In response to the complex challenges of navigating a transition to a climate-solved world, Penn State needs to equip our students and communities with the knowledge, skills, and competencies that will enable them to make sound environmental decisions at home, at work, and in the public sphere to promote a more just and verdant society. The direct impact of our operations pales in comparison to the impact of all the graduates, families, businesses, and communities connected with Penn State. Education is an immense opportunity for impact that manifests our values of responsibility, inclusion, and sustainability. The Faculty Senate and Vice President and Dean for Undergraduate Education can play key roles in launching this effort.

3. **Climate Research Leadership**. Penn State researchers are at the forefront of many of the grand challenges of climate and energy research, at scales ranging from nanomaterials to planetary models. Our interdisciplinary approach to integrated energy systems, climate research, and social science research is a proven accelerator for innovation and convergence research. With continued investments in outstanding faculty, facilities and programs Penn State can continue to provide the breakthroughs needed to solve climate challenges both locally and globally.

4. **Climate Research Infrastructure** can directly support operational carbon reduction programs with investments in field and laboratory instrumentation, models, and analysis. Across every college and each of our campuses Penn State has active research programs on climate science, climate resilience and climate solutions. Students and faculty can measure and model emissions from buildings, vehicles, cropland, and waste management.

Research groups and field laboratory classes can also document positive benefits from forest management, soil carbon accumulation, and more. Social scientists can help assess economics, policy, and behavioral challenges and opportunities. With the support of the colleges, campuses, and our University research institutes, faculty and students can help document progress toward our goals, learning-by-doing from a continuous improvement perspective.

5. **Embodied Carbon** demonstrates how this coupling of research and operations will be important. As Penn State's buildings become increasingly energy efficient, the carbon footprint of the materials used to construct the buildings becomes a larger and larger fraction of its life-cycle carbon impacts. Penn State researchers are at the forefront of innovation in carbon-negative and living materials, and where possible we should utilize carbon-capturing materials like wood and carbon-negative concrete in building plans, making them part of drawdown efforts.

6. **Climate Smart Procurement** should extend beyond the carbon footprint of materials used for our buildings and facilities, and include purchases of food, office supplies, laboratory equipment, and much more. In the terminology of GHG inventories, these are our Scope 3 emissions, and because we do not directly control the manufacturing and supply chain Scope 3 emissions can be the most difficult to reduce. Life cycle analysis can help support decisions about our purchasing options at both individual and institutional levels. Penn State has many faculty and students already developing and using life cycle analysis, supply chain management, blockchain, and other sustainability tracking, measurement, accounting, communication and decision tools. We should engage these internal partners, and partner with our peers at BTAA and other U.S. and international research university networks to both encourage smart purchasing decisions, and to drive carbon emissions reductions across these supply chains. By documenting and using climate impacts as criteria for our purchases, Penn State and our partners can encourage changes in the business practices of our suppliers, addressing not only our own Scope 3 emissions but all the other customers of our suppliers that lack our purchasing clout.

7. **Climate Smart Investing**. Penn State financial leaders should investigate how other institutions have evaluated and addressed investments in emission intensive industries and helped support new as well as legacy companies that are innovating to reduce emissions. Integrating climate performance into an investment portfolio can help motivate businesses to improve their performance and increase the value and income from our investment portfolio. A 2018 Corporate Knights report found that divesting from fossil fuels 10 years earlier would have made states $22.2 billion, for California and Colorado the amount was $19 billion.[76] As with procurement, we can partner with other climate responsible investors to encourage companies in energy, mining, construction, and other sectors to embrace the future and become climate positive.

[76] https://www.corporateknights.com/uncategorized/divestment-made-ny-pension-fund-22b-richer/

8. **Responsibility, Accountability, and Governance for Decarbonization.** Penn State has significantly reduced its carbon emissions over the past two decades through sustained effort to advance the energy efficiency of buildings and systems and expand the use of renewable energy. Achieving our decarbonization goals by 2035 will also require sustained organization-wide attention to decarbonization at a time scale of decades. We will need a "whole-of-organization" approach that can mobilize all parts of the University, leveraging and expanding on existing relationships within and across units. The benchmarking done for this report suggests that the most robust climate planning reports at peer institutions include participatory processes for community and stakeholder inclusion during carbon reduction plan development, transparency in reporting through online dashboards, and institutionalization of Climate Action Plans with clear governance structures and policies. Penn State's implementation efforts will be well served by clarifying formal executive level responsibility and accountability for carbon reduction, including governance practices that keep the Board of Trustees, Faculty Senate, and all the University leadership appraised of progress on carbon reduction, with active oversight through periodic reviews and reporting.

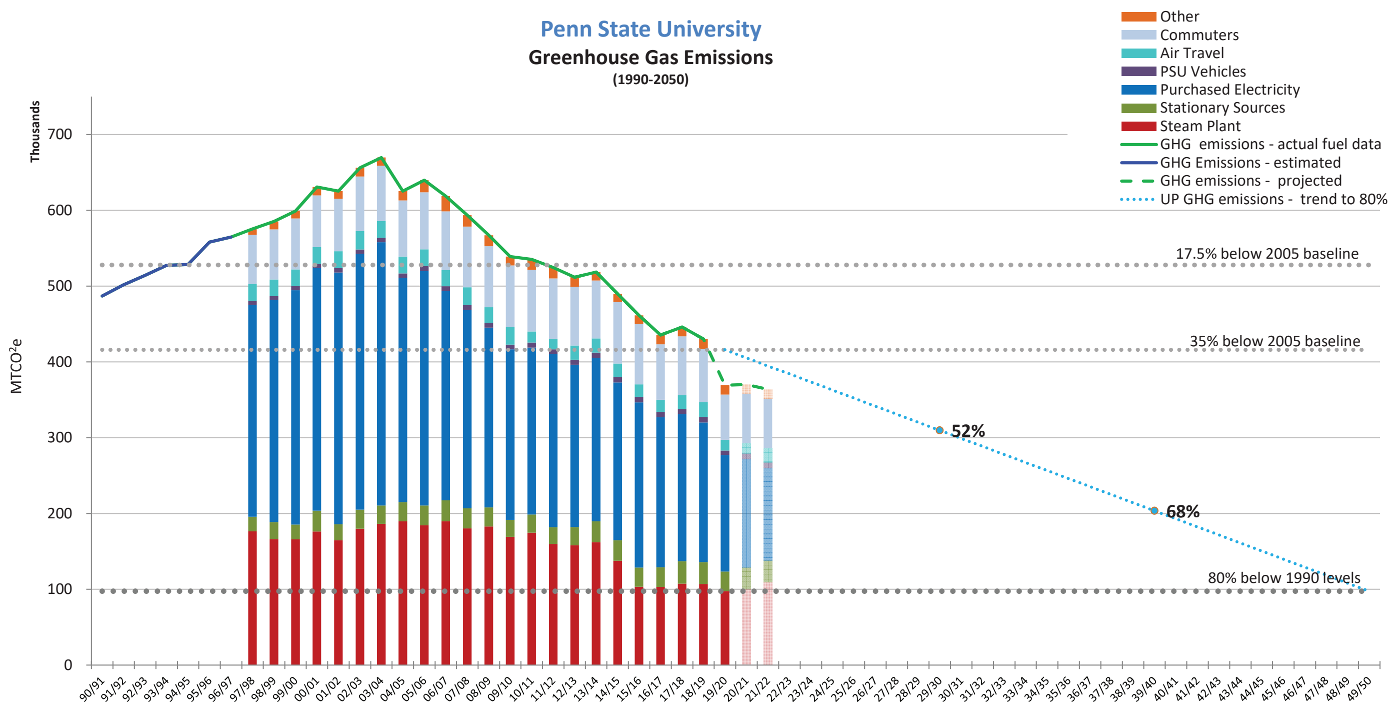
9. **Community Outreach and Public Engagement.** With this roadmap, Penn State has an important opportunity to engage both internal and external stakeholders in designing and implementing pathways toward a climate positive future. We can engage individuals and communities through town halls, forums, classes and community plans. Our corporate partners can help us drive innovation to commercialization and help us demonstrate that innovation in our own operations. Already we are hearing increasing calls for assistance from our community and business partners as they address their own carbon emissions, and we should organize our research, education, and outreach enterprise to provide them with the support they need.

# Appendices

## Appendix A: CERTF Charge

The following text is verbatim the charge for the task force as received from the President.

Penn State implemented an aggressive strategy to reduce carbon emissions ten years ago, consistent with the goal articulated by the Commonwealth of Pennsylvania, and since that time has made significant progress in reducing greenhouse gas (GHG) emissions. The University is ahead of schedule to meet its goal of GHG emissions reaching 80% below 1990 levels by 2050, as shown in the figure below. This has been achieved through disciplined and aggressive strategies, the deployment of new policies and novel technologies, and leveraging new opportunities when they present themselves. While the current goal was “audacious” when first conceived, current circumstances and the advent of new technologies demand that we revisit our approach to GHG emissions reduction and consider revising the goal itself (to zero GHG) as well as the timeframe in which this might be achieved.




Penn State GHG Emissions include stationary sources, purchased electricity, OPP & Fleet vehicles and estimated commuter miles, air travel, waste & wastewater, refrigerants and animal management.
Hershey Medical & Penn College of Technology not included.

*Figure 23: Penn State’s Historic GHG Emissions and Reduction Goals*

To that end the Carbon Emissions Reduction Task Force (CERTF) is charged to:

1. Review the organizational and operational boundary, scopes and sectors currently included in the current Penn State inventory, identify appropriate changes or additions needed to determine the specific set of operations and activities to be included in the goal.
2. Review Penn State's progress to date in GHG emissions reduction, catalog the interventions made, and assess their relative impacts.
3. Assess potential for expanded strategic deployment of existing approaches to further reduce emissions i.e., how do we maximize existing approaches.
4. Reconsider Penn State's GHG emissions goal with a view to setting a more aggressive yet attainable target or set of targets (e.g., zero, or negative) as well as a revised time frame in which this might be reasonably achieved.
5. Identify specific strategies focused on reduction of GHGs in our electric, thermal, and commuter portfolios, as well as other areas or opportunities where we can achieve carbon neutrality.
6. Identify emerging technologies that might be deployed to achieve these revised targets and provide specific recommendation to include an assessment of both risks and opportunities.
7. Assess investments required to deploy such approaches and develop elements of a business model that would enable their realization in a long-term, strategic, cost-efficient manner.

The scope should consider operations at all of Penn State's distributed campuses, facilities, and properties, including activities of employees and students while engaging in, or traveling to engage in, University and University-related activities. The scope should include, but not be limited to, electrical generation and purchase, thermal energy needs, travel and transportation, farm and related operations and potential effects of institutional policy changes re: telecommuting, etc.

While ideas that represent "stretch" or aspirational goals are welcomed, we are looking for specific, actionable, practical, and economically viable recommendations that when implemented will position Penn State as a leader in GHG emissions reduction and a model for other institutions and organizations to follow.

# Appendix B: Greenhouse Gas Emissions & Reductions History Report

## INVENTORY HISTORY

Penn State's first investigations into its greenhouse gas emissions began with students. In 1999, a GHG Inventory was completed for year 1997 by a graduate student.[77] In 2004, an inventory reviewing 10 years of historic emissions was conducted and included future projections.[78] In 2005, mitigation strategies were explored.[79] Since 2005, Penn State's GHG Inventory has been managed by the Office of Physical Plant and is updated annually. The inventory was expanded to include the Commonwealth Campuses in 2006. Over the years, data inputs and calculation methodologies have been updated along with the addition of Air Travel emissions.

The accounting methodology follows the generally accepted accounting principles provided by the World Resources Institute in the Greenhouse Gas Protocol. This accounting and reporting standard follows the guiding principles of relevance, completeness, consistency, transparency, and accuracy. Penn State's GHG Inventory organizational boundary follows the operational control approach and includes a separate inventory for each campus, with 22 locations in all. The Penn State Health System, including the College of Medicine and the Pennsylvania College of Technology, are excluded from the current inventory. Emissions are calculated for all GHGs including carbon dioxide ($CO_2$), methane ($CH_4$), and nitrous oxide ($N_2O$) as well as hydrofluorocarbons (HFCs) and perfluorocarbons (PFCs). The emissions are normalized into a common unit, metric tons of $CO_2$ equivalent (MTCO2e) using 100-year Global Warming Potential Factors (GWP) for each gas. Source data are collected from various units across the University (OPP, Transportation Services, Financial Information Systems, Farm Operations, Commonwealth Campuses, and outside vendors). Some data are carried over from previous years. Fuel or activity-based emissions factors are then used to calculate emissions.

Emissions are separated into three scopes. Scope 1 emissions are direct emissions from sources owned and operated by Penn State. Scope 2 are indirect emissions related to the generation of Penn State's purchased electricity. Scope 3 covers all other indirect emissions associated with Penn State's operations. Together, the three scopes provide a comprehensive accounting framework for managing direct and indirect emissions. Penn State's current GHG inventory includes all Scope 1 & 2 emissions as well as a few select categories of Scope 3 emissions.

## REGULATORY CONSIDERATIONS

In addition to the voluntary GHG Inventory completed annually, Penn State has regulatory obligations relating to GHG emissions. In 2009, the Environmental Protection Agency (EPA) finalized the Mandatory Reporting of Greenhouse Gases rule (40 CFR Parts 86, 87, 89 et al.) The rule applies to fossil fuel suppliers, direct greenhouse gas emitters, and manufacturers of heavy duty and off road vehicles and engines. The rule does not currently require control of GHG, rather it requires only sources above certain threshold levels (25,000 MTCO2e) to monitor and report emissions. University Park and Hershey Medical Center campuses have emissions above this threshold and report emissions to the EPA GHG Reporting Program (GHGRP) annually. In addition, UP reports carbon dioxide and methane emissions annually to the PA Department of Environmental Protection (PA DEP) as part of its Emission Inventory Production Report for the regulated stationary sources under its Title V Air Quality permit.

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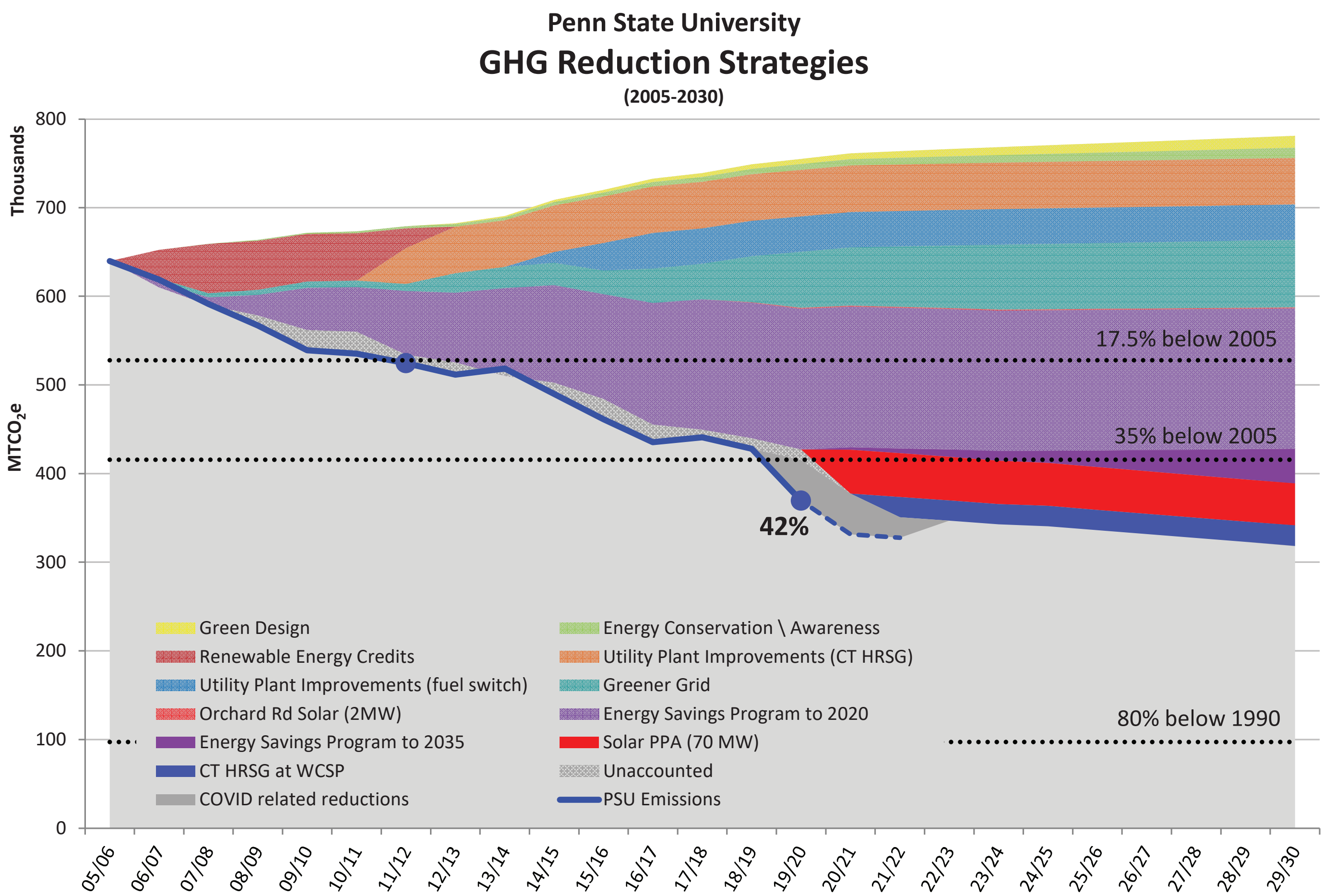
[77] A Greenhouse Gas Inventory of the University Park Campus, S.F. Lachman.
[78] A Greenhouse Gas Emissions Inventory and Projection for the University Park Campus, C. Steuer.
[79] Local Mitigation of Greenhouse Gases: Informing the Development of a Mitigation Action Plan for the University Park Campus, B. Nagle.

*Table 12:Penn State's Greenhouse Gas Emissions FY 19/20*

| Fiscal Year 2019-2020 (MTCO2e) | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Sectors** | **Energy** | | | | **Transportation** | | | | **Other*** | **Total** |
| | Stationary Sources | Steam Plant | Purchased Electricity | Total | Campus Vehicles | Commuters | Air Travel | Total | Other | |
| **Abington** | 1,236 | 0 | 1,754 | 2,990 | 94 | 3,158 | 83 | 3,335 | 74 | 6,400 |
| **Altoona** | 1,581 | 0 | 3,221 | 4,803 | 59 | 2,929 | 181 | 3,168 | 607 | 8,578 |
| **Beaver** | 337 | 0 | 1,649 | 1,986 | 3 | 450 | 16 | 469 | 60 | 2,514 |
| **Berks** | 791 | 0 | 2,549 | 3,340 | 13 | 1,891 | 92 | 1,997 | 135 | 5,472 |
| **Brandywine** | 566 | 0 | 1,361 | 1,927 | 23 | 1,616 | 42 | 1,681 | 45 | 3,653 |
| **Dickinson** | 218 | 0 | 396 | 614 | 4 | 597 | 44 | 645 | 27 | 1,285 |
| **Dubois** | 859 | 0 | 862 | 1,722 | 13 | 790 | 33 | 836 | 20 | 2,578 |
| **Erie** | 3,573 | 0 | 6,409 | 9,982 | 175 | 2,687 | 211 | 3,072 | 131 | 13,186 |
| **Fayette** | 525 | 0 | 1,768 | 2,293 | 12 | 852 | 26 | 890 | 79 | 3,262 |
| **Great Valley** | 0 | 0 | 625 | 625 | 9 | 637 | 24 | 670 | 13 | 1,308 |
| **Harrisburg** | 546 | 1,225 | 3,292 | 5,064 | 34 | 8,221 | 182 | 8,438 | 216 | 13,718 |
| **Hazleton** | 635 | 0 | 1,464 | 2,099 | 21 | 1,182 | 26 | 1,228 | 102 | 3,430 |
| **Lehigh Valley** | 47 | 0 | 601 | 648 | 28 | 1,255 | 52 | 1,335 | 10 | 1,993 |
| **Greater Allegheny** | 686 | 0 | 1,671 | 2,358 | 9 | 557 | 15 | 581 | 13 | 2,951 |
| **Mont Alto** | 427 | 0 | 1,688 | 2,115 | 9 | 1,022 | 38 | 1,069 | 44 | 3,227 |
| **New Kensington** | 120 | 0 | 1,591 | 1,711 | 8 | 597 | 22 | 627 | 11 | 2,350 |
| **Schuylkill** | 296 | 0 | 718 | 1,014 | 11 | 663 | 41 | 716 | 31 | 1,760 |
| **Shenango** | 806 | 0 | 956 | 1,762 | 8 | 760 | 4 | 772 | 30 | 2,564 |
| **University Park** | 11,038 | 96,508 | 118,628 | 226,174 | 5,438 | 27,438 | 12,871 | 45,746 | 10,562 | 282,482 |
| **Wilkes Barre** | 604 | 0 | 735 | 1,340 | 4 | 525 | 9 | 538 | 1 | 1,879 |
| **Worthington Scranton** | 213 | 0 | 793 | 1,006 | 11 | 1,119 | 52 | 1,183 | 8 | 2,197 |
| **York** | 523 | 0 | 1,054 | 1,576 | 0 | 895 | 33 | 928 | 0 | 2,504 |
| | | | | | | | | | | |
| **Total By Sector** | **25,626** | **97,734** | **153,787** | **277,147** | **5,987** | **59,841** | **14,097** | **79,925** | **12,220** | **369,292** |

**Other includes Solid Waste, Wastewater, Sythetic Chemicals, Animal Management and Land Management*




## GOALS AND REDUCTIONS

### *2005-2012*

In 2006, Penn State announced its first GHG reduction goal. This "significant double digit-reduction" goal was refined to the specific goal of **17.5% reduction by 2012 from a 2005 baseline**. To jump start the effort, Renewable Energy Credits were purchased from 2006 to 2011. A combustion turbine with a heat recovery steam generator (CT HRSG) was added to the East Campus Steam Plant, increasing the campus' use of combined heat and power technology. Emissions from purchased electricity are calculated based on eGRID emissions factors published by the Environmental Protection Agency (EPA). These are factors are developed from fuel consumption and emissions reports by electricity generators. Penn State realized reductions related to its purchased electricity based on reductions in these emissions factors. The Energy Savings Program funded $39 million dollars of projects from 2005-2012. In 2012, **Penn State met its goal by reducing its emissions by 18%**.

### *2012-2020*

In 2012, Penn State announced a new goal of a **35% reduction by 2012 from a 2005 baseline**. Also in 2012, the University announced the switch from coal to natural gas at the West Campus Steam Plant. This decision was in part due to additional air quality regulations (Boiler MACT that would have required additional control devices to be installed to continue on coal. The last day on coal was in March 2016. In addition, multiple utility system improvement projects were completed including the replacement of two steam turbines at the West Campus Steam Plant. In 2013, Penn State entered into a 10-year power purchase agreement from a 6 MW hydroelectric generation plant. In 2019, a 2 MW on-campus solar array located at University Park was installed. The ESP funded $89 million dollars of projects from 2012-2020, some of which went towards the large utility projects. Although the effects of the COVID-19 pandemic on University operations contributed to the larger reductions seen in FY 19/20, the 35% reduction goal was expected to be met prior to the pandemic. **Penn State met its goal by reducing its emissions by 42%**.

### *2020 and beyond*

Penn State's current goal is an 80% reduction by 2050 from a 1990 baseline. Using a 2005 baseline, that is an 85% reduction. This was developed based off the Paris Accord and is in line with the State of Pennslyvania's goal of an 80% reduction by 2050 from 2005 levels. In 2019, Penn State entered into a 25-year Solar PPA to purchase power from a 70 MW solar project across three sites in Franklin County near Penn State's Mont Alto campus. The array will provide 25% of Penn State's statewide electricity requirements. Penn State began taking power from this project in October 2020. A combustion turbine with a heat recovery steam generator and an additional steam turbine at the West Campus Steam Plant will be in operation in January 2022. These two major initiatives will move Penn State towards a 48% reduction. The University continues to investigate financially responsible opportunities to reduce emissions.

### *Reduction Strategies*

Energy is the largest contributor to Penn State's GHG emissions. It costs over $20 million annually to provide heat, cooling, electricity, and hot water to buildings. Penn State's reductions have been achieved on the foundation of energy conservation, increased efficiency, including increased levels of combined heat and power (CHP), targeted renewable purchases, awareness as well as programs in sectors other than energy.

### *Combined Heat and Power Systems*

On March 30, 2016, Penn State's West Campus Steam Plant burned its final load of coal, bidding farewell to coal-fired operations at UP after more than 150 years. The West Campus Steam Plant was built in 1929 and has been in almost continuous operation for 86 years. Three coal-fired boilers have been replaced by two, new, high-capacity, gas-fired boilers. Both the West Campus and East Campus Steam Plants are part of Penn State's district energy system that produces steam distributed to more than 200 individual buildings via a network of 19 miles of underground piping. Penn State's district energy system produced 100% of campus steam and emergency power needs and 20% of campus electrical needs. At an average efficiency of over 70%, Penn State's system is more than twice as efficient as a typical utility power station.

### *Campus Chilled Water System*

At University Park, a district cooling system serves 130 buildings. By aggregating the cooling needs of a network of buildings, district cooling creates an economy of scale that drives efficiency, balances electric loads, and reduces costs. The system is expanded as new buildings are built or existing buildings are connected to the distribution system as building chillers are retired.

### *Energy Supply – Renewables*

**70 MW Solar PPA** – In 2019, Penn State entered into a 25-year Solar PPA with Lightsource BP. With over 150,000 solar panels sited on roughly 500 acres across three locations in Franklin County near Penn State's Mont Alto campus, the arrays will provide 25% of Penn State's statewide electricity requirements.

**2 MW Solar PPA** – A 25-year PPA with the Alternative Energy Development Group (AEDG) for a 2 MW on-site solar array located on the University Park campus began operating in April 2019 and acts as a true living lab that combines operations with teaching, research and outreach opportunities.

**6 MW Hydroelectric PPA** – In 2013, Penn State entered into a 10-year PPA with Mahoning Creek Hydroelectric Company for energy produced by a hydroelectric generating plant at the existing USACE dam on Mahoning Creek in PA.

**EV Charging Stations** – A solar array outside the main Office of Physical Plant building provides power to charge OPP's 100% EVs. Transportation Services, in collaboration with OPP, added three EV charging stations at the Nittany Parking Deck, the first on campus to be available to the public.

**Solar Bus Stop** – A gift from the Penn State Class of 2015, a solar panel array powers a bus stop near Beaver Stadium and also has phone charging capabilities.

### *Energy Conservation*

The Office of Physical Plant Energy Program administers the behind-the-scenes mechanical, technical and operational aspects of energy efficiency and conservation in buildings and utilities. The Program consists of energy usage monitoring and benchmarking, performance contracting, energy efficiency and continuous commissioning. Penn State focuses on energy conservation and efficiency projects in building systems and utilities and has committed to a 20% reduction in building energy intensity by 2024 via the Department of Energy's Better Building Challenge.

**Energy Savings Program** (ESP) – Penn State has invested in campus-wide energy conservation measures via its Energy Savings Program, which was originally modeled after the Pennsylvania Guaranteed Energy Savings Program. To date, the program has invested over $100 million with $79 million in program funding slated in the current Capital Plan. Penn State awards performance contracts to pre-approved firms for large energy projects (bundling multiple conservation measures) at any of the University locations or contributes funds that ensure energy efficiency in projects where energy is not necessarily the primary focus. In either case, the energy funds, including financing, are recovered through the avoided utility costs over a 10-year payback period. Multiple ESP projects have been completed at University Park as well as Abington, Altoona, Beaver, Berks, Brandywine, Erie, Fayette, Great Valley, Harrisburg, and Hazelton campuses. More than 200 projects have been funded through ESP or benefited from contributions.

*The ESP program is the single largest contributor toward the University's greenhouse gas emission reduction strategy to date.*

**Continuous Commissioning (CCx)** – Commissioning occurs shortly after a building's completion to verify if it is functioning according to its design objectives. Implemented in 1998, the UP Continuous Commissioning Program (CCx focuses on the re-commissioning, retro-commissioning, and maintenance of campus buildings. The goals of the program are to reduce energy costs and optimize building performance. CCx are "corrective" projects that typically have a 5-year simple payback. The program currently includes 2 CCx Engineers and (3 2-person technical service crews.

**Energy Conservation Measures (ECM)** – These projects are smaller in scope and are completed in E&G buildings. The average simple payback is less than 5 years. Solutions in the past have included: improving steam traps, installing low-flow water fixtures, upgrading chiller/chilled water, programming thermostats, reprogramming and upgrading control systems, tuning up systems and equipment, switching fuel selection, cleaning and flushing heating, venting and air conditioning (HVAC) piping, installing room occupancy sensors, and winter break shutdown.

**Green Design** – Penn State maintains rigorous Design and Construction Standards. In addition, Penn State has developed and implemented a University policy that guides sustainable elements in the design and construction of University facilities in accordance with USGBC's Leadership in Energy and Environmental Design (LEED. All new buildings and major building renovations at Penn State will be, at a minimum, LEED certified. Penn State has 48 LEED Certified buildings with 19 pending.

**Building Automation Systems** – Approximately 350 buildings at the UP campus are controlled via building automation systems (BAS). This functionality maintains customer environmental satisfaction by keeping the buildings climate within specific range and providing lighting based on occupancy schedules as well as monitoring system performance for device failures.

**Enterprise Utility Management System** – Penn State utilizes an Enterprise Energy Management Suite for the tracking of energy commodity purchasing, energy and water consumption, meter data and real time energy data for a select number of buildings. This system allows for accurate tracking of energy consumption and the data is used to inform development of Energy Program projects.

**Energy Conservation Policy (AD 64)** – In 2009, Penn State instituted an Energy Conservation Policy (AD64 that established guidelines and practices that will lower the University's energy consumption, reduce expenditures on energy and reduce greenhouse gases. The policy is applicable to all Penn State owned or leased facilities at all campus locations.

### *Transportation*

The University is working to sustainably manage its growing transportation demands by switching to alternative fuels, reducing oil consumption, increasing the fuel efficiency of and electrifying fleet vehicles, and encouraging the use of public transportation. Electric vehicle charging stations are available to the public at three locations at UP. Although the majority of campus fleet vehicles are traditional gasoline, efforts have been made to convert to sustainable alternatives. In collaboration with State College Borough, Penn State developed a Bicycle Master Plan to promote bicycle commuting and expand on-campus mobility for students and staff. Penn State collaborates with Centre Area Transit Authority (CATA) to offer cost-effective solutions for students and staff. CATA operates free on-campus shuttle buses for students, faculty, and staff. CATA's Ridepass program provides access to all CATA bus routes to eligible UP graduate students for only $15 per month. CATA's Rideshare program encourages carpooling among employees who live near one another. For groups of 7 to 12 people living in the same area, CATA offers a Vanpool Program.

# Appendix C: Scope 3 Analysis

## SCOPE 3 EMISSIONS

During the summer of 2021, the Sustainability Institute and Institutes for Energy and the Environment funded two student interns through the Drawdown Scholars program in the College of Engineering. The students were co-supervised by SI and OPP to get a broad understanding of the University's Scope 3 emissions. One of the interns did a more thorough investigation of the Procurement Category, and the other investigated the remaining categories more generally.

The below table shows the Scope 3 Emissions Categories as defined by the Greenhouse Gas Protocol "Corporate Value Chain (Scope 3) Standard."[80] The standard lists four common reasons businesses cite when creating their Scope 3 emissions inventories:

- *Identify and understand risks and opportunities associated with value chain emissions.*
- *Identify GHG reduction opportunities, set reduction targets, and track performance.*
- *Engage value chain partners in GHG management.*
- *Enhance stakeholder information and corporate reputation through public reporting.*

For Penn State, the value chain includes our 'customers' – groups like students and their families, alumni, and community members – which is slightly different from what is considered as part of the value chain of a corporation. However, many of these categories are still part of our footprint. The table gives an estimated, qualitative relevance/size of each category and a recommendation for next steps, including which office(s) at the University could take the lead.

As an additional category, instead of 'products sold', we could think of our students as our 'output' and consider their personal emissions after graduation as part of our Scope 3, value chain emissions. It would be exceedingly difficult to estimate all of our students' emissions, however it could be an excellent challenge and opportunity to work with our students to ensure they graduate with the knowledge, skills, and motivation they need to live successful climate-conscious lives.

[80] Greenhouse Gas Protocol's Corporate Value Chain (Scope 3) Standard (https://ghgprotocol.org/standards/scope-3-standard)

| Scope 3 Emissions Category | Relevance to PSU | Recommendations |
|---|---|---|
| **Upstream** | | |
| 1. Purchased Goods & Services | Likely one of the largest Scope 3 categories | Work with the largest suppliers in each spend category to determine ways to measure and influence emissions associated with purchases (Procurement Services + delegated procurement units) |
| 2. Capital Goods | Likely one of the largest Scope 3 categories | Same as purchased goods/services (Procurement + OPP/Design+Construction) |
| 3. Fuel- and energy-related activities (not included in scope 1 or scope 2) | Directly related to Scope 1 and 2 | Review energy and fuel-related purchases, determine measurement/influence opportunities (OPP/Energy) |
| 4. Upstream transportation and distribution | Connected to Category 1, might be difficult to separate in some cases | Work with the largest distributors to determine ways to measure and influence emissions associated with transportation (Procurement Services + delegated procurement units) |
| 5. Waste generated in operations | Included in Inventory | Review |
| 6. Business travel | Air travel included in current inventory | Covered in main report |
| 7. Employee Commuting | Included in Inventory | Covered in main report |
| 8. Upstream leased assets | Likely small, but hard to estimate | Review leased spaces and lease terms for opportunities to track and influence (OPP/Real Estate, Space Management) |
| **Downstream** | | |
| 9. Downstream transportation and distribution | Could include student and visitor travel emissions here, could be large | Start with large contributions like large events and move-in/out and work on measurement and influence opportunities (Athletics, Enrollment, others) |
| 10. Processing of sold products | Likely small, we do not directly sell many products | Work with Lion Surplus to determine their impact (Lion Surplus) |
| 11. Use of sold products | See 10 | See 10 |
| 12. End-of-life treatment of sold products | See 10 | See 10 |
| 13. Downstream leased assets | Likely small | If investigating 8, investigate this in tandem (OPP/Real Estate, Space Management) |
| 14. Franchises | N/A | N/A |
| 15. Investments | Unknown right now but potentially large | Research ways to measure and influence (Office of Investment Management) |

*Penn State Units are already working to understand their opportunities with Scope 3 emissions*

There is already work that has been started in some areas of the Scope 3 inventory. These initiatives should be encouraged, recognized, and coordinated through the future work of a broader Penn State Carbon Emissions Reduction activity. These initiatives include:

- **The formation of a Sustainable Procurement Policy and Program (Category 1)**. As part of the Procurement Transformation Project, a Sustainable Procurement Policy document has been drafted that includes the requirement that all purchasers consider sustainability, including GHG emissions, when making purchases. As part of this initiative, a Sustainable Procurement Manager will be hired, and all Procurement Services staff will receive Sustainability in the Supply Chain training. There is a parallel effort to draft a Diversity, Equity, and Inclusion Procurement Policy aimed at increasing our supplier diversity. These combined efforts could be leveraged to engage with suppliers to increase the overall sustainability of our supply chain.

- **Calculation of the emissions associated with the food served on campus (Category 1)**. Dining Services worked with students over the summer and into Fall 2021 to estimate the GHG emissions associated with production of the ingredients used to create meals in the dining halls. This work could be leveraged in determining our overall footprint for food on campus, educating diners about the implications of their choices, and possibly to set goals or initiatives for reducing the footprint of our menu items.

- **Measurement and discussions of Embodied Carbon in our buildings (Category 2)**. A group of staff, faculty and students interested in carbon emissions associated with our purchases generally and our buildings specifically participated in an embodied carbon training experience in April 2021. Embodied carbon refers to the carbon emissions released during the life cycle of the materials that go into constructing a building – from raw material extraction, to manufacturing, to building construction, maintenance, and demolition. As operational efficiency increases, the carbon emitted during the manufacture of the building components and the construction activity becomes a larger proportion of the overall building emissions. Since the initial carbon training, the group has been meeting regularly internally and with external stakeholders to understand the current state of building embodied carbon at Penn State and what improvements could potentially be made. This work could be supported and encouraged to develop relationships with architects, builders, and other building owners to increase our knowledge and action.

- **Unit-level GHG inventories (Category 1, 6)**. Recently several of the Sustainability Councils have calculated their own unit-level greenhouse gas inventories. The benefit of this activity is that each unit has access to more details regarding their purchased goods and transportation. The action of reducing emissions being more localized in units is a great opportunity.

- **Waste-to-landfill reduction efforts (Category 5)**. For many years, Penn State has had a history of working to reduce the waste that goes to the landfill. In recent history, a Waste Stream Task Force made several recommendations for how to reduce waste to landfills. Since then, many activities have been continued and should continue to be supported and encouraged.

- **Lion Surplus improvement efforts (Category 5, 10, 11, 12)**. Lion Surplus is one entity that reduces waste to landfill, but also sells products, thus contributing to multiple categories of Scope 3 emissions. Improved data collection has been started at Lion Surplus to be able to track the amount of material that goes through Lion Surplus. This activity should be encouraged, and any improvements in Lion Surplus could reduce the Scope 3 emissions in Category 5.
- **Education Abroad Sustainability (Category 6)**. The Education Abroad Office is actively working to reduce their emissions footprint, educate their students about carbon emissions, and work on ways to work with partners to offset the emissions associated with traveling abroad. This is an opportunity to engage a globally minded stakeholder group in efforts to reduce our footprint.
- **Remote Work Task Force (Category 7)**. Since the pandemic started and the University was forced to move to remote work, there has been a shift towards more remote activities. A Remote Work Task Force was initiated to make recommendations for how the University can continue to leverage remote work. Although not every role can be accomplished remotely, there are many that can be done successfully out of the office either full- or part-time. This Task Force should include considerations of emissions reductions benefits in their work.
- **Athletics Sustainability working group (Category 9)**. For the past year, a group of interested staff, students and faculty have been meeting to discuss sustainability in Athletics. This is an early activity; however, it could potentially be leveraged, encouraged and supported to include for carbon emissions reductions efforts. Athletics events bring in a large number of visitors, the footprint of which would need to be included in a Scope 3 emissions inventory and reduced.
- **Investment Management Office early work on an Investment Advisory Council (Category 15)**. The Office of Investment Management is interested in learning more about sustainable investing. A new Investment Advisory Council could potentially assist with determining opportunities to measure and reduce the emissions associated with our investments.

# Appendix D: Benchmarking

In this section, we describe results from a benchmarking analysis of the Big Ten Academic Alliance (BTAA) universities on existing climate action plans (CAPs). The goal of this analysis is to support decision-making in other sections of the report by (a) identifying strategies, challenges, and opportunities to reduce carbon emissions, and (b) help define Penn State's unique potential for differentiation from our peer institutions. Below we summarize our major findings.

## METHODS

In this report, we restricted analysis to BTAA peer institutions, but we recognize comparisons to other institutions of similar size and in similar climates would be useful moving forward. Here, we reviewed reports found online from institutions and made comparisons across institutions for priority categories. Assessment categories were chosen after consultation with the full Task Force membership. These included: year and level (%) of commitments, description of what Scope 1, 2, and 3 emissions are accounted for and included in decarbonization plans, the role of offsets, and energy strategies (renewable natural gas, green hydrogen, power purchase agreements (solar/wind), combined heat and power, efficiencies, and geothermal). We also noted financial strategies and communication plans when these were included.

Following this preliminary analysis, we had 1:1 meetings via Zoom with chairs of reports from several institutions, including: University of Michigan (Michigan), Rutgers University (Rutgers), University of Illinois (Illinois), University of Wisconsin (Wisconsin), University of Minnesota (Minnesota), and University of Maryland (Maryland).
The purpose of these meetings was to confirm details of the reports, identify any updates to the published materials, and discuss barriers and opportunities that supported the plan recommendations. These personal conversations were robust and constructive, signaling potential for greater collaboration across BTAA networks moving forward.

## SCOPES AND STRATEGIES

We acknowledge that each university's CAP is dependent on external factors such as location, climate, external constraints, and regulations (local and state government, etc.), availability of renewable resources and infrastructure, plus many more. Table 13 and Table 14 provide a brief overview of the major technologies and strategies that are being considered at peer institutions to address Scope 1 and 2 GHG emissions respectively.

*Table 13: Brief overview of recommended strategies by selected BTAA institutions for reducing Scope 1 emissions.*

| University | Scope 1 Major Approach |
|---|---|
| Michigan | • Consultant report concluded GeoExchange with heat recovery chiller technology (GHX/HRCH) was best option<br>  ○ Will require eventual campus wide conversion from steam distribution to medium temperature hot water (MTHW) distribution, as well as the construction of new cooling distribution networks, tied to a geo-field.<br>  ○ This solution would decrease energy consumption by 47%<br>  ○ Estimated savings of $1.6B in operating costs over the first 3 decades.<br>  ○ Estimated overall project cost (geothermal + solar PV + building conversion, and contingency) of $3.5B across all campuses |
| Ohio State | • Currently, geothermal power supplies 5 dormitories and another building, and OSU has built two new chiller plants<br>• Future *recommendations*:<br>  ○ campus-based solar energy generation,<br>  ○ green hydrogen and/or green biogas fuel replacement,<br>  ○ EV charging stations, and<br>  ○ renewable natural gas |
| Maryland | • 20-year-old CHP system is going into RFP process and UMD plans to completely overhaul entire facility and distribution system (RFP for external group to determine strategy has 5 finalists).<br>• Any new thermal load from new buildings will be offset. |
| Iowa | • Biomass |
| Illinois | • On-site wind/solar, University-owned, that serves as Living Lab (3% of power demand)<br>• Exploring geothermal<br>• DOE funding for pilot study on micronuclear was pursued (not successful)<br>• Retro commissioning (RCx) optimizes a building's heating, ventilation, and cooling systems and controls to maximize energy savings. Since August 2007, RCx teams have updated systems in over 80 campus buildings, reducing energy consumption by an average of 27% and avoiding $70M in utility costs for more than 10 million GSF of facilities. |
| Minnesota | • Has switched from coal to natural gas and now transitioning to renewables.<br>• A "portfolio" approach being pursued:<br>  ○ Biofuels<br>  ○ Heat recovery<br>  ○ Green hydrogen<br>  ○ Electrification |
| Nebraska | • Decrease Building EUI (Energy Use Intensity) |
| Rutgers | • Not relying on targets to reach Scope 1 and 2 emissions goals<br>• Co-generation and heating plan TBD<br>• Estimate solar to cover 15% of electricity demand<br>  ○ 11 MW Solar existing;<br>  ○ RFP for an estimated 18 MW from solar on parking lots<br>  ○ PPAs (under consideration) |
| Wisconsin | • Agrovoltaics and solar/wind on agricultural research stations<br>• Plan to revisit strategy every 3 years |

Table 14: Brief overview of strategies for reducing Scope 2 emissions by selected BTAA institutions.

| University | Scope 2 Major Approach |
|---|---|
| Michigan | • PPA renewables by 2025 |
| Ohio State | • PPAs |
| Maryland | • RECs (100% of purchased electricity is from renewable sources (since 2020) done by purchasing and retiring bundled and/or unbundled Green-e Certified Renewable Energy Credits. |
| Illinois - Chicago | • PPAs (25% of UIC's purchased electricity from renewable sources by 2025. ) |
| Minnesota | • A portfolio of contracts is seen as necessary (which would also buffer economic uncertainties), including REC swaps. Net positive $19 million over 10 years. VPAA electricity purchase from the market. |
| Wisconsin | • PPA: utility solar (University purchases 50% of production)<br>• RECs to help with Scope 1 and 2 initially, included REC "swaps" |

## OFFSETS SECTION

Across BTAA institutions, the approach to using offsets as part of a carbon reduction strategy was different. On one hand, offsets were seen as a quick solution and could be responsive to demands for immediate action, in some cases supporting LivingLab or natural carbon capital strategies that had substantial co-benefits. On the other hand, they were seen to 'distract' investment or intentionality away from the goals of Scope 1 and Scope 2 emissions reductions. In all cases, verification, evaluation, and continual review of offset strategies and programs was seen to be essential.

**Examples:**

- **Michigan** – Scope 1 goals were presented with offsets included as a *"bridge"* approach. An appendix of the report includes a rebuttal to this approach.
- **Maryland** – Offsets are seen as a *"last option"* as the main goal is continual improvement to net zero. Land-grant perspective means it considers the state land base as potential for stewardship and offset. A student sustainability fee pays for offsets from student commuting. Air travel offsets are centrally funded.
- **Rutgers** – Offsets were not included in ambitious Scope 1 and Scope 2 goals because they were seen as a *"complementary strategy of last resort"* from meeting Scope 1 and 2 targets. There is recognition that offsets may be needed for Scope 3 emissions.
- **Minnesota** – Small forestry offsets were included through partnership with the National Indian Carbon Coalition. Offsets are also seen as an *"emergency strategy"* (for example, during a cold snap and reduced natural gas supply, the University needed to purchase coal-based fuel from Texas and these purchases these were immediately offset by the institution).
- **Wisconsin** – Offsets are part of a *"portfolio approach"* to climate action and are a way to be *responsive to student demands for immediate action*. They are seen to be a *"bridge solution."* Exploring use of *natural capital solutions* such as quantification of carbon and ecosystem services from on-campus lakeshore nature preserve. Interest in *voluntary offset program for study abroad students*.

## DETAILED HIGHLIGHTS FROM OTHER BTAA INSTITUTIONS

Below, we highlight, in more detail, BTAA universities who have active CAPs to shed light on strategies that might inform our future CAP development. When available, we summarize each university's goals, identify their process, and highlight their strategies (operational, financial, emissions scope, etc.) to provide a snapshot of their process and progress. This section includes information from Michigan, Illinois, Rutgers, Wisconsin, and Maryland. We draw these conclusions from assessment of published reports and conversations with chair or co-chairs of the reports (conducted over Zoom during Fall 2021).

### *University of Michigan*

- Closely link carbon emissions reductions to a set of **guiding principles** (carbon neutrality, sustainable, equity & justice, scalable & transferable, regional community involvement, University participation & accountability, financial responsibility). For example, it was recommended that procurements that reduce carbon emissions be linked to efforts to businesses owned by underrepresented groups.

- **Recommended Goals**
    - Carbon neutrality of Scope 1 emissions through offsets by 2025, with elimination of Scope 1 offsets by 2040.
    - All Scope 2 emissions would be eliminated by 2025.
    - Due to data limitations, recommendation for Scope 3 goals be established by 2025 through establishment of an offsets committee, with a target of reducing Scope 3 completely by 2040. The overall guiding **principle is to have cumulative total emissions be reduced 45% below 2010 levels by 2030**.

- A consultant[81] was hired to evaluate and model technically and financially feasible decarbonization strategies. The GREET model was used to estimate emissions, including upstream emissions such as methane leakage. REGGI permit pricing was used for assessing the offsetting gaps. Benefits, risks, and outlook of alternative strategies were qualitatively assessed Electrified systems centered on ***geoXchange*** *with heat recovery chiller technology* was deemed as the optimal solution of those evaluated, with a *payback period of 61 years*.

- Pricing was presented by including normal cash flows as well as normal cash flow plus the social cost of carbon (assessed at $50/MTCO2e).

- Although **Scope 3 assessment** is ongoing, the CAP report has a strong emphasis on standards for procurement and policies for *carbon-friendly food*. Other Scope 3 recommendations included *fully electrifying the University fleet*, more *charging stations*, investments in *rideshare* and *cycling*, and potential *carbon price on University-sponsored travel to support a renewable energy fund (REF)* seeded by $25 million. Standardization of data to track carbon across travel was also seen as a need.

- CAP planning included two interim reports and a final report, with **substantial input from the University and non-university stakeholders (e.g., utility companies)**. Strategic communications and outreach events were regular components of plan development.

- Institutionalization of the CAP plan includes the establishment of an **Executive Leadership position that reports directly to the President** (personal communications indicate this search is underway).

[81] Integral Group, Inc., DOI: http://doi.org/10.3998/mpub.12106210

### *University of Illinois*

- iCAP contains 56 SMART (specific, measurable, achievable, relevant, and time-based) objectives organized into eight key themes: Energy, Transportation, Land & Water, Zero Waste, Education, Engagement, Resilience, and Implementation.
- Committed to becoming **carbon neutral no later than 2050**. Goal to use 140,000 MWh/year of electricity from clean power sources **(i.e., approximately 35% of annual power demand) by FY25**.
- Reducing the percentage of staff trips made using single-occupancy vehicles from 60% to 50% by FY25 and 45% by FY30.
- Reducing net air travel emissions from the FY14 baseline: 50% by FY24; 100% by FY30.
- Received Tier 2 Sustainable Fleet Accreditation from the National Association of Fleet Administrators (NAFA). The first university in the Big Ten — and the first university in the state — to receive this accreditation, which comes as a result of decreased fuel usage, idling time, and GHG emissions.
- Leads the Big Ten in overall energy efficiency, also known as Energy Use Intensity (EUI)
- Tracking and reporting food waste in at least five new areas by FY22. Establishing a culture of reuse, with two major campus-wide zero-waste events using durable goods and composting in FY22, four in FY23, six in FY24, and eight in FY25. Developing a comprehensive Zero Waste messaging campaign by FY21.
- In January 2015, the University became an EPA Green Power Partner. The Green Power Partnership (GPP) initiative is a 19-year-old cohort with the goal to elevate voluntary adoption of green power in the U.S.
- Divesting endowment and all University of Illinois System funds from fossil fuels, reinvesting their financial resources in sustainable and socially responsible funds, and making all investments more transparent
- Developing a collaborative plan for **environmental justice** that will assess metro area resilience and actively address related issues. The plan will be written and publicized by FY24.
- In 2018, Illinois students voted 82% in favor of maintaining a self-imposed fee to promote a "Sustainable Campus Environment."

### *Rutgers University*

- Final Report of the Presidential Task Force on Carbon Neutrality and Climate Resilience released September 2021.
- Overarching goal: Mobilize Rutgers' academic, operational, and economic capacities to advance just, equitable climate solutions and help achieve national net-zero GHG emissions no later than 2050.
- Final recommendations:
    - Reduce fossil fuel consumption 20% by 2030 and 100% by 2040.
    - Eliminate emissions from purchased electricity from the grid by 2030.
    - Reduce indirect emissions (Scope 3) associated with commuting, travel and the supply chain by 30% by 2030. Expand the categories that are tracked.
    - Expand carbon sequestration on Rutgers land by 1000 tonnes $CO_2$-eq by 2030 (land, buildings, and peer-verified Rutgers-managed, off-campus projects).
    - Employ 3rd party offsets as a complementary strategy of last resort to address remaining emissions.

- Use Rutgers economic and institutional capacity to advocate for addressing the societal choices that underlie indirect emissions.
- Work with communities to support plans for just and equitable climate adaptation.
- Build a culture of sustainability that integrates climate action into academic research, teaching, outreach, engagement, campus life, and university policy, including living lab approaches.
- Be a global model for cross-sectoral education and collaboration activities to advance climate action.

- Overall phased approach: Laying the groundwork (2021-2024), Moving Forward (2025-2030), Getting to Net-Zero (2031-2040), Becoming Climate Positive (2041-2050)
- Eliminating Scope 1 and 2 emissions through a combination of improved energy efficiency, expanded campus solar, purchase of off-campus renewable energy, and electrification of the fleet, followed by decarbonization of heating.
- Limited detail on financial investments required (goals to "conduct detailed analysis of technology options, costs, and time frames for eliminated fossil natural gas-powered heating; and determine how much debt to take on in order to achieve climate objectives.")
- Institutionalization: Advisory Board to oversee investments in off-site offset approaches.

| Table 2.1. Solutions for Direct and Grid Emissions | Potential Emissions Reductions (t $CO_2$) | Estimated Total Capital Costs | Estimated Annual Financing Costs* | Estimated Annual Savings | Estimated Additional Staffing Needs (FTEs) | Estimated Net Annual Financial Impact | Net Annual Financial Impact per est. t $CO_2$ |
|---|---|---|---|---|---|---|---|
| **Reduce Building Energy Demand** | 72,000 | ($100 M) | ($6 M) | $20 M | 10 | $12 M | $170 |
| Retrofit less efficient buildings | | | | | | | |
| Decommission old, inefficient buildings | | | | | | | |
| Adopt new construction and energy standards | | | | | | | |
| Install metering, monitoring and control systems | | | | | | | |
| **Decarbonize Vehicles and Equipment** | 5,000 | ($35M) | ($4 M) | $4 M† | 3 | $0 M | $0 |
| Electrify fleet | | | | | | | |
| Electrify maintenance equipment | | | | | | | |
| **Decarbonize Electricity Supply** | 116,000 | ($770 M)‡ | ($26 M) | $40 M§ | 3 | $13 M | $110 |
| Expand on-campus solar generation | | | | | | | |
| Purchase off-campus solar or wind electricity | | | | | | | |
| **Decarbonize Heating** | 172,000 | ($1,500 M) | ($85 M) | $23 M | 5 | ($60 M) | ($360) |
| Phase out fossil natural gas heating and cogeneration | | | | | | | |

* All calculations assume an interest rate on loans of 4.75%, consistent with Rutgers' current blended rate. Amortized over 30 years for buildings and 12 years for vehicles.

† Includes avoided cost of new diesel bus purchases

‡ For a third-party Power Purchase Agreement (PPA), capital costs would be borne by the third-party owner, not the University. However, discussions with rating agencies indicate that PPA obligations may effectively constitute debt for rating purposes, so the per-kWh cost of the PPA is shown here as a financing cost.

§ Includes subsidies of $80/MWh based on current New Jersey Transition Renewable Energy Credit prices.

*Figure 24: Estimated Costs from Rutgers 2021 Climate Action Plan*

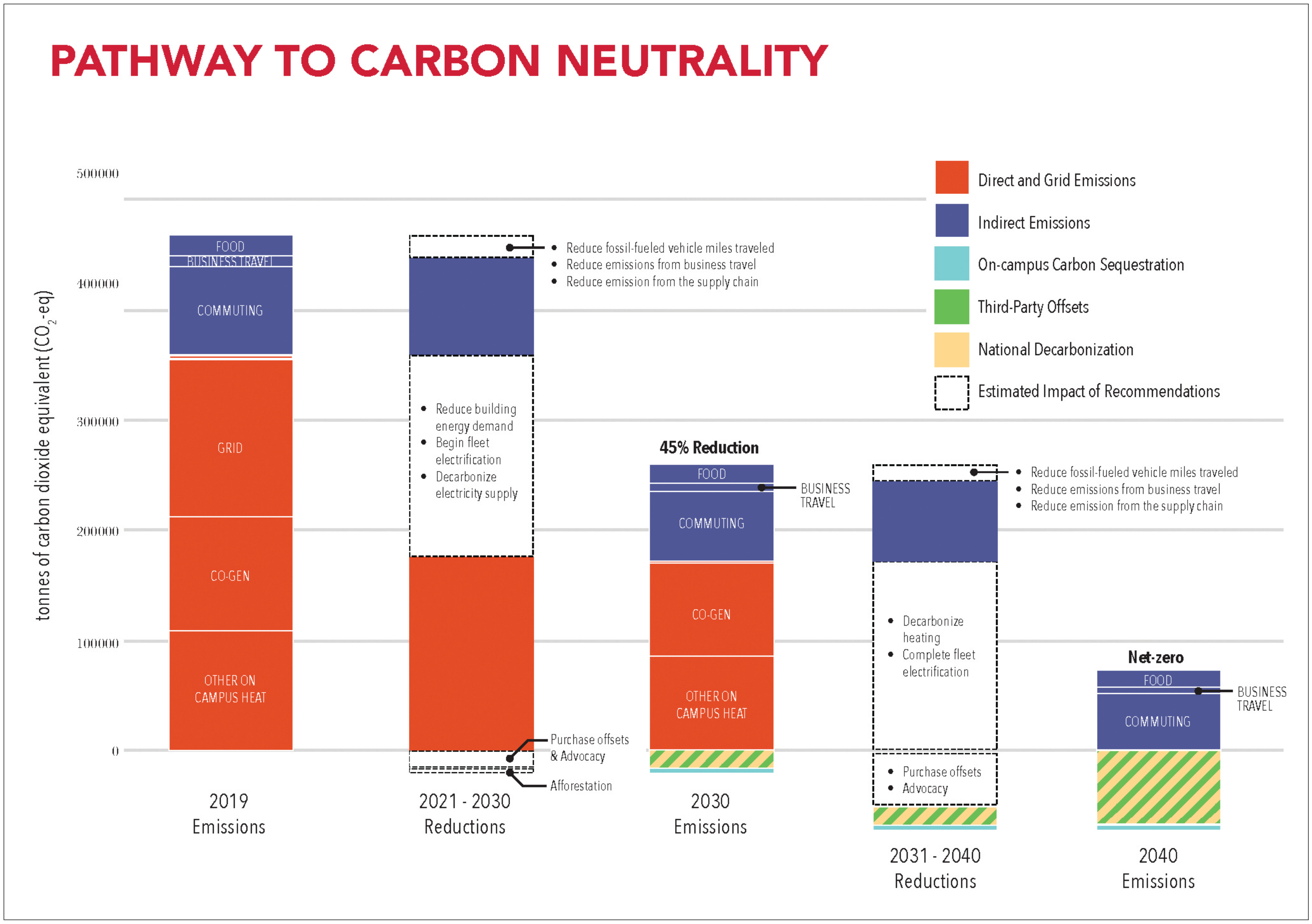



*Figure 25: Rutgers Climate Action Plan*

## *University of Wisconsin*

- Wisconsin's plan is unique among BTAA because it is focused on resilience. Implementing a CAAP (Climate Action and Adaptation Plan), following commitment to Second Nature's *Resilience Commitment.*

- The University already reduced emissions 40% since 2007, including switching from coal to natural gas.

- Institutional Structure: Office of Sustainability tasked with implementation, with sustainability advisory council to support community engagement and decision-making.

- Three phased process:
  - Phase 1: Identification of campus and community assets and potential impacts from climate change, *including external stakeholders*.
  - Phase 2: Resilience assessment focused on vulnerabilities to: (1) extreme rain and flooding, (2) power supply and resilience, (3) impacts of the pandemic, and (4) extreme heat and cold.
  - Phase 3 (current): strategies for emissions reductions and resilience.

- Exploring: solar and wind (on campus and PPA, RECs), agrivoltaics on MG&E facility (University currently using 50% of that produced energy), and offsets as a bridge solution (including the natural capital already on campus).
- Scope 3 emissions being assessed related to student travel, voluntary offsets, and procurements
- Student-led 100% renewable energy resolution.

***University of Maryland***

- Maryland's CAP is a "living document" encompassed in an interactive, innovative, and user-friendly website.
- April 22, 2021, University President Darryll Pines announced the University of Maryland will achieve net-zero carbon emissions by 2025.
- Maryland became a charter signatory of the American College and University Presidents' Climate Commitment in 2007 and finished its first CAP in 2009.
- The University achieved its target to reduce carbon emissions by 50% in 2018, two years ahead of schedule.
- All-Electric Fleet by 2035.
- 100% of the university's air travel emissions associated with faculty, staff, and student travel are offset (since 2017).
- 100% of purchased electricity is from renewable sources (since 2020) through purchasing and retiring bundled and/or unbundled Green-e Certified Renewable Energy Credits (RECs). NET PRESENT VALUE (based on 2016-2040 costs & savings) = $12/MTCO2e.
- Use algae-based carbon capture technology to absorb $CO_2$ from the Combined Heat and Power Plant's flue emissions. Capture 3,000 MTCO2e by 2020 and, with advances in technology, will capture 6,000 MTCO2e by 2025.
- Implementing various infrastructure improvements to achieve 17% decrease in electricity use. These include an Energy Performance Contract for nine energy intensive facilities, FM and Auxiliary-led projects, proactive O&M, IT projects including cloud computing, and other initiatives. NET PRESENT VALUE (based on 2016-2040 costs & savings) = $99/MTCO2e
- Maryland has reduced its carbon liability and benefited the economy by $43.7 million by preventing emission of approximately 1,220,830 MTCO2e.

## IMPLEMENTATION AND INSTITUTIONALIZATION

Below we highlight several examples of institutionalization of recommendations resulting from climate action plans at our peer institutions.

*University of Illinois (Urbana-Champaign)* developed Sustainability Working Advisory Teams (SWAT teams) that work in conjunction with the iCAP working group and the iSEE (Institute for Sustainability, Energy, and Environment). "In order to engage both subject matter experts across campus and interested members of the campus community, iSEE formed seven topical iCAP teams (Education, Energy, Transportation, Land and Water, Zero Waste, Resilience, Engagement). Each Team consists of a core group of faculty, staff, and students who will do the detailed analysis, heavy lifting, and formulation of recommendations. The core group will be surrounded by

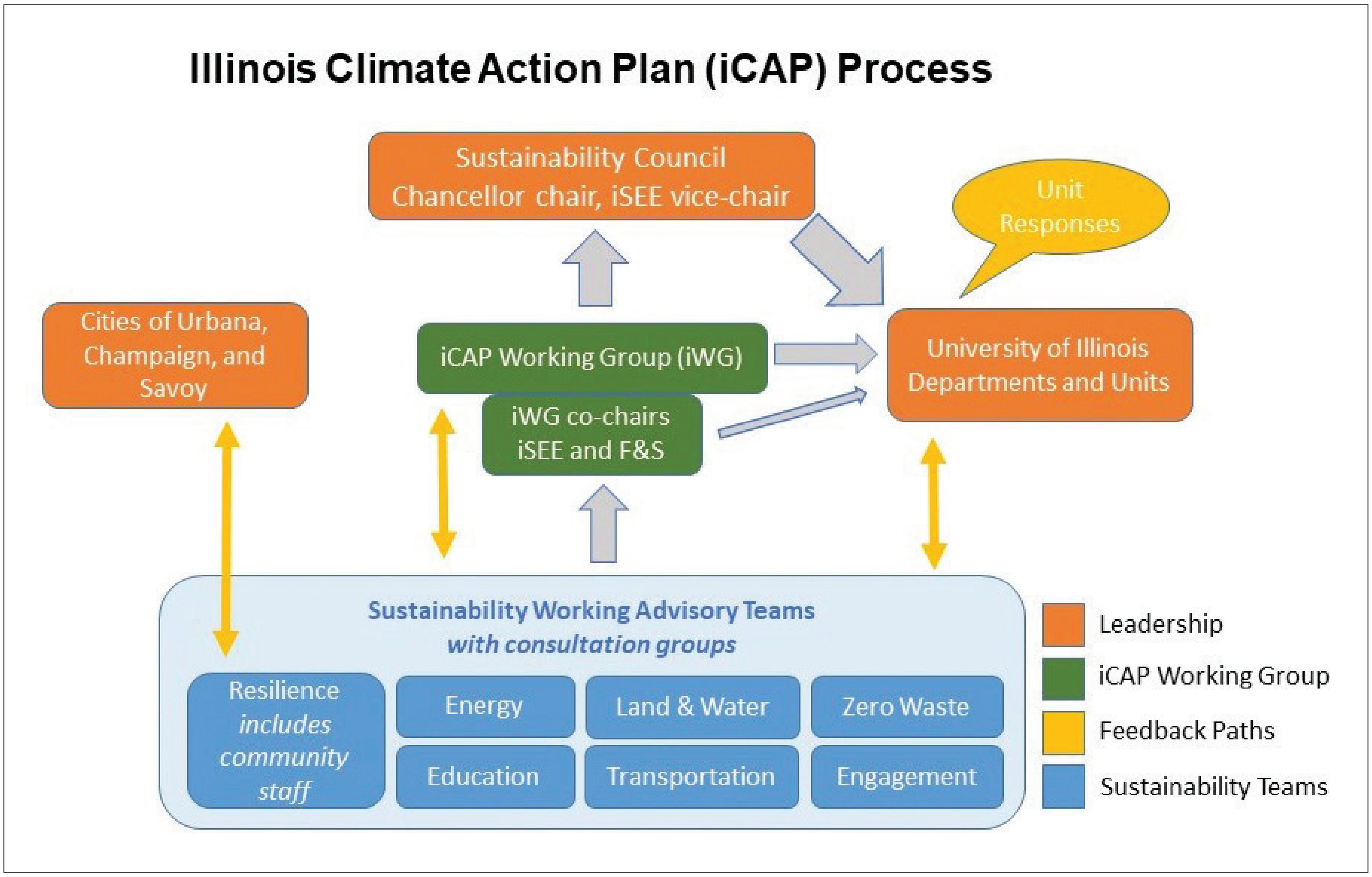



*Figure 26: iCAP SWATeam Process Flowchart*

a larger consultation group of experts and stakeholders from around campus to provide information, advice, and ideas the core group." **There is a Director of Sustainability in the Facilities and Services who is charged with implementing the campus sustainability solutions (funded 50% F&S, 50% through the Institute of Sustainability, Energy, and Environment (iSEE).**

*Rutgers University* has established a Climate Action Office with the goals to: (1) advocate for climate mobilization and sustainability at the highest level of University leadership, (2) monitor CAP implementation and updating, (3) convene and facilitate engagement among university, community, state, and industry stakeholders in University climate action, and (4) coordinate, seed, and facilitate research, teaching, and engagement that advances climate action and leverages University investments in climate action. In addition, the Office will establish a University Leadership Climate Mobilization Council, establish task forces, create a dashboard, establish Living Labs for climate action, and develop a detailed financial model and a communications strategy. **The Climate Action Office is co-chaired by two Directors and an Associate Director and support the academic and operation goal of the report**.

*The University of Maryland* has committed to making no new investments in the top 100 Fortune 500 companies in its investment portfolio. A faculty coordinator was recently hired. The University recognized the importance of efforts reporting to a VP or Provost. This is accomplished by having a **Council that meets 6 times per year, which is chaired by the VP of Administration**.

## NEXT STEPS

We recommend this analysis be extended to other comparable institutions beyond the BTAA that have long-standing CAP plans to further address potential opportunities and challenges. Penn State could take the lessons-learned by other universities and apply them to our process so we can optimize our CAP and overcome historical shortcomings.

## ENGAGEMENT AND EDUCATION

The University of Illinois developed several notable recommendations for engagement and education around the climate action plan:

- First-Year Sustainability Seminar: First-year students will attend a mandatory seminar to learn about best practices for living a sustainable lifestyle on and off campus. The goal of the seminar is to enhance students' behavior impacts on energy use intensity. Behavioral factors like car idling times, carpooling, biking, zero waste, water consumption, and computer charging on campus will be covered (iCAP).

- Develop a green incentive program for all on-campus buildings to participate in. Buildings that reduce their energy use by a prescribed amount will receive special recognition from the University President and a Green Building Certificate to display at their entryways (iCAP).

- Develop signage to hang around campus promoting various sustainable practices (e.g., anti-idling, zero waste, and water usage).

- Create and host a yearly event for the local community in which companies and professionals who specialize in sustainable industries are invited to lead conversations and keynote presentations. This will foster relationships with the local community surrounding sustainability initiatives (iCAP).

- Create a Sustainability General Education (GenEd) Credit (iCAP).

- 100-level Courses: By FY24, they aim to integrate a sustainability unit into each 100-level course designed to onboard students and transition them to college life (iCAP).

- Create a permanent Chancellor's Committee on the status of the environment or campus sustainability (Illinois-Chicago)

- Education, research, and public engagement are crucial to the success and implementation of the UIC CAP. The mitigation strategies reduce UIC's GHG emissions. The educational aspects ensure that students become responsible stewards of the environment, interdisciplinary research focuses on solutions, our staff work in a place that promotes a positive culture and environment and our community becomes engaged (Illinois-Chicago).

# Appendix E: Transportation

## BACKGROUND

The transportation area of Penn State's operations that are accounted for in the GHG Inventory can be split into Scope 1 and Scope 3 emissions. Table 15 outlines all the emissions associated with the transportation sector at PSU.

The goal was to investigate strategies that reduce the GHG emissions associated with the University's transportation-related activities. This focused on Scope 1 emissions activities (i.e., University-owned vehicles) plus the Scope 3 activities that are currently included in the University's GHG inventory (i.e., University-funded air travel and commuting). Table 16 highlights the transportation data sources used to perform the current University GHG inventory. The specific strategies modeled are replacing gasoline-powered passenger vehicles with EVs and instituting remote workdays for the entire University. Recommendations outside these strategies are also included but were not investigated in enough detail to provide specific GHG emissions reduction or cost quantification. Finally, recommendations for emission sectors described in Table 15 under "Out of Scope for Task Force Committee" section are provided at a very high level. Since no data is readily available for these sectors, no modeling was performed.

This Appendix is separated by each of the sectors in the transportation category: (1) University-owned vehicles, (2) the University-owned aircraft, (3) University-funded travel; and (4) commuters. In each sector, our data analysis is presented, along with benchmarking from other universities and recommendations.

*Table 15: University Transportation Categories, GHG Emissions Scope, and Inclusion in Current Inventory.*

| Sectors | Scope | Current GHG inventory |
|---|---|---|
| ***In Scope for Task Force Committee*** | | |
| Office of Physical Plant Vehicles | Scope 1 | Yes |
| Fleet Vehicles | Scope 1 | Yes |
| Public Transport (funded/supported by the university) | Scope 3 | Yes |
| Commuters | Scope 3 | Yes |
| Business Travel - Air Travel | Scope 3 | Yes |
| ***Out of Scope for Task Force Committee*** | | |
| Miscellaneous Fuel Use by Office of Physical Plant | Scope 1 | Yes |
| Business Travel – Other (rental cars, taxis, ride-share services, trains) | Scope 3 | No |
| Business Travel – non-university funded travel related to professional responsibilities | Scope 3 | No |
| Event Travel by Campus Visitors | Scope 3 | No |
| Waste to Landfill | Scope 3 | No |
| Goods and Services | Scope 3 | No |

*Table 16: Data sources for information in the University Greenhouse Gas Inventory for Transportation*

| Sectors | Data Available |
|---|---|
| OPP Vehicles | Total fuel dispensed at OPP fueling station (tracked by budget, vehicle) |
| Fleet Vehicles | Total fuel dispensed at Fleet fueling station |
| Fleet Vehicles | Roll-up of fuel purchased on Fleet purchasing cards |
| Misc. Fuel Use – OPP | Fuel delivered at various locations (e.g., OPP shops, Farms, etc.) |
| CATA | UP only – estimate based on CATA route mileage data |
| Commuters | UP – estimated mileage based on zip codes from parking permits<br>CC – rough estimates based on student enrollment, 2021-22 student enrollment residential versus nonresidential and faculty/staff numbers from the COVID-19 dashboard for on-campus work or enrollment |
| Business Travel - Air Travel | Mileage is calculated using each employee's expense account from Concur and an average fare of 13.7 cents\mile. |

## UNIVERSITY-OWNED VEHICLES

### *Overview*

The objective of this portion of the transportation evaluation is to estimate the capital and operational cost of replacing all University-owned vehicles with EVs. The inventory of these vehicles and other motorized University equipment spans those from Fleet Services, Office of Physical Plant, the University Park Airport, and all vehicles that obtain license plates from the Commonwealth, including those owned by schools and departments. The inventory was categorized as follows:

- Sedan
- Van/SUV/Station Wagon
- Ambulance
- All-Terrain Vehicle
- Boat Trailer
- Bus
- Horse Trailer
- Motorcycle
- Truck (Pickup Trucks, Box Trucks)
- Trailer
- Tractor Trailer
- Neighborhood Electric Vehicles
- Miscellaneous Vehicles (Kubota®, etc.)

Due to the large number and variety of vehicles, uses, and locations in the University's fleet, it was out of scope to investigate potential replacements for all vehicles. However, it was also described to us that the number of vehicles the University owns could be reduced if more vehicles were shared across departments. A consultant has been commissioned by Transportation Services to perform a study and recommend how to right-size and right-type the University's fleet of vehicles. We support this work and recommend the next phase would be to create a decarbonization plan for the fleet.

For this analysis, it was determined that two test cases with a limited scope would be modeled to determine the technical and financial feasibility of electrifying the University's fleet. The test cases chosen were vehicles managed by the OPP Garage (Bruce Cifelli) and Transportation Services (Rob DeMayo). The OPP Garage owns and manages over 700 vehicles of various types – from landscape equipment to stationary generators and welders to farm equipment to large trucks and utility vehicles. Transportation Services' Fleet operations includes approximately 500 vehicles, most of those being passenger vehicles of varying sizes – from small sedans to large buses.

For this analysis, we modeled the electrification of passenger vehicles and smaller utility/work vehicles (sedans, SUVs, pickup trucks, cargo vans, and minivans). This was due to the availability of these vehicle types on the market now, or in the near future, so information was publicly available for the estimated battery performance, gas mileage, and purchase prices. Although some rebate and grant funding may be available for purchasing non-fossil fuel-based vehicles, these financial incentives were not included in this analysis. The modeling effort is described in detail in Appendix I.7.

### *Benchmarking from Other Universities:*

*Items being done in some capacity at Penn State, though some possibly only at UP.

*Office of Physical Plant:*

- Develop Fleet EV Transition Planning Document
    - Creation of an alternative-fuel vehicle revolving loan pool for departments to encourage purchase of EV or other alternative-fuel vehicles.
- Strengthen fuel-efficiency standards in the specifications for purchased and leased vehicles.
    - Focus vehicle maintenance on actions that emphasize fuel optimization.
- Strengthen the Vehicle Idling Policy.
    - Evaluate retrofits to reduce idling time in diesel vehicles.
- Create University-operated EV car-share program.
- Increase production, use and efficiency of hydrogen and biofuels in University vehicles.
- Maintain roads to encourage optimal fuel use in vehicles.
- Electrify all landscaping equipment*
- (California is banning gas-powered lawn equipment, www.caranddriver.com/news/a38004981/california-ban-gas-powered-lawn-equipment/)

*Fleet Services:*

- Fuel efficiency as part of purchasing requirements.
- Resize (rightsizing) the fleet.*
- Enforcement of the anti-idling policy.
- Increase efficiency of the campus delivery system.
- Increase use of vehicles that use carbon-neutral or low-carbon fuel sources.
- Have the police/security officers use bicycles.*
- Increase number and use of hybrid vehicles.
- Increase fuel efficiency during maintenance operations.

### *Recommendations for University-Owned Vehicles*

- Vehicle electrification is technically feasible now for some vehicle types in our inventory. However, consideration should be given to the infrastructure required to electrify the inventory to ensure the scale-up is done appropriately with incremental upgrades made over time. We recommend purchasing fully electric and hybrid vehicles starting now for the OPP Garage and Fleet Services to start getting employees and renters accustomed to the new technology. Supporting employees who travel between campuses with electric vehicles would decrease our footprint and engage more stakeholders.

- Technology development in the areas of electrification, battery technology and recycling, autonomy, green hydrogen, fuel cells, etc., is happening quickly and should be monitored continuously to determine when alternatives exist that are applicable to our operations. This is also an opportunity for PSU research and development.

- A full analysis of the decarbonization of the entire inventory of University vehicles should be completed after a right-sizing analysis is completed. In addition, a 5 to 12 year strategy should be developed for this decarbonization since 5 to 12 years is the average replacement cycle for University vehicles. As part of this analysis, the use of plug-in hybrids to address range issues should be considered and investigating newer technologies such as biofuels and fuel cells should be included.

- A vehicle purchasing policy should be created/modified to require that when purchasing vehicles, the purchaser must evaluate the availability of hybrid, electric and/or lower carbon emitting versions. If a purchaser finds they cannot replace their vehicle with an alternative vehicle, then an exception must be requested and approved. At the very least, an anti-idling policy and fuel efficiency minimums should be enacted.

- Vehicles with small, inefficient engines should be electrified as soon as possible (e.g., lawn mowers, small landscape equipment), since these are already part of the University's operations and are a known improvement over fossil-fuel based equipment.[82]

- Shuttle service should be evaluated for campus-to-campus travel for those campuses where fleet vehicle use is frequent. Ride-sharing from fleet services should also be emphasized for meetings where multiple people from the same campus attend, e.g., Faculty Senate. Currently, a successful shuttle service exists between University Park and Hershey Medical Center.[83]

- In order to track improvements in GHG emissions and costs associated with University-owned vehicles data collection should be streamlined. Current data systems do not include all the information needed to calculate emissions and costs, and data needs to be retrieved from multiple sources in order to do the calculations. A system that would improve this would include vehicle data (i.e., model, purchase year, type of fuel, purchase price, etc.) as well as vehicle usage data (i.e., mileage, maintenance costs, etc.) in one place.

## UNIVERSITY-OWNED AIRCRAFT

### *Overview and Data*

Data on the fuel usage of the two university-owned aircrafts were obtained from the University Airport personnel. This is a Scope 1 emissions source, *yet not currently included in the University's GHG emissions inventory.*

Using the data from FY 05/06 through FY 18/19 (pre-pandemic), the average fuel use was calculated and converted from gallons of fuel to MTCO2e using conversion factors.[84] The results of this analysis are shown in Table 17. These results are on an annual basis and demonstrate that much of the airplane use is consistent year-over-year (small coefficients of variation).

*Table 17: Average Annual Fuel Use by University-Owned Aircraft*

| | Gallons | $CO_2$ | $CH_4$ | $N_2O$ | MTCO2e |
|---|---|---|---|---|---|
| Average per year | 60,598 | 591 | 0 | 0 | 596 |
| Standard Deviation | 10631.98 | 103.6618 | 0 | 0.00319 | 104.6123 |
| Coeff. Of Variation | 0.175 | | | | 0.175 |

[82] "Penn State's Office of Physical Plant seeks to prevent pollution through electric landscaping equipment," collegian.psu.edu
[83] https://www.research.psu.edu/shuttle
[84] https://www.epa.gov/sites/default/files/2021-04/documents/emission-factors_apr2021.pdf

A detailed analysis and precise recommendations cannot easily be made on how to reduce the trips or fuel expenditures since no data is available regarding the purpose or destination of these trips. Note that the estimated emissions per year for the aircraft are approximately 25% higher than total emissions calculated by one College, as noted later in this report under University-funded air travel.

### *Recommendations for the University-Owned Aircraft:*

- Add the University-owned aircraft emissions to the annual GHG inventory, including information on trip types and distances.
- University personnel who use this aircraft should consider other, lower carbon options when traveling.
- Many universities and companies are researching and testing sustainable aviation biofuels either as a stand-alone fuel or as a biofuel. Penn State should be involved in this research (www.energy.gov/eere/bioenergy/sustainable-aviation-fuels) (www.intelligent-partnership.com/aviation-biofuels-which-airlines-are-doing-what-with-whom/).
- Battery-operated small aircrafts are being pre-purchased by United Airlines (United Airlines Is Buying 100 Electric Planes From Heart Aerospace – Robb Report). At the time of replacement of our aircraft, the status of battery-operated or solar-powered planes should be included in the evaluation of the benefits and drawbacks of purchasing a different aircraft.

## COMMUTING

### *Overview*

Many PSU students and almost all faculty and staff reside off campus. Some may live within walking or biking distance of their campuses, but many more reside outside of a reasonable distance to walk or bike to campus. Some students and faculty/staff take public transportation.

This section describes the calculation used to highlight one strategy that supports Penn State's Remote Work policy and how potential Carbon-Reduction Days could be built into the academic calendar with an estimated reduction in carbon emissions. Then, benchmarking against other BTAA Universities and a select number of large universities that are not near public transit/rail service are highlighted. To close this section, recommendations for improved data collection and strategies that could be used to reduce our commuting sector carbon footprint are given.

### *Penn State Public Transit/Parking Cost Landscape:*

This section describes the information on public transit accessibility and on commuter parking costs that were readily available from each campus' website. One aspect of reducing individual vehicle usage will be accessibility of other methods of commuting, and a second will be the cost.

Each campus' website was reviewed for information regarding how to access campus. If a campus is not listed, it is because the information was not readily available on their website. The following campuses note that they have on-campus public transportation (typically bus) stops:

- Brandywine (SEPTA)
- Erie (Erie Metropolitan Transit Authority)
- Fayette (Fayette Area Coordinated Transportation)
- Harrisburg (Capital Area Transit)
- Lehigh Valley (LANTA)
- University Park (CATA)
- York (York County Transportation Authority)

The following campuses have readily available information on accessing public transit, but they do not have a designated stop on campus listed on their website:

- Abington
- Altoona
- Beaver
- Great Valley
- New Kensington
- Scranton

A second issue associated with a choice to drive a personal vehicle or take public transit is cost. One cost that Penn State can control is the cost of parking. An analysis looking at campus websites was conducted to document the cost of parking permits for faculty, staff and students.

The following campuses have free parking passes for at least students:

- Abington*
- Beaver
- Brandywine
- Dubois*
- Fayette*
- Great Valley
- Hazleton
- Lehigh Valley
- Mont Alto*
- Schuylkill*
- Scranton*
- Shenango
- Wilkes-Barre
- York

**Information was found only for student costs. For many campuses, information on faculty/staff parking permit costs was not available without logging into their campus system.*

The following campuses have a tiered pricing structure with the cost of permits being less for students than for faculty and staff:

- Altoona
- Erie
- Harrisburg
- University Park

No information was readily available on websites for the Berks and Greater Allegheny campuses.

### *Data Analysis*

The current population at each campus was estimated from the COVID-19 dashboard based on the 2021-2022 enrollments who are required to either report vaccination status or test weekly (obtained on September 25, 2021). This was assumed to be the best estimate of campus populations. It does not include students who are taking online programs. It was not matched with numbers of parking permits for each campus.

The estimated mileage per campus was estimated by the Office of Physical Plant based on the number of permits (University Park) or population (Commonwealth campuses) and estimated miles for commuting. The most recent data available was for the FY 19/20-time frame. Since that included the start of the COVID-19 pandemic, the March-June miles and emissions were adjusted by 50% to address the reduction in commuting by most students, faculty, and staff.

When the analysis was performed, residential students were not included since it was assumed that they either walk, bike, or skateboard to class from their housing on campus.

On August 10, 2021, an enhancement of the remote work policy was announced in the Penn State Newswire. At the start of the semester, the University Administration issued a memo to the faculty that 24% of in-person classes could be delivered in another mode. Using this information, an assumption was made that the faculty, staff, and administrators' commuter mileage could be reduced by 20%, assuming, on average, that each person works from home one day per week. This assumption was used to balance the fact that some positions must be on campus full-time, and others could work from home more than one day per week. The students' commuter mileage was assumed to drop by 15%. This was estimated using an assumption that every MWF class had a remote session once every two weeks.

Table 18 highlights the results of that calculation. Using these estimates, the commuter category can be reduced by 16.3%. This can be assumed to be a 16.3% reduction in emissions from the estimated emissions from FY 19/20. The emissions would be reduced from an estimated 56,000 tons to approximately 46,900 tons.

The cost of having remote working days would be negligible due to the amount of infrastructure that has already been put in place to allow for remote work during the pandemic. Ensuring everyone has access to stable internet would be important, so some costs may be incurred to provide students, faculty, and staff with appropriate technology based on their needs.

A co-benefit of this strategy is that if Remote Workdays are coordinated throughout the University, some building spaces could be left in unoccupied mode during the absence of users. This would result in a savings in building energy usage and costs.

*Table 18: Estimated Reductions in Commuter Emissions with an Adjusted Remote Work and Remote Teaching Policy.*

| Campus | 19/20 driver miles (adjusted 50% Mar-June) | 19/20 Commuter Emissions (adjusted) | 19/20 Diesel Bus miles | 19/20 Bus Services/ Vanpools | Total Commuters | Non-Residential Students Fraction of Commuters | Faculty, Staff, Administration Fraction of Commuters | Miles Saved |
|---|---|---|---|---|---|---|---|---|
| **Abington** | 5,110,798 | 2,760 | 67,410 | 399 | 3023 | 0.890 | 0.110 | 794,684 |
| **Altoona** | 5,423,662 | 2,929 | 0 | 0 | 2262 | 0.804 | 0.196 | 866,659 |
| **Beaver** | 833,327 | 450 | 0 | 0 | 364 | 0.692 | 0.308 | 137,820 |
| **Berks** | 3,502,768 | 1,891 | 0 | 0 | 1713 | 0.830 | 0.170 | 555,167 |
| **Brandywine** | 2,992,875 | 1,616 | 0 | 0 | 1157 | 0.858 | 0.142 | 470,143 |
| **Dickinson** | 1,105,962 | 597 | 0 | 0 | 330 | 0.803 | 0.197 | 176,786 |
| **Dubois** | 1,463,337 | 790 | 0 | 0 | 476 | 0.807 | 0.193 | 233,642 |
| **Erie** | 4,975,303 | 2,687 | 0 | 0 | 2781 | 0.788 | 0.212 | 799,072 |
| **Fayette** | 1,577,254 | 852 | 0 | 0 | 610 | 0.844 | 0.156 | 248,870 |
| **Great Valley** | 1,179,409 | 637 | 0 | 0 | 364 | 0.745 | 0.255 | 191,978 |
| **Harrisburg** | 15,224,971 | 8,221 | 0 | 0 | 4439 | 0.877 | 0.123 | 2,377,551 |
| **Hazleton** | 2,188,031 | 1,182 | 0 | 0 | 450 | 0.711 | 0.289 | 359,809 |
| **Lehigh Valley** | 2,324,081 | 1,255 | 0 | 0 | 940 | 0.887 | 0.113 | 361,716 |
| **Greater Allegheny** | 1,031,470 | 557 | 0 | 0 | 385 | 0.699 | 0.301 | 170,260 |
| **Mont Alto** | 1,891,849 | 1,022 | 0 | 0 | 635 | 0.794 | 0.206 | 303,292 |
| **New Kensington** | 1,105,259 | 597 | 0 | 0 | 580 | 0.853 | 0.147 | 173,888 |
| **Schuylkill** | 1,228,143 | 663 | 0 | 0 | 492 | 0.778 | 0.222 | 197,826 |
| **Shenango** | 1,175,398 | 635 | 0 | 0 | 361 | 0.801 | 0.199 | 188,031 |
| **Wilkes Barre** | 972,861 | 525 | 0 | 0 | 397 | 0.793 | 0.207 | 155,976 |
| **Scranton** | 2,072,597 | 1,119 | 0 | 0 | 1067 | 0.884 | 0.116 | 322,933 |
| **York** | 1,656,771 | 895 | 0 | 0 | 832 | 0.828 | 0.172 | 262,754 |
| **University Park** | 68,267,439 | 24,112 | | 3,326 | 43328 | 0.666 | 0.334 | 11,378,799 |
| **TOTAL** | 127,303,566 | 55,992 | | | | | | 20,727,656 |

**Benchmarking against Other Universities:**

Many of the ideas in each of the six benchmarking categories were noted at several institutions. Therefore, university names are not included by each item.

*Electric and Alternative Fuel Vehicles:*

- Create parking incentives for EVs
- Expand campus charging infrastructure*
- Switch vehicles powered by compressed natural gas (CNG) to green hydrogen

*Human-Powered Transportation:*

- Develop a bicycle incentive program
- Support campus/town infrastructure upgrades (bike lanes, racks, etc.)*
- "Share the Road" educational campaign*
- Identify additional non-motorized transportation routes*
- Student operated bicycle rental and repair shop on campus*

*Ride-Sharing/Carpooling:*

- Create car-share programs; develop supporting website; and promote this*
- Provide shuttles to off-campus parking lots and to nearby apartment complexes, especially late at night.
- Reduce costs for parking permits for people who drive in ride-share programs*
- Provide air for Commuters' Tires Day
- Research program on improving public transportation

*Parking Pass Incentives:*

- Clean Vehicle Permit – price parking pass based on fuel efficiency
- Cheaper parking passes for motorcycles and scooters
- Reduced cost or free parking passes for vehicles registered in and used in ride-share programs
- Occasional Parker Program (discounted daily passes up to 60/year)
- Cheaper parking passes for employees that are hybrid/remote
- Allow for purchase of offsets when purchasing permits

*Teleworking/Remote Learning/Education:*

- Expand and support teleworking
- Developed course scheduling and remote learning options
- Class on Transportation, Innovation, and Climate Change

*University Policy:*

- Create Campus Transportation Committee
- Increase options for alternative transportation – electrify campus buses; promote mass transportation passes with price reductions
- Subsidize use of public transportation*
- Work with transit authority to optimize route scheduling*
- Promote location-efficient mortgage programs to increase local housing availability and affordability
- Promote living close to campus for students
- Create and implement travel offset policy

** Items are being done in some shape or form at Penn State, though some possibly only at University Park.*

**Benchmarking by Penn State's Travel emissions Reduction and Information Program (TRIP):**

- University of Colorado Boulder Positive Impacts Points (PIPs) Program:
    - Faculty, staff, and students accumulate points for sustainability-related activities (e.g., bicycling to campus).
    - Tracked through mobile app.
    - Recommended to bring this to campus with a focus on transportation.
- Appalachian State Opt-In Carbon Offset Program:
    - Carbon neutral commuters pay $8 per year to offset 2 tonnes of carbon.
    - Money used for local carbon capture program or buying offsets.
    - TRIP noted that if 10% participate, this could offset 12,000 tonnes of $CO_2$ and generate $50,000.

### *Behavioral Changes*

Changing behavior is a complex challenge. As noted by Steg (2003), private-vehicle users could be divided into two categories: fervent users and more ambivalent users. For fervent car users, public transit did not perform well, and the car represented cultural and psychological values. It was a status symbol. People who alternated car use with other means of transportation are more open to using public transit. This article recommended that policies be developed to reduce "the functional, psychological and cultural values of private cars, as well as increasing the performance of public transport and other (more) environmentally sound modes of transport on these aspects."[85]

An example of how Penn State encourages car use can be found on some campuses' websites. All of the directions focus on automobiles for transportation, even though Amtrak has a stop in Middletown and the airport is directly across PA 230 from the campus. Capital Area Transit also has a stop on campus.

In contrast, the Abington campus highlights the public transit options as a separate link on its website. The "Visit Us" link does initially go to GPS directions for drivers, but it also provides a link to public transit. These two examples highlight how Penn State's public face to visitors and prospective students may be a barrier to encouraging the use of public transit.

### *Recommendations for Commuting*

- Data Collection Improvements
  - Associating information on classes of vehicles with parking permits would improve predictions of emissions. Simply classifying vehicles at registration based on the categories used by OPP and Fleet Services of Sedan, Light Truck, Heavy Truck, and Sport Utility Vehicle would improve the estimates so that an average fuel efficiency, which varies greatly, could be applied.
  - Vehicle registration should include whether this is an electric or hybrid vehicle.
- Remote Work and Teaching
  - It is recommended that hybrid and remote working be considered normal arrangements that managers are allowed and encouraged to use based on the necessary work in their team. Managers should consider the reduction of commuting related GHG emissions when deciding on remote work arrangements. The modeling presented above shows an example for how an increase in remote working, such as the conversion of some positions to remote positions or to hybrid positions that require presence at the University between 1-5 days per month will increase emissions reductions. This will not be possible for all positions, but possibly for many.
  - A shift to approximately one-sixth of the semester as remote for all students would reduce commuting emissions in the students provided that the following are addressed:
    - Remote days would need to be designated by the University, similar to the Wellness Days during the pandemic. This will not work if a student has one class remote and the others in-person.
    - Technology and broadband equity issues must be addressed.
    - Course design may need to be adjusted to address these Remote Days.

[85] Linda Steg, Can Public Transport Compete with the Private Car?, IATSS Research, 27(2):27-35. 2003. https://doi.org/10.1016/S0386-1112(14)60141-2.

- Incentives/Surcharges
  - EVs should receive priority parking on the campuses, similar to what handicapped parking receives.
  - Daily parking passes should be available instead of monthly/annually. Flexible parking would allow financial incentives for using methods of transportation other than single occupancy vehicles.
  - Parking price points should be reviewed.
    - Distant parking lots could be offered at a lower price for parking. The distance would encourage people to not move their cars during the day.
    - Parking lots could be assigned to each permit holder with permits not valid in other lots, again to encourage not moving the car during the day for convenience. Parking in the unassigned lot would require buying a day pass.
    - Many schools charge a higher parking price for faculty and administrators, compared to staff and students, and staff may pay slightly more than students.
  - Investigate opportunities for increasing bike and pedestrian safety. Look for possible infrastructure upgrades on and around campuses to increase the ability of students, employees and visitors to walk and bike to and around campuses. This also has the benefit of strengthening the town-gown relationship throughout the Commonwealth. The University could provide non-financial support to the locality to pursue grants and other opportunities for upgrades.
- Update websites to make public transit information readily available. Other universities highlight sustainable transportation options.
- Examine housing availability to determine if the University can assist with making housing closer to campuses more affordable.

## BUSINESS TRAVEL – UNIVERSITY-FUNDED AIR TRAVEL

This analysis is broken into two sections – a University-wide analysis based on the cost of air travel that is converted into estimates of carbon emissions and the analysis of carbon emissions from the travel of a single College.

### *Data Analysis*

**University-Wide Analysis.** In the current GHG inventory, air travel mileage is calculated using data from each business unit of the University and dividing by The Bureau of Transportation's estimate for the average fare of a domestic flight at 13.7 cents/mile. For FY 19-20, the total cost of air travel throughout the University was approximately $1,150,000. Using the estimated conversion factor above of dollars spent to miles flown, this was estimated as approximately 87,000,000 miles and 14,425 MTCO2e in estimated carbon emissions.

Because FY 19-20 includes 3 months of the pandemic, this likely reflects travel for only 9 months. Therefore, simply scaling up by 1.33, the annual carbon emissions for travel can be estimated as 20,000 MTCO2e.

This method is limited because it is based on air travel cost as reported by each business unit, rather than actual flight mileage. The single college analysis below highlights the differences when actual flight mileage as recorded in Concur is used.

**Single College Analysis.** One UP College completed a unit-level GHG inventory and analyzed air travel data for both FY 18-19 and 19-20 as seen in Table 19. In this process, the unit was able to acquire detailed flight information and actual mileage traveled from the SAP Concur Reimbursement System (2nd row, unit-level flight data. In comparison with the unit's data available to the University-wide GHG inventory (first row, inventory-level flight data, there is a substantial difference in mileage calculated versus actual mileage traveled.

*Table 19: Air Travel Emissions differences between the University and single unit GHG inventories.*

| Single College Air Travel Analysis | FY 18/19 | | FY 19/20 | |
|---|---|---|---|---|
| | Total Miles | Carbon Emissions (mtCO2e) | Total Miles | Carbon Emissions (mtCO2e) |
| Inventory-level flight data (Calculated mileage) | 5,263,609 | 857 | 5,201,887 | 847 |
| Unit-level flight data (Actual mileage) | 2,833,573 | 438 | 2,697,506 | 392 |
| Change | (2,430,036) | (419) | (2,504,381) | (455) |
| | 46% | 49% | 48% | 54% |

The number of trips was surprisingly not substantially different, likely indicating that planned travel is increasing, resulting in increased carbon emissions. In FY 18/19, the college's travel was approximately 2,835,000 miles, while in FY 19-20, it was 2,700,000 miles. Estimated emissions in FY 18/19 was 438 MTCO2e, and in FY 19/20, 392 MTCO2e.

GHG emissions are calculated using emissions factors based on short (< 300 miles), medium (>= 300 miles, < 2300 miles) or long (>= 2300 miles) haul travel according to the EPA. The proportion of each trip type is highlighted in Table 20 for two colleges. The interesting question that this data analysis raised was why College 2 had such different proportions in their travel segments, especially in the short-haul segment. A further analysis would be needed to determine whether this is because the faculty and staff are taking other means of transportation to the major airports to avoid that first short-haul flight segment.

*Table 20: Proportion of Flight Distances University-wide vs. two UP Colleges*

| Air Distance | Empirical Proportion of Trips UP FY 06/07 | College 1 Proportion of Trips FY 18/19 | College 2 Proportion of Trips CY19 |
|---|---|---|---|
| Short Haul (< 300 miles) | 18% | 27% | 6% |
| Medium Haul (>= 300 miles) | 39% | 59% | 38% |
| Long Haul (>= 2300 miles) | 43% | 14% | 57% |

***Recommendations for University-Funded Air Travel:***

- Data collection and sharing:
  - Improve the accuracy of the University-level GHG inventory by allowing the mileage of flights to be available to OPP for calculation of emissions and not only cost of trips.
  - Make emissions associated with University-sponsored travel available to departments or individuals at some regularity (annually for the department) or at time of booking (through Concur).

- Reduce University-sponsored travel:
  - For faculty, ensure virtual engagements are considered equal to the value of in-person engagements in promotion and tenure decisions.
  - For faculty and staff, consider a policy/guidance or rubric for when travel is necessary or acceptable. This is a place where the soft power of Penn State, given its size and travel dollars, could be used in this post-pandemic era to continue to promote that professional societies offer virtual or hybrid conference and meeting options. The goal is not to stop air travel since conferences/seminars/workshops featuring Penn State experts raises Penn State's profile and reputation, but to consider whether all travel is necessary.
  - Encourage faculty, staff, and students who are members or on boards of organizations to advocate for reducing the travel necessary for meeting organizational requirements and encourage the use of virtual and hybrid events when possible.
  - Develop a rubric similar to the one in "When to Meet In-Person", published by the Harvard Business Review, July 2021, to help faculty and administrators determine when to consider travel and when to pursue virtual connection options.

- Offsetting:
  - Where we cannot reduce our University-sponsored air travel, offsetting will be required. Airlines do offer offsetting emissions associated with the trips passengers take on their airlines, and some PSU employees already take advantage of this feature. We recommend an accounting be done on how many offsets employees are already buying, as well as examining the offset projects those funds go toward to understand our current activity.
  - It is also recommended that an option to give to Penn State approved offsets projects or funds be added to the Concur system.

- Pursue research opportunities in sustainable aviation fuels, electric and solar-powered planes, as well as social aspects of air travel and in-person events.

## TOPICS RELATED TO TRANSPORTATION BUT OUTSIDE SCOPE OF THE CHARGE AND/OR CURRENT GHG INVENTORY

Table 21 shows travel-related emissions sources that are not currently included in the University GHG inventory. It is recommended that an inventory of these sectors be attempted to understand their contributions to the overall emissions footprint of the University.

The only sector of business travel currently inventoried is air travel reimbursed through Concur; however, the use of rental cars, personal cars, and other public transportation methods could be a substantial part of the University's transportation-related emissions. The systems in place to fund those transportation methods vary, thus the data is not easily available to calculate GHG emissions. It may be necessary to collect more information from travelers during reimbursement or have departments relay this information to the college-level to get the information needed for a GHG emissions calculation. In addition, many faculty likely do not pursue reimbursement for travel between campuses

Table 21: PSU travel-related emissions sources that are not currently included in the University GHG inventory.

| Sectors | Scope | Current GHG inventory |
|---|---|---|
| ***Not Included in Analysis*** | | |
| Business Travel – Other (rental cars, personal cars, taxis, ride-share services, trains) | Scope 3 | No |
| Business Travel – non-university funded travel related to professional responsibilities | Scope 3 | No |
| Event Travel by Campus Visitors | Scope 3 | No |
| Waste to Landfill | Scope 3 | No |
| Goods and Services | Scope 3 | No |

because of the hassle of filling out paperwork for reimbursement. Finally, faculty, staff, and administrators who are participating in professional organizations, governing boards, or who are invited speakers may have their travel supported by other entities. While this travel technically may not be part of our University's emissions, these individuals are representing Penn State. Observers may not be able to separate in their minds this type of travel from University-funded travel and from other types of travel.

For scale, rental spending through Enterprise is roughly $5 million per year. This includes personal travel using the University discount, but this is still a large number. Enterprise does provide regular reporting of Penn State's rental business, so this is a possible source of data for inventorying travel emissions. In addition, athletics teams are regularly chartering buses, and this is not included in the GHG emissions inventory. While large electric buses are not available for the longer transportation distances required of the teams' travels, future evaluations of transportation emissions should review this status periodically to determine when Penn State should require the teams to use charter buses that consume lower-carbon fuels or are electric/hybrid.

Event travel by visitors will be very challenging to estimate unless information about modes and distance of travel is collected at time of ticketing and then compiled. Events that can be held virtually would have a smaller footprint. It is recommended that incentives be considered for visitors to take advantage of modes of travel other than driving a single occupancy vehicle – such as encouraging the use of public transportation and bike shares to arrive on campuses or having priority parking for high performance or electric vehicles. The other potential strategy would be to allow visitors to offset the emissions from their travel in some way.

For waste-to-landfill, the transportation emissions would be possible to calculate if data is available from the Centre County Refuse and Recycling Authority on the number and types of trucks that carry our waste from their facility to the landfill. The transportation related to recycling may be more challenging since those trucks will go to various locations instead of just one.

When goods and services are purchased, all purchasers should be working to minimize the GHG emissions involved in the creation of products, as well as the transportation of the people or goods to our facilities. Suppliers need to be continually engaged on this topic so that transformation is spread throughout our supply chain and consultant pool. A Sustainable Procurement Program is in development and should be encouraged to include this facet of sustainability when the program is deployed. It would also be useful to determine if the GHG emissions associated with our purchases can be calculated. For example, PepsiCo was able to estimate the average emissions associated with transportation of PepsiCo products to Penn State's campus from their warehouses and create a reduction goal for those emissions. This kind of conversation should be had with all our large vendors to start and then working into all of our suppliers.

# Appendix F: Farms

**Reduction in the emission of methane** will be mostly attributed to a reduction in emissions from animal production or reductions in the overall livestock inventory. Emissions of methane from irrigated rice production are also relevant on a per unit area basis but are not addressed here since it is not part of the Penn State agriculture portfolio. In developed economies with a large agricultural base like the United States, methane emissions are mostly due to ruminal fermentation of carbohydrates emitted by eructation. There is a large potential to reduce emissions based on diet control and dietary supplements, an area of active research, with the tradeoff that some of the methods reduce productivity, thus incentivizing more production elsewhere. In lesser developed economies with large livestock inventories like Kenya or India, emissions are also relevant, but less susceptible to dietary or other controls.

**Reductions in the emissions of nitrous oxide** from agriculture are a primary concern and relate to the fate of reactive nitrogen additions to the biosphere through biological nitrogen fixation and synthetic fertilizers. Nitrous oxide emissions occur mostly due to incomplete denitrification (conversion of nitrate to dinitrogen with release of nitrous oxide along the pathway) and during nitrification (conversion of ammonium to nitrate). Other less important processes also contribute to nitrous oxide emissions. Both nitrate and ammoniacal nitrogen sources originate in fertilizer (nitrate, ammonium) or biological nitrogen fixation (ammoniacal form). Cash crops or forages that are not legumes, need to receive nitrogen addition that at least match up to extraction by harvest plus a safety factor that accounts for potential storage in the system (low, and rather unusual), and losses to air and water. The nitrogen sources are synthetic fertilizer, addition of manure (which recycle nitrogen and other nutrients), decomposition of residues (if legumes, a net addition of reactive nitrogen), and atmospheric deposition. These sources have different properties that are relevant from the GHG perspective. While synthetic fertilizers have an intrinsic carbon footprint associated with the energy consumed in the Haber-Bosch process of 4.8 kg $CO_2$ eq per kg of nitrogen, its addition rates can be controlled. This carbon footprint can go down if renewable energy is used for the synthesis of ammoniacal fertilizer sources. As a reference, a baseline nitrous emission factor of 2% of the fertilizer nitrogen addition renders a carbon footprint of 9.7 kg $CO_2$ eq per kg of nitrogen. Comparatively, addition of nitrogen through manure is hardly controllable because the composition of manure is variable at the time of field application. Thus, nitrogen sources from manure carry a large uncertainty, and safety application to prevent nitrogen shortages for crops can create nitrous oxide emissions. Similarly, the addition of nitrogen in the system through legumes and green manure has the benefit of not including the cost of nitrogen synthesis (although a cost is embedded in the use of the land to grow that legume), the actual nitrogen fixation rate is difficult to estimate, and the nitrogen addition through decomposition happens alongside an ample supply of decomposable carbon that favors nitrogen emissions. From a GHG perspective, all nitrogen sources offer opportunities for management, and reducing the use of synthetic fertilizer is not an automatic way of reducing emissions; in fact, it may increase emissions due to interactions with the environment or poor management.

Reducing emission by denitrification would require a) decreasing denitrification and, b) if denitrification is active, force it to full reduction of nitrogen to dinitrogen. The second pathway is difficult and in general is impractical in large fields, but practical in denitrification reactors used to reduce nitrate load in water. Reducing denitrification is the most convenient option because it also implies retaining costly nitrogen within the bounds of agricultural systems. This requires a case-by-case assessment of production systems to find opportunities to manage nitrogen in a climate friendly manner without hampering productivity with some general rules to follow as there are plenty of opportunities to accomplish such reductions.

Some options are challenging and are still being researched, such as controlling residue input rates via cover crops: very large biomass from cover crops can elicit high nitrous oxide emissions. Other options are more straightforward and promising and require controlling the timing and magnitude of synthetic nitrogen fertilizer application beyond looking into agricultural productivity, or in other words, enacting precision nitrogen management in full force. Within fields, subfield areas with high productivity can benefit from higher nitrogen fertilizer application rates, while more importantly, areas with lower productive should receive lower fertilizer rates. Technologies for such approaches are already commercially available as the concept is decades old. Refining manure application rates can also enable large reductions in nitrous oxide emissions, but that approach is still challenged by the variability in manure composition.

Reducing emissions by limiting nitrification is also an option and relates mostly to avoiding the conversion of ammonium to nitrate by nitrifying microorganisms in soil. Nitrification can be slowed down by using commercial denitrification inhibitors that while slightly costly, can be beneficial. Reducing nitrification can: increase nitrogen uptake efficiency and therefore reduce fertilizer application rates with the added benefit of erasing part of the carbon footprint associated with the synthesis of fertilizers, reduce nitrogen leaching, reduce nitrous oxide emission from nitrification, and block the denitrification pathway by reducing nitrate availability. Even if partially successful, nitrification inhibitors are one of the simplest and least controversial means of decreasing nitrous oxide emissions.

There are a few key management or systems changes with the potential to make significant contributions toward a more carbon neutral agriculture. First **perennialization** of the system can lead to increases in soil organic matter on the order of perhaps 2 Mg $CO_2$ eq per ha per year, which compares favorably with emissions of nitrous oxide just from nitrogen fertilizer synthesis (about 1 Mg $CO_2$eq per ha per year for annual crop fertilized with 200 kg/ha of nitrogen) and is similar or less than emissions associated with medium nitrous oxide emission rates. Soil organic carbon gains are mostly associated with soils with initially low soil organic carbon. However, a trade-off exists: perennialization that reduces grain output by reducing the acreage of annual crops in a region may simply elicit land use change elsewhere. In other words, perennialization may store soil organic carbon in one place, and favor emissions elsewhere. A full accounting is needed to avoid a zero-sum game or worse.

Second, **addition of biochar** to soils is likely one of the most direct ways of increasing (pyrogenic) soil organic carbon. Because about 2/3 of the carbon in biochar has a very low turnover rate, additions of biochar can increase soil organic carbon storage without losses by microbial decomposition. Third, **transition from high-tillage to no-till** agriculture systems when that transition has not happened and is economically and agronomically viable (as described briefly above). Fourth, **cover crops** can have carbon benefits, but these are of lower magnitude as cover crops fit in regions in which climate does not allow double cropping but instead leaves the ground uncovered for a good portion of the year. In such cases, cover crops even producing limited aboveground biomass can reduce erosion, nitrogen leaching, may increase the yield of cash crops and soil carbon, but the same considerations that question potential large rates of soil carbon storage apply. With cover crops, it is the bundle of benefits that make it an attractive proposition.

**Combined approaches that displace fossil fuel usage and increase soil carbon and possibly geological carbon storage** also deserve attention, encompassing the aforementioned soil amendment with biochar and referring generally to the use of biomass crops or the use of crop residues. When using crop residues, this approach can be conceptualized as asking the microbes to share their meals with us to enable bioenergy production and in the most complete cycling of carbon, with carbon capture and storage, or BECCS (bioenergy production with carbon capture and storage). Instead of oxidizing residues in the field, we can harvest the residues, extract energy as heat, biogas or liquid fuel, and return the byproducts of those industrial processes to the soil or funnel them towards further industrial processing, while also capturing resultant carbon dioxide in smokestacks, and directing it to geological carbon storage. There are other potential benefits that need to be researched as there are potential synergistic and positive effects as well as negative interactions with nitrous oxide emissions. But in the medium to long term, these are options to be considered in any approach to climate smart agriculture. The technology to produce biogas from land fields or biodigesters is mature, and if manure is available, capturing and using biogas remains a viable option.

**Radiation management**, for example by integrating photovoltaics in farming operations is also an innovative way of reducing the carbon footprint of agriculture by generating energy in areas with limited productivity, or, in some cases, during dry spells. When soil is moist, there is no water stress and plants actively grow, and approximately 25% of incoming solar radiation is reflected. The rest of the radiation including the balance between incoming and outgoing long wave radiation (i.e., the net radiation) is used to heat the soil and canopy surface which in turn heats the air above it, and on evaporation (known as sensible and latent heat transfers). While the soil is moist, evaporation takes perhaps 2/3 of the net radiation. Energy in biomass likely accounts for $<1\%$ of the total incoming radiation. However, when soil is dry, growth can cease and most of the solar energy heats the soil surface and stresses crops. Partial shading at noon and early afternoon could relieve crops from water and heat stress, at the same time that demand for energy to support air conditioning systems increases, for example.

Thus, photovoltaic panels with tracking capabilities that can be used to shade crops only when needed and that do not disturb farming operations can become an innovative addition to agricultural landscapes. Permanent, non-tracking photovoltaic systems require management of surface water (as runoff increases) and possibly imply losses of soil productivity if deployed in areas with prime agricultural farmland. However, tracking systems can be a smart addition in areas with shallow or stony soils prone to water stress. Alternatives to radiation management, such as enhancing the surface albedo (increasing solar radiation reflectance) are worth further research.

An often-ignored component of climate smart agriculture is to simply increase yield without changing the use of resources, but without altering GHG emissions, i.e., **reducing the carbon intensity of agricultural outputs**. This benefit is akin to the reciprocal effect of indirect land use change. If productivity in each area increases, then there is area that is not needed for such production elsewhere. There are economic considerations that make apportioning avoided emissions complex. However, if the indirect land use effect stands (i.e., if land use changes from an annual crop to a perennial for bioenergy, and the production of that annual crop will be produced somewhere else to balance the demand thus allocating a GHG footprint to the area of bioenergy crop production) then the reserved indirect land use should also stand. It is however a difficult case to make in terms of carbon accounting because the production that replaced displaced production might not be comparable. In other words, all corn and soybean tend to be considered the same in world markets (except for transportation costs) as externalities are not directly included in the price per unit.

# Appendix G: Offsets

## PEER INSTITUTION OFFSET APPROACHES

This section is a short summary of peer university strategies or approaches regarding carbon offsets, specifically those with climate action reports (and see table below. Overall, most of the universities recommended that carbon offset purchases are not sufficient without companion strategies for carbon emissions reduction, and there is a particular focus on the intersection of offset decisions with issues of equity and justice.

*Table 22: Peer university strategies and/or approaches regarding carbon offsets.*

| University | University Offset Program - Recommended or existing? | Third Party Offset Purchase as Bridge Solution? | Offset Verification Method Mentioned? | Offset Evaluation Criteria? | Review of Approach Over Time? | Governance/Leadership Structure? |
|---|---|---|---|---|---|---|
| Michigan | Yes | Yes | Yes | Yes | Yes | Yes (recommended), executive reporting to President |
| Maryland | Yes | No | Yes | Yes | No | Yes (current), council, chaired by VP of administration |
| Illinois | Yes | Yes | Yes | Yes | No | Yes (current), council made up of sustainability related positions |
| Ohio State | Yes | No | Yes | Not found | No | Yes (current), council reporting to President and Provost |
| Rutgers | Yes | Yes | Yes | Yes | Yes | Yes (recommended), council made up of senior leadership, and Sustainability Councils |
| Michigan State | No | No | No | No | No | Yes (current), Director position, but identified weakness in non-central approach |
| Northwestern | Yes | No | No | No | No | Yes (current), council made up of senior leadership, and Sustainability Councils |
| Purdue | Yes | No | No | Yes | Yes | Not found |
| Delaware | No | Yes | No | No | No | Not found |
| Buffalo | Yes | No | No | No | No | Not found |
| Wisconsin | Yes | No | No | No | No | Yes (current), council reports to Provost and VP of Finance and Admin |

A few university reports (e.g., Michigan, Illinois, and Rutgers) mentioned that third-party carbon offset purchases should be considered as a bridge solution only, or to fill gaps that have no other viable option – instead prioritized effort and resources should be placed on rapid and direct reduction of emissions. If a third-party offsets purchasing strategy is to be employed, reports mention the importance of verification – otherwise any university investment in offsets could be questioned or even compromised. To that end, both the University of Michigan and Rutgers University reports outline specific criteria for evaluating offsets either purchased or produced. In these cases, the university strongly influenced verification methods or used vetted verification standards that had been rigorously evaluated. Many reports mentioned the importance of consistently evaluating offsets purchasing or university carbon offsets production over time, rather than simply setting a strategy that is not revisited. Finally, some reports mentioned actions regarding offsets in addition to or instead of a third-party carbon offset purchase including targeted and/or voluntary offset purchases related to air travel (with some universities, such as the University of Maryland and the University of Illinois U-C, already doing this), the development of university sponsored and/or developed offset projects, a shift towards renewable energy, and the creation of green infrastructure on university land.

## EXTERNAL OFFSETS

Carbon offsets available for third-party purchase are produced by organizations that remove $CO_2$ from the atmosphere that would otherwise not have been removed. Many of these offset programs are based on capturing biological uptake of $CO_2$ by plants through photosynthesis. In addition, innovative programs are being developed for offsets that reduce emissions through time-tested technologies like generation of biogas using manure digesters, and through deployment of solar arrays and other renewable energy projects. Many of the available third-party offset programs are based on increasing carbon uptake through tree planting and improved forest management. Such programs are distributed across the globe and have been part of voluntary carbon markets for decades but vary in their authenticity. Among the challenges are accounting for indirect land use swaps (e.g., planting a forest by displacing a pasture may trigger pasture development elsewhere) also known as leaking, quantifying carbon storage, and the risk of loss of the forest (fires or other disturbances). Priorities for Penn State in consideration of forest-based carbon offset programs should include projects that have additional societal benefits and pass the most rigorous verification protocols. They could include improved forest management in Pennsylvania and surrounding states. Additional land-use based offset programs include agricultural practices that increase non-transient soil carbon storage without increasing carbon dioxide emissions along the pathway that led to such increase in carbon storage (i.e. net $CO_2$ removal from the atmosphere), reduce existing GHG emissions from agricultural lands, reducing agrochemical inputs that have a high carbon footprint (e.g. nitrogen fertilizer), or producing biogas that can substitute for natural gas or other fossil fuel consumption.

A third-party carbon offset purchase offers certain advantages, not the least of which is the immediate ability to manage and impact the University's GHG emissions and do so in a rapid manner. Doing so could start momentum towards a university goal of carbon neutrality or negativity, demonstrate the seriousness with which the University views this issue, and set the University on a pathway to continue to reduce emissions through the purchase of carbon offsets. There is an opportunity for Penn State to assist in carbon reduction projects in Pennsylvania and/or the world with positive environmental impact while supporting economic development and the livelihoods of PA citizens and beyond. An additional advantage of a third-party offset strategy is that the purchases could be temporary while the University focuses on direct reduction of emissions. Further, third-party offset strategies can be flexible, changed year to year, to support emerging new technologies and management approaches and be responsive to the changing needs of the University community.

There are also many disadvantages to the purchase of third-party offsets. Perhaps most importantly, financial resources used to purchase third-party offsets are thereby not available to be invested in technology, research, education, extension, internal infrastructure or partnerships to directly reduce carbon emissions, that may reduce the potential multiplicative effect of technologies developed at Penn State, used by Penn State, and then adopted by other entities worldwide. Such multiplicative effect, although not included in our GHG balance, would have an immense impact on branding and leadership as it signals investments towards research and education with a broader goal in mind. A third-party offset strategy may not ultimately support Pennsylvanians directly if the offsets are purchased from outside the Commonwealth, thus reducing the potential positive investment impact. Further, the approach may exclude students and faculty from the task of pursuing carbon emission reduction directly and could limit opportunities for partnerships and collaborations that otherwise might develop through focused attention on direct emission reduction. Some universities, e.g., the University of Michigan, have described difficulty in the evaluation and verification of third-party carbon offsets. Thus, the purchase of third-party offsets may be less valid in terms of purchase sources and could be viewed as the University choosing the least expensive (and perhaps least effective approach to obtain permission to pollute. Finally, the cost of the purchase of third-party offsets, as more and more requirements are placed on entities to purchase them, could rapidly increase and be somewhat unpredictable moving forward.

The schedule over which such a strategy could be developed is an important consideration, which we frame here simply as long and short timelines. A long-term strategy involves the University purchasing third-party offsets on the voluntary market for the foreseeable future as part of our carbon emissions reduction strategy. These long-term, verifiable (by reputable certifiers and us, if possible), and additional offsets will become part of the university's carbon emissions reduction strategy for a long time, e.g., decades. A short-term strategy involves the University purchasing third-party offsets in a short time frame of years. Just as with the long-term timeline strategy, these shorter timeline offsets will share all the above principles and will become part of the university's carbon emissions reduction strategy for a time. The distinction is that, under this strategy, the purchasing of offsets will be employed into the immediate future while the University works to directly reduce and eliminate its carbon emissions.

A long-term timeline strategy of purchasing third-party offsets has some advantages, though given the cost of offsets and the unpredictability of this cost, caution would be warranted with this approach. However, if there is some predictability with cost, such as a long-term contract, this risk of cost variability could be reduced. Additionally, these longer-term agreements could be of mutual benefit to the University and partners. A longer-term strategy could help bolster carbon emission reduction efforts if Penn State is not able to produce offsets or reduce carbon emissions in some manner. Additionally, if some emissions from the University were not able to be eliminated, a longer-term approach could help close a gap towards a GHG emissions reduction goal. Further advantages include the reality that staff or faculty time would not be as highly required through a third-party offset purchase, and the quality of offset options (whether source or impact could potentially be higher than the offsets Penn State could produce. Additionally, some third-party offsets on a longer timescale could perform better with more time, such as carbon offsets produced through forests.

A short-term timeline approach to the purchase of third-party carbon offsets has certain advantages as well. A shorter-term purchasing approach could place a time limit on the purchase of third-party carbon offsets by the University, sending the message that our intent to reduce carbon emissions is clear and that we cannot purchase our way out of our emission production indefinitely. Eventually, purchasing of third-party offsets could be replaced by internal or hybrid-based approaches. A shorter-term approach could allow us to buy time to establish leadership, branding and support for viable and verifiable offset projects that the University wished to sponsor. A short-term approach also allows us some degree of flexibility in the likely case that offset purchasing prices increase; or if our strategy towards emission reduction needs to be altered. Additionally, putting the purchase of third-party offsets on a more limited timescale allows us to perhaps utilize the latest technology in emissions reduction; making offset purchasing a strategy from which we can move away and invest resources elsewhere.

As well, the local, regional, national, and international geography of third-party offset programs and Penn State's purchase of them should be considered. If third-party offsets were purchased from local providers, they could be viewed as an activation of the University's land-grant mission. Local offset purchases (and associated production could develop local jobs in our surrounding communities, impact where we live and work, allow for deeper (and mutually beneficial relationship building with those communities, and could of course engage Penn State faculty, staff, and students (who are often also members of these communities in the work surrounding the creation of these offsets (such as research or technology transfer. Local offset programs could be more easily verifiable by Penn State experts so the University could be confident that the purchases are the best/most valid offsets possible. This could help improve Penn State branding and perception when it comes to reduction of carbon emissions and demonstrating how University expertise can be applied to the offset purchasing process as an example that other communities or Universities (or even corporations might deploy.

Third-party offset purchases from regionally developed projects, perhaps focused on the states within the Regional Greenhouse Gas Initiative[86] might also simplify verifiability of the carbon offset purchases from a third party. A regional approach could provide a degree of flexibility in the types of offsets purchased – allowing offset purchases from multiple sources and contexts, while still close enough that verification by Penn State representatives could be relatively easily accomplished. A regional approach could allow a strategy to be scalable to other states/regions with similar geographic and resource (as well as emission realities as Pennsylvania. A regional approach could be rooted in environmental justice, land use ethics, animal welfare, ecosystem welfare, as well as the economic development of the region (especially with investments in energy production that may be bound to non-sustainable sources. Finally, there is the potential for greater partnership impact from a regional approach than perhaps a local approach, and we would want to ensure that these offset purchases could allow for faculty/student research and engagement.

A national approach to the purchase of third-party offsets could further broaden and amplify the University's impact and could allow us to target specific areas and communities nationally and help lead them towards clean energy development pathways. Internationally purchased offsets could provide an opportunity for Penn State to have a major role in the sustainable development of the global south. We could continue to build relationships with global

[86] https://www.nrdc.org/resources/regional-greenhouse-gas-initiative-model-nation

partners and expand and strengthen the Penn State brand, which may pay off in enrollment or funding returned to the University. A program of purchasing international third-party carbon offsets could also be cheaper in the long run, though cost needs to be balanced with the difficulty of verifying the validity and viability of internationally developed third-party carbon offsets. Finally, a national or international approach could allow us to deliver on our strategic plan, specifically the foundation of ensuring a sustainable future and the thematic priority of stewarding our planet's resources– applying the UN Sustainable Development Goals at a national and/or international level.

## INTERNAL (PENN STATE) OFFSETS

Penn State developed offsets have potentially transformative implications, but this strategy should not be divorced from efforts to reduce carbon emissions through methods other than offset production. Realistically, Penn State likely cannot produce sufficient offsets needed to offset our current emissions, and thus this approach should be considered as part of a portfolio of offset solutions. Nonetheless, the development of Penn State offsets could be effective and could certainly help with branding, visibility, building pride and the development of partnerships among the greater University community. First and foremost, Penn State developed offsets could build from existing assets of land and infrastructure, faculty expertise and technology transfer pathways. They could help to improve research, hedge against increased carbon offset purchasing cost in the future, improve local communities, and leverage our strengths as an institution in many productive ways, such as engagement opportunities for faculty, staff, students, and community members. Given that Penn State's geographic footprint is large, we may also be able to create an internal offset strategy that is much broader than most other universities in the U.S. We could have control over the budget and guide resource allocation using scientifically grounded data, as well as have no limits on the data we collect, which could help improve research and potentially improve technology development through a variety of external funding sources. Further, we could better control the transferability of research/technology development and build stronger links to existing educational activities and opportunities. Finally, an internal strategy should be revisited regularly and guided by accurate data that comprehensively portrays carbon emissions goals. As the inventory of our carbon emissions gets more accurate over time, we may see an increase in University-reported carbon emissions, and this offset strategy should be placed in that context.

Climate-smart agriculture can also have positive impacts on the institutional GHG balance, as well as a multiplicative impact through Penn State showcasing these technologies and practices. Penn State produces grain on about 2000 acres of land owned by the institution. Although emissions from these activities are only a small portion of the GHG balance of the institution, altering agricultural management practices can reduce emissions. The main targets are reductions in the emission of nitrous oxide and the use of nitrogen fertilizer, the production of biogas, storage of carbon in soil in areas where there is room to improve management above the status quo, and development of precision photovoltaics to use solar radiation with higher efficiency. Nitrous oxide emissions can be reduced through refined management of the nitrogen cycle by regulating the amount, type, and timing of nitrogen fertilizer use, as well as manure and cover cop use and other adjustments. Beyond using standard emission factors, this may require monitoring for verification purposes. The biodigester for manure and other organic residues will generate biogas that offsets sources of energy from fossil fuels. Soil carbon storage has some promise in areas with low soil carbon when the management can bring other benefits like the production of biomass that can be added to the digester. A more innovative approach that is promising and that requires more research is including photovoltaic panels to capture sunlight in areas of low productivity, without altering grain production. Working along with Farm Services and thanks to prior efforts, this Task Force has a careful inventory of current practices and can develop a detailed path forward to serve carbon reduction goals (see Farms section of report.

## HYBRID OFFSETS

A variety of possible hybrid approaches can be imagined, and we provide more detail for each of these below. A common thread in these examples is that they draw on existing Penn State expertise and/or focus on addressing issues long-term environmental degradation in Pennsylvania. Capturing methane from existing orphaned oil and gas wells (Well Done Foundation and coal mines (CNX) would help to address statewide problems and may be deployable on a small subset of our Commonwealth campuses on which these features are known to exist. Similarly, the presence of inadequately reclaimed and abandoned mine lands throughout the state represents an excellent opportunity to sequester carbon in soils by soil restoration and reforestation in partnership with GreenForestsWork and the PA Department of Environmental Protection. Conversations with the Centre County Planning and Development Office indicate a strong interest in partnering with the University to develop regional programs of agricultural land management to increase sequestered carbon in farm soils while helping to protect water quality. And, finally, Plant Village, led by PSU faculty member David Hughes, is a USAID-funded program to engage small farms in Africa including an effort to plant trees, sequester carbon, and develop an offsets program – PSU investment in and overall support of this program could be far reaching in climate action impact and in broadening the Penn State brand internationally.

### *Well Done Foundation*

**Plugging Abandoned Oil and Gas Wells**

According to the EPA, there are approximately 3 million abandoned oil and gas wells currently leaking over 120 million metric tons of methane emissions into the atmosphere in the United States. In Pennsylvania alone, the DEP estimates there are between 300,000 to 760,000 wells that have been drilled in the state since oil drilling started in PA in 1859. The DEP has a Well Plugging Program to plug these wells, which is done by pouring liquid cement down the well casings into each well's aquifer. This program is only able to plug around 12 wells per year, a rate at which would take 17,500 years to plug all these wells.

This is a massive environmental problem that Penn State is in the position to act on being the state's sole land-grant institution; an issue that by helping mitigate would allow the University to accumulate gathering carbon offsets.

**Recommendation: Strategic Partnership with Well Done Foundation**

When compared to other types of offsets available on the carbon market, plugging wells is a suitable and even preferable option. The Well Done Foundation (WDF is a 501(c(3 non-profit organization that specializes in the plugging and monitoring abandoned oil and gas wells.

Forming a strategic partnership with the WDF and collecting carbon offsets via funding WDF projects would be substantially beneficial for Penn State in reducing its carbon emissions due to these components:

- Cost Effective
  - As a baseline figure, a well that emits 3,500 MTCO2e a year would cost $30,000 to plug per the WDF's specifications. This expense breaks down to spending approximately $8.5 per ton; a competitive price when placed into the market range of $0.1/MTCO2e to $70/MTCO2e according to a 2019 publication out of NC State Extension titled *An Introduction to Forest Carbon Offsets*.

Figure A: WDF plugging an oil well in Bradford Township, PA on Oct. 2, 2021. This well is a legacy well spudded in the late 1800s and was emitting an average of 661 MTCO2e/year prior to its plugging.

  - Offsetting Penn State's 435,465 MTCO2e of annual emissions with this strategy would cost approximately $3,732,557; the cost of plugging 124 wells.

- Transparent Disclosure & Trust: WDF has plugged ten (10) orphan oil and gas wells in the State of Montana and has reduced methane emissions by more than 500,000 metric tons of CO2e. Its carbon offsets are registered under the American Carbon Registry (ACR). Founded in 1996, the ACR was the first private registry in the voluntary carbon offset market. ACR acts as a third-party that verifies the validity of the WDF's projects and offers credits to interested buyers.

  WDF has an approved carbon methodology that breaks down into five (5) parts when carrying out their projects:

1. Identification: WDF identified orphaned wells, performs background research and creates a well profile for a field team including:
    a. Well History
    b. Well Characteristics
    c. Location
    d. Surface Ownerships
    e. Existing O&G Leases
2. Qualification: WDF performs field verifications and generates a detailed orphaned well report to determine if the well qualifies for further analysis and works with surface owners for an access agreement to perform further testing for:
    a. GHG emissions
    b. Surface conditions
    c. Accessibility
3. Adoption: The orphaned well is monitored and analyzed for a period. A bond is then posted and the orphaned well is Adopted from the State. A campaign budget is prepared and a new orphaned well campaign is launched to raise the funds or use the Well Done Carbon Finance strategy for the Plugging, Abandonment and Surface Restoration of the orphaned well.
4. Closure: WDF works with the State to develop approved Plugging & Abandonment Plans. The campaign work activities are then planned with the Surface Owners, State and Local Agencies.
5. Restoration: WDF works with the Surface Owners, State and Local Agencies to complete the Surface Area Restoration and develop a long-term site monitoring plan.

- Local & Immediate Impact: As indicated in the Figure A above, WDF has begun plugging wells in PA, with 9 additional projects slated for completion in McKean County. Unlike with forest carbon offset projects, these projects stop the release of methane emissions immediately, the emissions are more easily measurable, and the sites of these wells can be visited or examined at any time.

- Benefits PA Economy: WDF uses local and regional service companies to perform the work to create jobs and support the state economy. For instance, the Appalachian Legacy Project LLC., based out of Bradford, PA, is run by a fourth generation PA oil family that now has several projects on its project line because of WDF's expansion into the state.

- Potential research and teaching opportunities: There is potential to leverage this partnership and allow for the WDF to sponsor research projects focused on well resiliency and sustainable materials. For instance, a team of Penn State researchers, including Arash Dahi Taleghani, Associate Professor of Petroleum Engineering, and Maryam Tabatabaei, Postdoctoral Scholar in the John and Willie Leone Family Department of Energy and Mineral Engineering, developed a nanomaterial cement mixture, made with graphite, that could prove effective in ensuring cracks in traditional cement poured down oil and gas wells do not form overtime. This is just one example of an innovative technology coming out of Penn State that could gain practical exposure in the field and, in turn, prove to become an industry standard.

- Promotes sustainable industry transition: Sponsoring these projects highlights how the petroleum and natural gas industries are positioning themselves to be more sustainable going into the future. Students, particularly petroleum and EMS students, would be allowed to visit the sites of these well projects during their plugging processes to see how these industries are providing sustainable jobs across the state, how their studies translate into practical solutions and how they, potentially, could be working these kind of jobs following graduation.

In all, forming a strategic partnership with the Well Done Foundation and funding well-plugging projects achieves Penn State's land-grant mission of teaching, research, and service, while drastically reducing Penn State's emissions in a cost-effective and impactful way.

Sources:

https://www.epa.gov/sites/default/files/2018-04/documents/ghgemissions_abandoned_wells.pdf

http://www.depgreenport.state.pa.us/elibrary/PDFProvider.ashx?action=PDFStream&docID=1419023&chksum=&revision=0&docName=ABANDONED+AND+ORPHAN+OIL+AND+GAS+WELLS+AND+THE+WELL+ PLUGGING +PROGRAM&nativeExt=pdf&PromptToSave=False&Size=411528&ViewerMode=2&overlay=0

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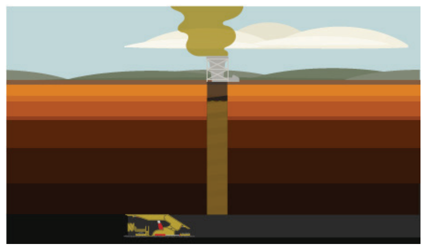
# CNX™ Methane Emissions Capture

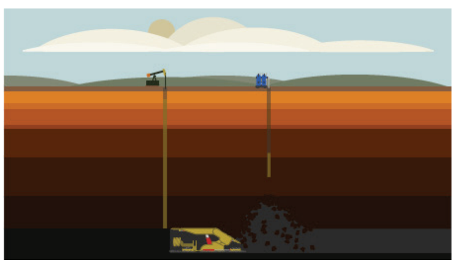
## MINE METHANE ABATEMENT

CNX manages one of the largest environmentally friendly natural gas fields in the country from our coal mine methane assets. This is methane that would have otherwise been vented into the atmosphere as a byproduct of third-party mining activities. CNX has been developing operations to capture methane emissions, process it, and put it into the nation's energy grid for benefits like power generation and heat.

## HOW DOES IT WORK?

When mining takes place, methane is liberated, creating a hazard for the miners as well as a greenhouse gas emissions source. Traditionally vents would be installed to ventilate methane from the mine into the atmosphere.





Instead, CNX drills wells to remove the methane, keeping the miners safe and then capturing methane that continues to emit from the mine for many years after mining activity is complete.

## Benefits of the Process

**Creating Jobs**
particularly in the communities most detrimentally impacted by the energy transition

**Methane is 25X**
more potent than $CO_2$ at trapping heat in the atmosphere

**Better than Carbon Capture**
brought to beneficial use and permanent

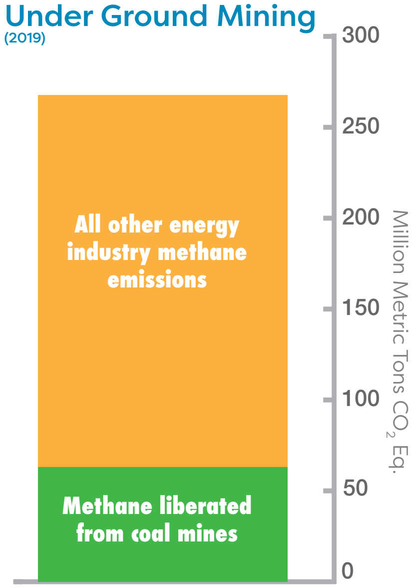
**Similar to RNG**
naturally occurring and emitted methane abated

## Reasons to Incentivise Methane Capture

**7%** of methane emissions come from active or abandoned coal mines. For safety purposes, mines evacuate methane from underground. Methane abatement devices can be used to permanently destroy mine methane rather than emitting into the atmosphere. Incentivizing this activity will create an immediate avenue to enable significant mine methane capture to reduce greenhouse gas emissions while helping coal communities.

***Lack of action leads to neglecting a methane emitting liability instead of generating a methane abating, job creating asset.***

### Total $CH_4$ Emissions from Under Ground Mining
(2019)




EPA Inventory of US Greenhouse Gas Emissions: Table 3-30

*Excludes abandoned methane mine emissions, which aren't reported to the EPA.*

# Green Forests Work for Appalachia

*Contractors examine maps to prepare a work plan prior to beginning site preparation.*

***... the Green Forests Work* program aims to reforest approximately 500,000 acres by 2030...**

*A tree nursery worker lifts bare root hardwood seedlings.*

*Professional tree planters reforest a mine site that has been decompacted by heavy equipment.*

The Appalachian region is a land of contrast: people have suffered from poverty for decades, but the region abounds with a wealth of natural resources; Appalachian forests support some of the highest biological diversity in the world's temperate regions, but extraction of the area's abundant coal reserves have scarred the landscape. With one program, we can address economic, environmental, and ecological challenges simultaneously. Since passage of the Surface Mining Control and Reclamation Act of 1977 (SMCRA), approximately 1.7 million acres of Appalachian forest have been impacted by surface mining. Since 2009, Green Forests Work (GFW) has reforested nearly 5,000 acres through the planting of nearly 3 million seedlings. Having established the proof of concept, Green Forests Work is ready to scale up these efforts. With additional funding, by 2030, the Green Forests Work program could employ more than 3,600 local residents from rural coalfield communities to re-establish over 500,000 acres of high quality, diverse forests on formerly mined lands, directly addressing unemployment rates that typically run higher than the national average and environmental issues such as forest fragmentation, invasive exotic species, and climate change.

<u>Employment and Economic Impacts:</u> The reforestation of 500,000 acres would require the creation of approximately 3,600 direct jobs throughout the region. Jobs for seed collectors, tree nursery workers, herbicide applicators, heavy equipment operators, and tree planters would be required. The added economic stimulus from investment in the region would create additional employment opportunities in the manufacturing, retail, service, transportation, and hospitality industries, providing approximately 8,200 additional jobs[1]. The reforestation of 500,000 acres of lands disturbed by coal mining and other activites would result in the planting of 330 million seedlings. Sustainable, long term future employment opportunities would be created through forest management and the harvesting of timber and non-timber forest products, economies that produce tens of billions of dollars in annual revenue throughout the region.

GFW and the Appalachian Regional Reforestation Initiative have developed methodologies that result in the successful reforestation of formerly mined lands, where the soils have been severely compacted, aggressive grasses cover the site, and mining companies have no further reclamation responsibility under Federal or State laws. Many of these lands are largely unused. Under GFW guidance and with government, corporate, and private investment, the goals of this program are to stimulate local economies, and to restore native, biodiverse forests and the ecosystem services that they provide for society. Improving the economic and environmental conditions of mining regions is a worthwhile investment that will lead to a sustainable future.

While this program initially focuses on the Appalachian region, it could easily be further scaled to support reforestation, fire rehabilitation, and ecological restoration efforts in other regions of the U.S. and elsewhere.

[1]Bivens, J., 2019. Updated employment multipliers for the U.S. economy. epi.org/160282

# Green Forests Work for Appalachia


*Before (l) and after (r) photos of a reforested surface mine and stream reconstruction project in eastern Kentucky that used GFW techniques. Photos were taken prior to planting (l) and in 2019 (r), after 11 years of growth.*

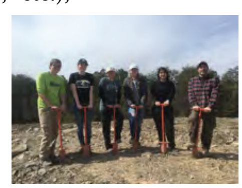
Society at large benefits from restoration of productive forests—Appalachian forests constitute an "environmental infrastructure" that produces ecosystem services of tangible value to local communities, the United States, and the world. For example, forested landscapes:

- maintain clean water supplies to Appalachian communities and larger cities fed by headwater streams;
- protect biodiversity, including globally significant numbers of declining, rare, threatened, and endangered fish, mussels, salamanders, birds, and mammals;
- buffer the effects of storm events through the interception and uptake of rainfall;
- reduce forest fragmentation, which increases the available habitat for many species that rely on large blocks of contiguous forest for breeding and foraging, including declining Neotropical songbirds, such as Cerulean warbler.

Furthermore, forested landscapes provide economic returns by:

- improving aesthetics, which is of importance to tourism and recreation industries and increases property values;
- improving the mental health of residents by reducing levels of depression and stress, which improves physical health and lowers medical costs;
- providing sustainable employment opportunities through the harvesting of timber and non-timber forest products (e.g. honey and bee products, medicinal plants, mushrooms, hunting leases, etc.);





Waning job opportunities in the mining industry (due to factors such as increased mechanization and low natural gas prices), ample opportunity, and tremendous interest in restoring Appalachian forests will allow this program to succeed. Within ten years, the *Green Forests Work for Appalachia* program could create 3,600 direct jobs and an additional 8,200 indirect jobs, revitalizing local and regional economies. Successful reestablishment of native hardwood forests that once dominated these sites will provide a **renewable, sustainable, multi-use resource** that will create future economic opportunities while enhancing the local and global environment.

www.greenforestswork.org

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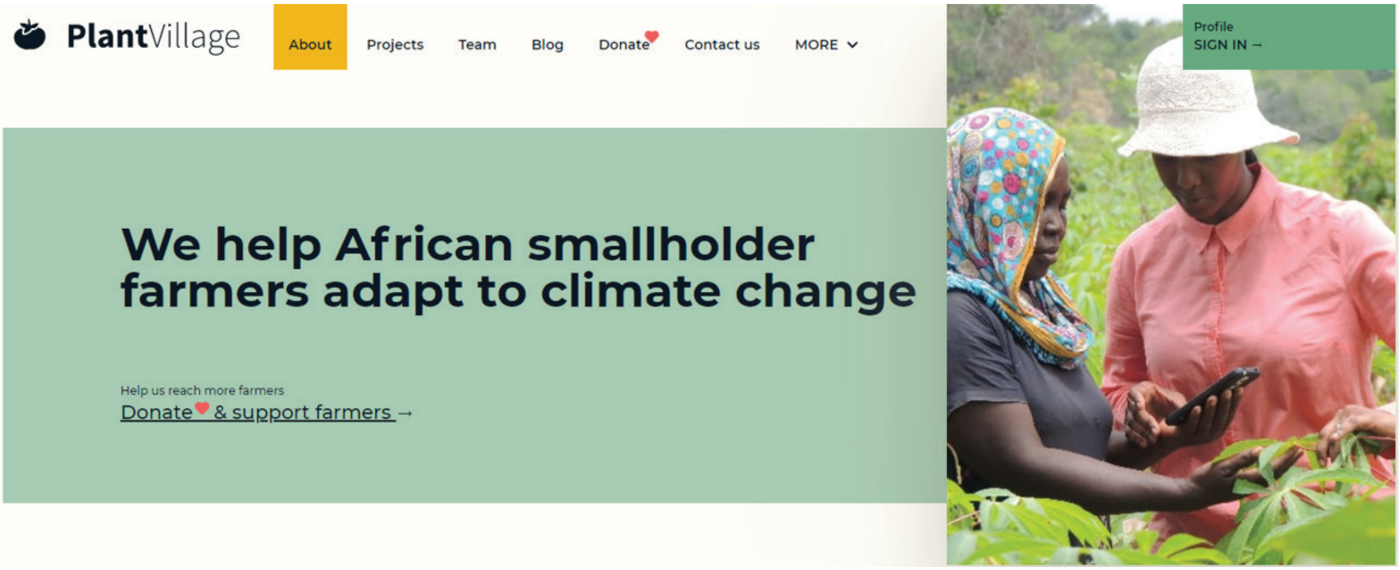



PlantVillage has planted 750,000 trees in Kenya since August 2021 and is in the process of planting 50,000 in Burkina Faso. Together with the Kenyan Forest Service, PlantVillage is establishing a nursery of 3 million trees which it will replace every 6 months (6 million/year) and then replicate x 3 to have 18 million tree production/year. Each tree can produce approx. 200 kg in three years.

In addition to planting new trees, PlantVillage works with millions of farmers in Kenya, many of whom have trees 7 to 10-year old trees they are planning to cut down for firewood. We can prevent this $CO_2$ from being released and use that tree to lay down more carbon. This tree would also add $CO_2$ at a higher rate than seedlings.

In addition to optimizing seedling distribution and identifying existing trees, PlantVillage has modified its best-in-class cloud architecture to store details on carbon sequestered based on locally relevant allometric equations. This means we are as precise as possible in determining carbon sequestered. This will be used by Carbon4Good.

As a customer, Penn State would have two deliverables:

1. Accurate determination of carbon sequestered which is not delivered by others.
2. Carbon offset where 98% of the value goes to the community to transform lives devastated by climate change.

# Appendix H: Modeling of Emissions Reduction Strategies

## IEP MODEL RESULTS FOR COMBINED SCENARIOS

The Combined Scenarios in the table below have been analyzed with respect to the key performance metrics provided in the table as well as time series analysis over time with respect to GHG emissions mitigation, annual cashflows, and annual capital expenditures as described in the Modeling of Emission Reduction Strategies section of the main report.

*Table 23: Key Performance Metrics for IEP Modeled Combined Scenarios Targeting Recommended Milestones*

| Scenario | Unit Cost of Carbon Reduction *($/MTCO2e)* | Net Cost *Negative = Savings* *($NPV)* | Total Carbon Impact *(MTCO2e)* | Total Capital Requirement *($)* | Annual Operating Cost *($NPV)* | Remaining Social Cost of Carbon *(Total $MM)* |
|---|---|---|---|---|---|---|
| Nuclear 1 | 43.15 | 384,651,300 | (8,914,420) | 719,040,000 | 30,063,935 | 0 |
| UP Biomass | 49.91 | 442,969,058 | (8,876,093) | 667,040,000 | 17,403,230 | 0 |
| Nuclear 2 | 52.93 | 469,841,861 | (8,877,407) | 749,040,000 | 16,210,945 | 0 |
| HW SW Geo | 73.48 | 624,178,081 | (8,494,232) | 696,800,000 | (15,789,021) | 0 |
| HW DW Geo | 83.45 | 710,402,186 | (8,513,010) | 785,800,000 | (11,713,449) | 0 |

The above scenarios all include the following strategies consistent with Goal #1 and the associated Milestone recommendations including the action items pertaining to energy infrastructure listed within each Milestone:

- **ESP Revised** – a continuation of the energy savings program under revised justification protocols.
- **CWC Solar** – the installation of solar on Commonwealth Campuses.
- **HBG Bio** – a biomass boiler installed at the Harrisburg campus to replace the current natural gas boiler.
- **WRF FC** – a fuel cell installed at the water reclamation facility utilizing currently flared natural gas to produce electricity.
- **EV Transition** – a change to Fleet and OPP vehicle replacement policy to purchase electric vehicles instead of traditional gasoline vehicles.
- **CWC SW Geo** – an electrification of the Commonwealth Campuses by replacing gas fired heating with electric heat pumps supported by ground source thermal obtained from shallow wells.
- **PPA2** – a second renewable PPA purchase to augment the Franklin County Solar PPA.
- **RNG** – a purchase of renewable natural gas to offset natural gas use prior to completion of the thermal conversion.

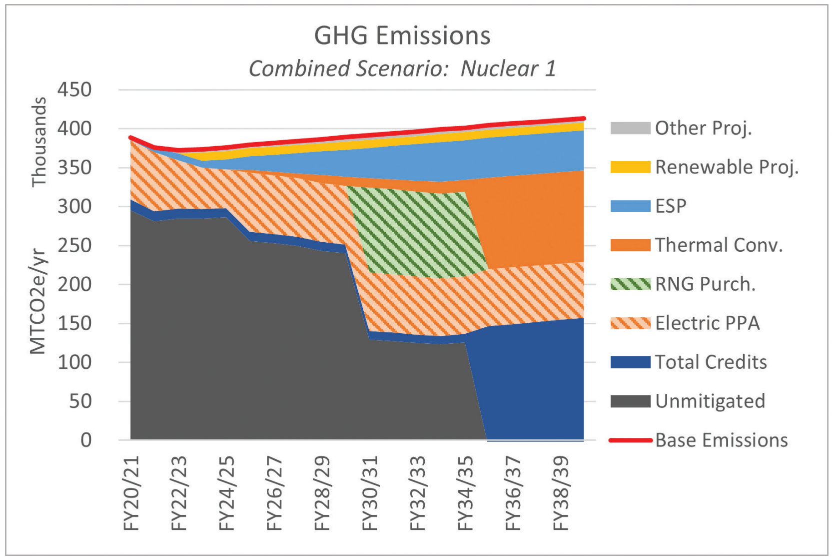
These scenarios are packaged with the five thermal conversion strategies shown in the table above to evaluate the relative impact of each thermal option with respect to the level of GHG emission reduction, annual cashflows and capital requirements. Each of the scenarios are presented below with a brief description of the scenario and observations of its impact. Further descriptions of the strategies that are included in the scenarios are provided in Appendix I.

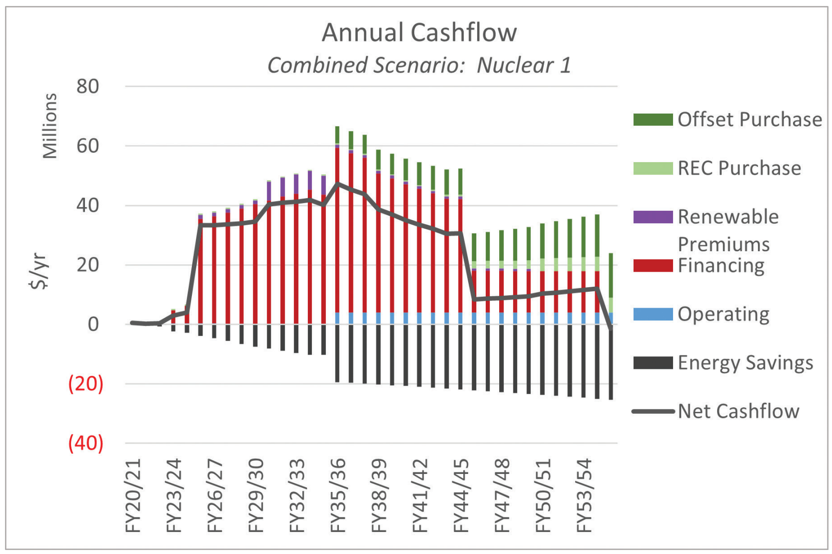
## NUCLEAR 1

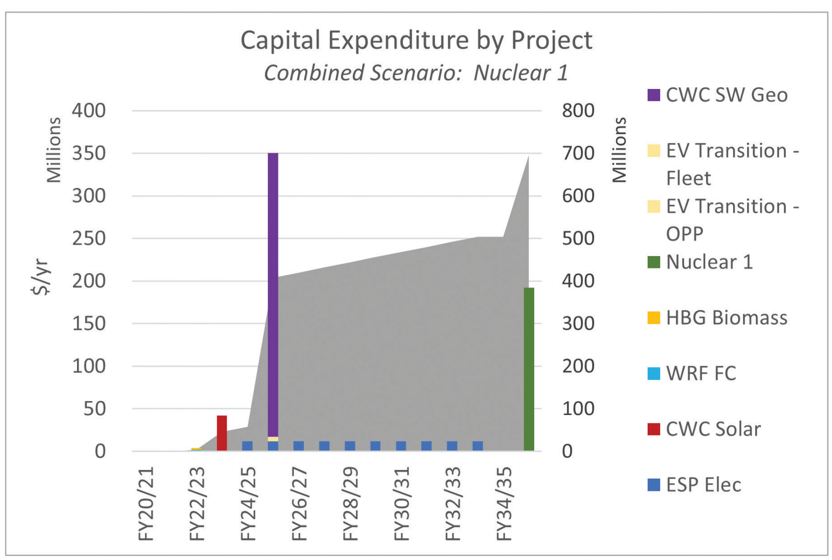
The Nuclear 1 scenario analyzes the impact of converting the natural gas steam boilers to nuclear technology with a molten salt core. For the analysis, the nuclear capacity was sized to address baseload and intermediate thermal requirements. The peaking needs are assumed to be provided by natural gas. Since the nuclear units are a high temperature solution, the existing steam distribution system does not need to be converted to hot water.

The annual cashflow changes reflect a large financing cost to cover the amortization of the capital expense, but the energy savings from higher electric generation and avoided natural gas more than offset all other costs over time, leaving the energy system operating at a discount to the current baseline by the end of the analysis term.

The capital requirements for the Nuclear 1 project are anticipated to be toward the end of the Goal term (2035). The other capital shown below is included in all scenarios evaluated. The nuclear project is expected to cost almost $200 million and covers the nuclear modules, connection to the existing system, high permitting costs and other site requirements.



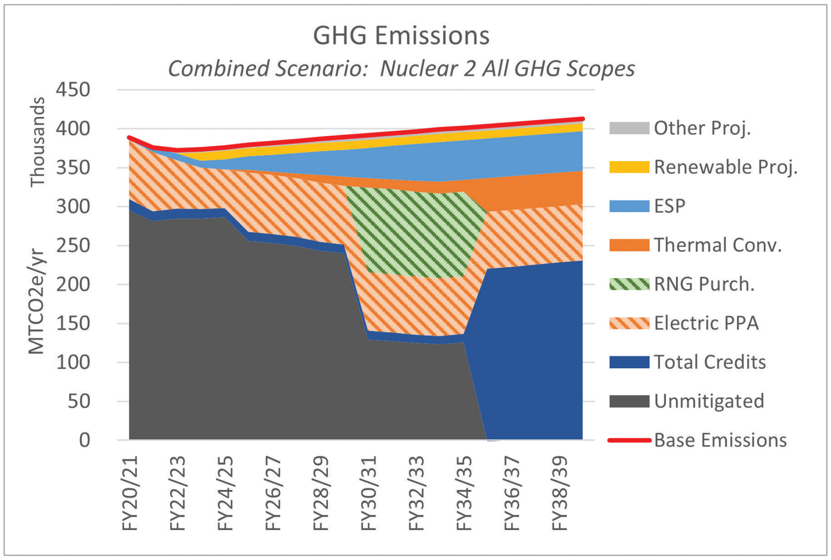



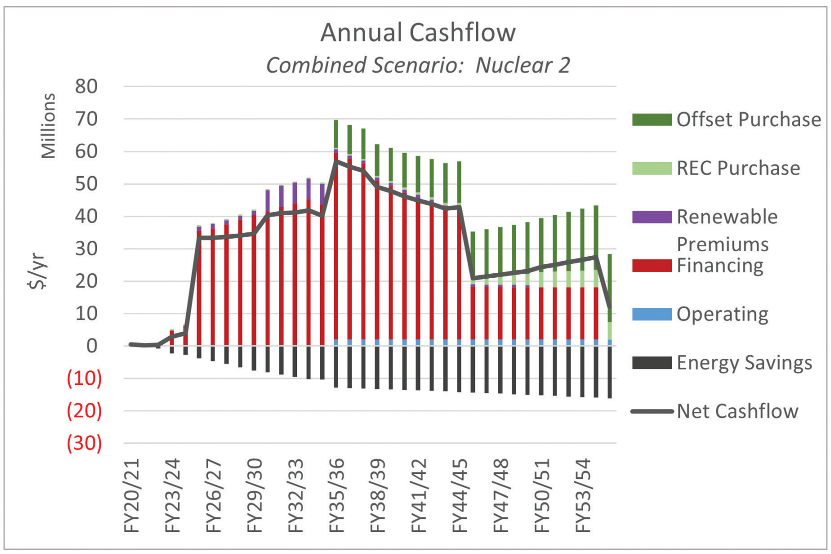
## NUCLEAR 2

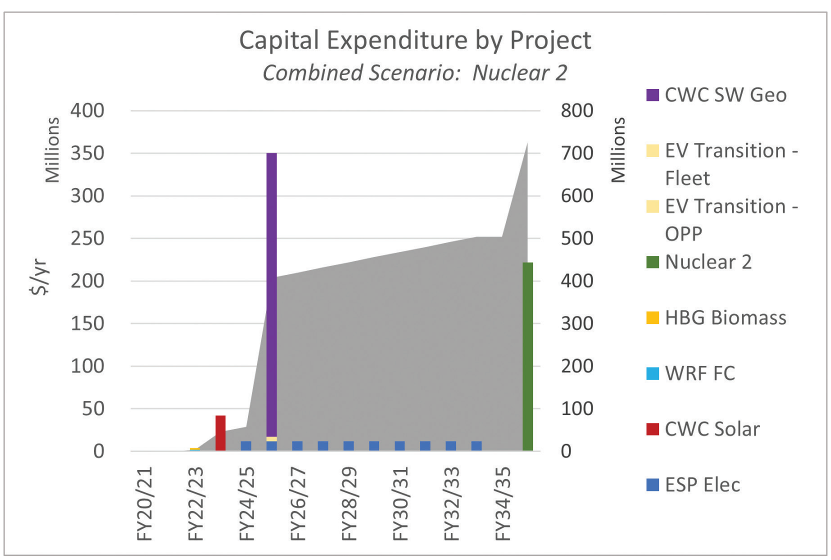
The Nuclear 2 scenario analyzes the impact of converting the natural gas steam boilers to nuclear technology with a solid-state core. Similar to Nuclear 1, the nuclear capacity was sized to address baseload and intermediate thermal requirements. The peaking needs are assumed to be provided by natural gas. Since the nuclear units are a high temperature solution, the existing steam distribution system does not need to be converted to hot water. Nuclear 2 differs from Nuclear 1 primarily due to the core technology having less flexibility to switch between high and low temperature outputs which impacts its ability to displace natural gas and generate as much electricity as the Nuclear 1 option.

The annual cashflow changes reflect a large financing cost to cover the amortization of the capital expense, and unlike the Nuclear 1 option, the energy savings do not fully offset other costs over time, leaving the energy system operating at a premium to the current baseline by the end of the analysis term.

The capital requirements for the Nuclear 2 project are anticipated to be toward the end of the Goal term (2035). The Nuclear 2 project is expected to cost over $200 million and covers the nuclear modules, connection to the existing system, high permitting costs and other site requirements.



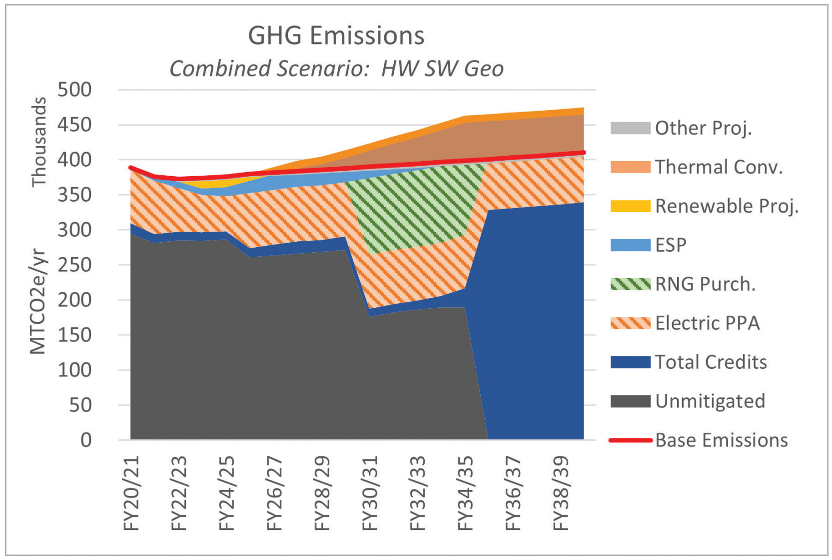



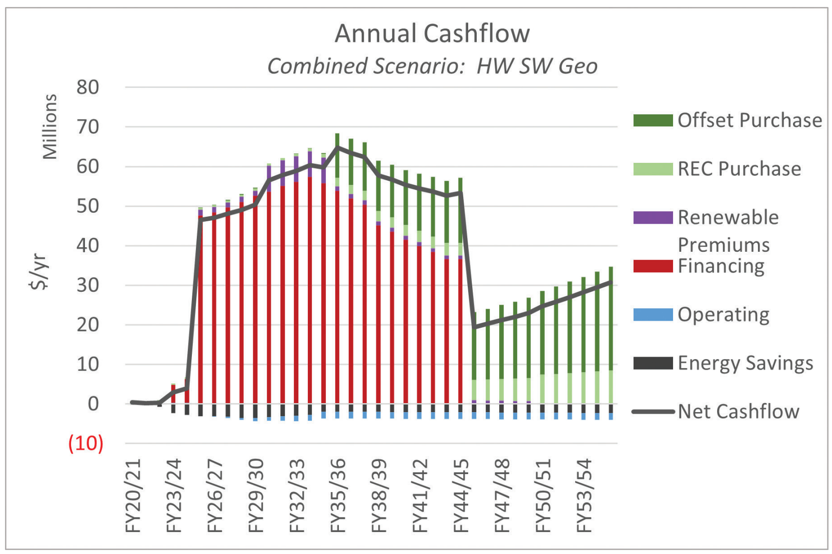
## HW SW GEO

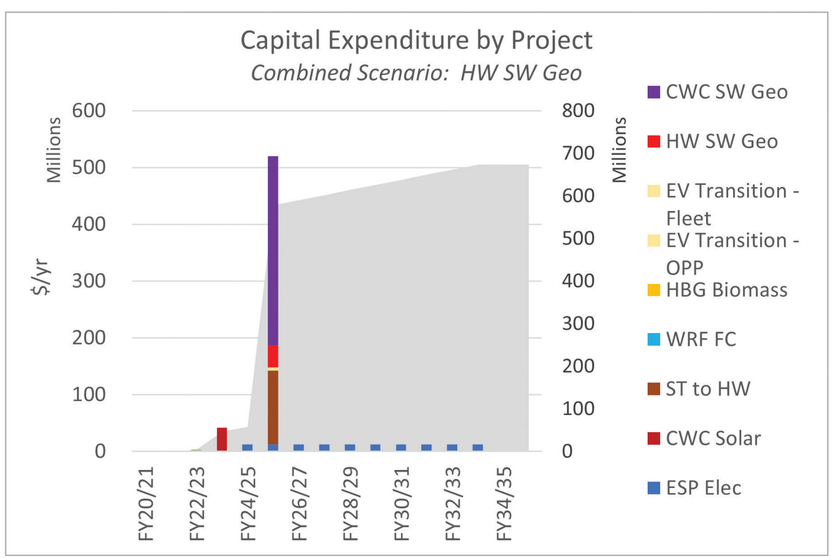
The HW SW Geo (Hot Water, Shallow Well Geothermal) scenario analyzes the impact of removing the natural gas steam boilers over time and replacing them with electric heat pumps supported by ground source thermal obtained through shallow geothermal wells.

The annual cashflow changes reflect a large increase in electricity sourced from the grid or other renewable sources delivered across the regional transmission infrastructure. A large capital cost and increase in electricity and renewable credits (likely bundled together in a PPA) are not offset by modest energy cost savings long term. This project can be expected to materially increase annual cashflow.

Because this is a low temperature solution, deploying it will require the existing steam distribution system to be converted to hot water. The capital requirements for the HW SW Geo are shown below as an upfront capital commitment, but actual capital expenditures are expected to be over a 10-year term as the UP steam distribution system is converted to hot water in phases.



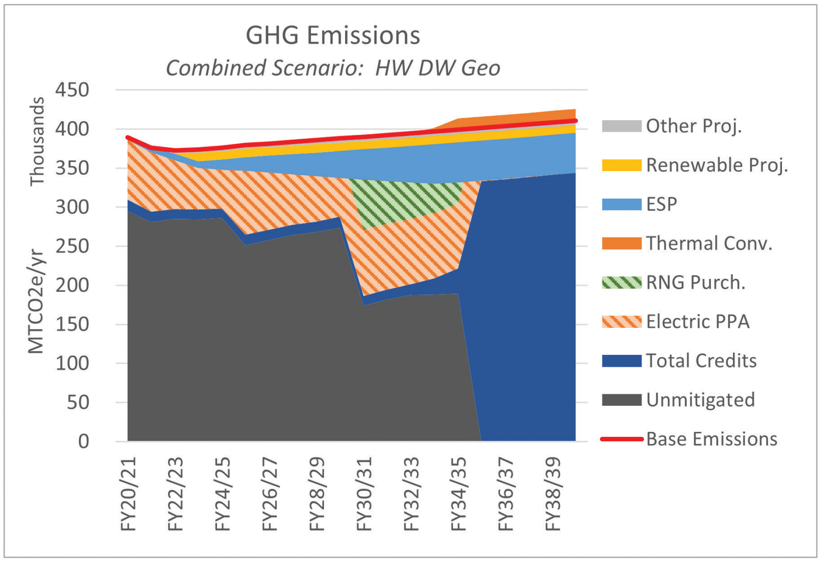



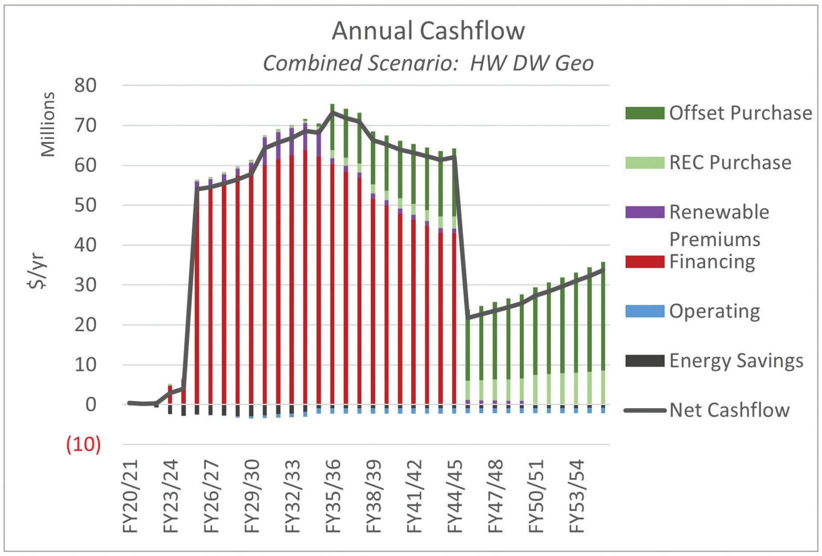
## HW DW GEO

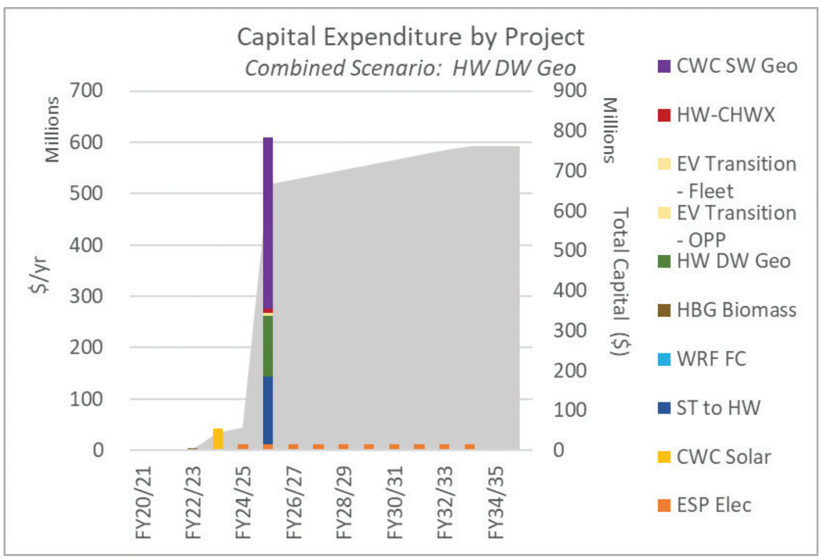
The HW DW Geo (Hot Water, Deep Well Geothermal) scenario analyzes the impact of removing the natural gas steam boilers over time and replacing them with electric heat pumps supported by ground source thermal obtained through deep earth geothermal wells. While shallow wells provide thermal in the colder months and act as a heat sink during warmer months, deep wells tap into high temperature heat deep within Earth's subsurface. As a result, its application has more impact during colder months than warmer months which limits its impact over a shallow well option. Additionally, the pumping requirements for a deep well system are higher, increasing electric purchases and requiring a larger offset strategy.

The annual cashflow changes are very similar to the shallow well option and reflect a large increase in electricity sourced from the grid or other renewable sources delivered across the regional transmission infrastructure. A large capital cost and increase in electricity and renewable credits (likely bundled together in a PPA) are not offset by modest energy cost savings long term. This project can be expected to materially increase annual cashflow.

Because this is a low temperature solution, deploying it will require the existing steam distribution system to be converted to hot water. The capital requirements for the HW DW Geo are shown below as an upfront capital commitment, but actual capital expenditures are expected to be over a 10-year term as the UP steam distribution system is converted to hot water in phases.



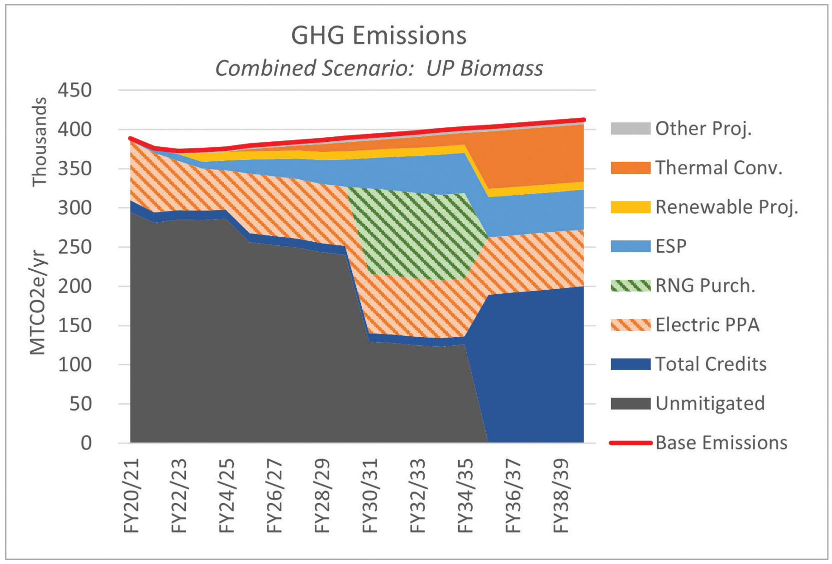



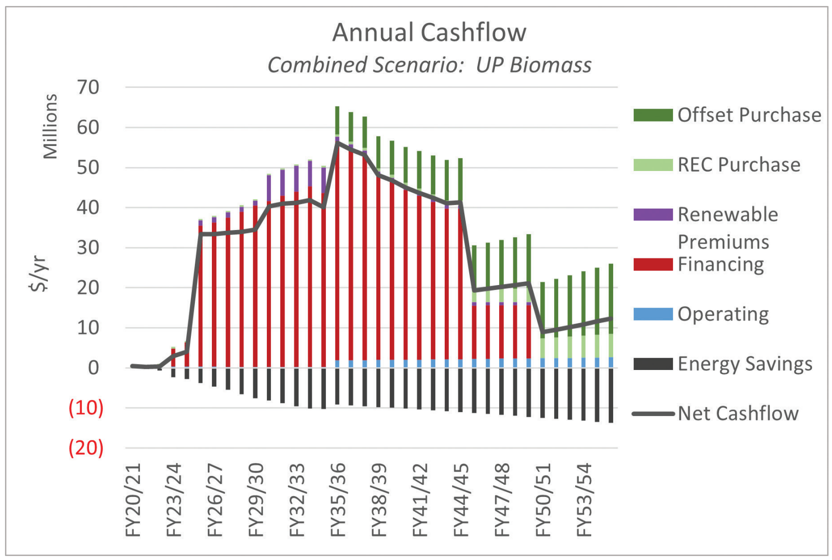
## UP BIOMASS

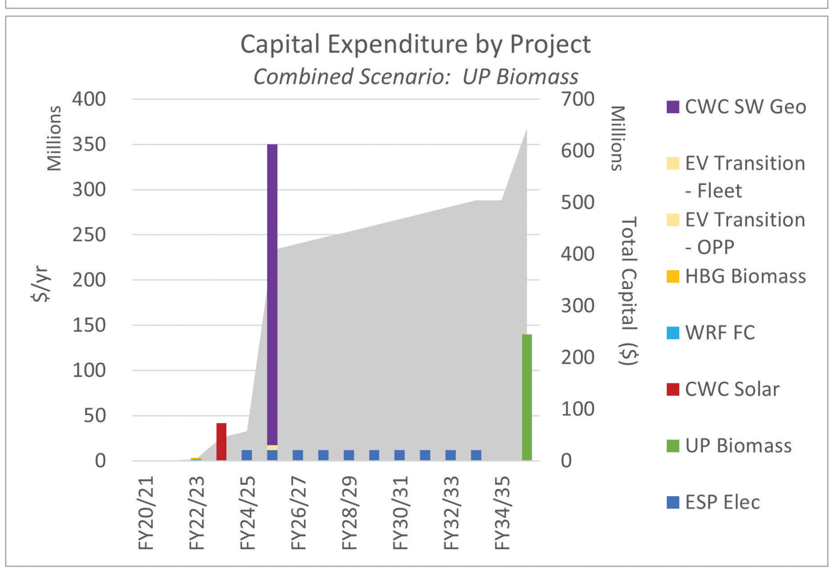
The UP Biomass scenario analyzes the impact of removing certain natural gas steam boilers and replacing them with biomass boilers. This project would reduce natural gas consumption and avoid related carbon emissions by consuming renewable fuel sources such as wood chips. Because the biomass boilers are not as responsive to peaking requirements as natural gas boilers, there would still be sizeable natural gas use requiring an offset solution.

The annual cashflow changes show a modest increase from the baseline to cover the higher cost of bio-fuel and some increase in operating expense. The biomass project is expected to increase electricity generation and the cost of bio-fuel is anticipated to be somewhat lower than the long-term cost of natural gas. However, since the remaining natural gas use will be offset with credit purchases, the energy savings are largely negated resulting in a net increase in annual cashflow requirements.

As a high temperature solution, the biomass option does not require a conversion of the steam distribution system to hot water and the capital cost is lower than the HW SW Geo and HW DW Geo solutions.



# Appendix I: Emissions Reduction Strategies – Detailed

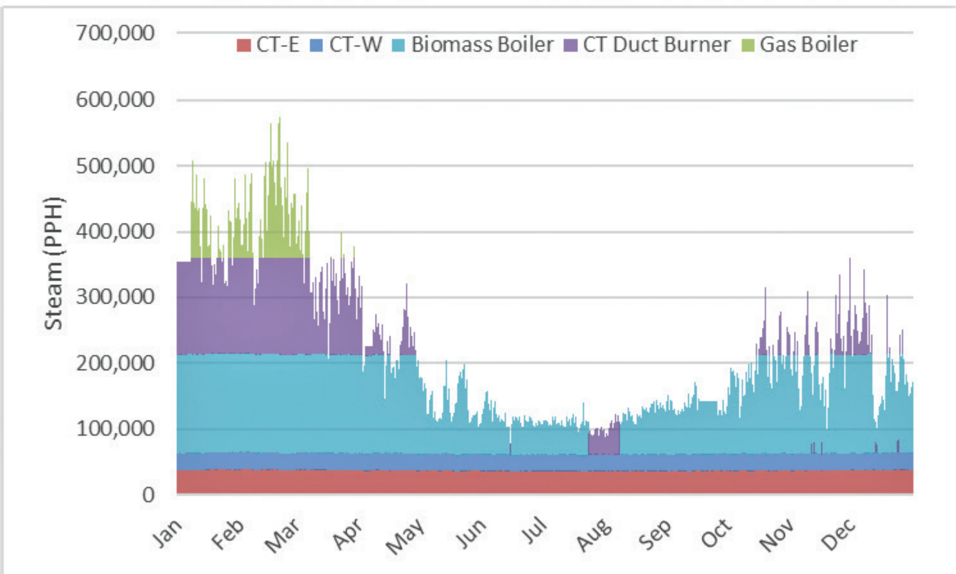
## I.1 BIOMASS BOILERS – UP

**Location:** University Park

**Description:** Installation of biomass boilers, material handling equipment and storage facilities

**Emissions Reduction Potential:** 43,000 MTCO2e/year

**Capital Cost:** $115 million plus $25 million to relocate Swine Facility; Total cost = $140 million




**Operating Cost:** Increased fuel costs over natural gas ($1.8 million/year), and increased operating costs from truck unloading dumper, chip yard building and conveying, emissions control (Baghouse), conveyors, hoppers, feeders, grates, etc., pneumatic ash handling system, and six additional staff positions ($1.6 million/year).

**Financial Considerations:** Increased operating costs due to higher fuel cost, and the new demand created when Penn State enters the market could drive fuel costs higher.

| GHG Reduction (MTCO2e/yr) | | | | Unit Cost of Carbon per MTCO2e | NPV Cost FY20/21 – 55/56 | Capital Cost |
|---|---|---|---|---|---|---|
| Scope 1 | Scope 2 | Scope 3 | Total | | | |
| -64,050 | 3,489 | -3,148 | -63,709 | $82.12 | $172M | $140M |

**Maturity:** Mature technology and commercially available.

**Scalability:** Various size boilers available.

**Advantages:**

- Does not require modifications to campus building.
- On-site fuel source.

**Disadvantages:**

- High capital and operating costs as previously described; requires Swine Facility relocation to create space.
- Consumes 33% of the available biomass within a 75-mile radius, requiring 30 trucks per day in winter season, or about 100,000 tons per year.
- Solid fuel handling with conveyors and ash collection.
- Public outreach needed for acceptance on the use of this selectively harvested sustainable resource.

**Adaptability to the Future:** Abundant source of biomass in Pennsylvania, use of low-use wood species and residues from logging and from forest thinning operations supports more sustainable forest management.

**Social Justice Concerns:** Logging activities may be viewed critically. Since this is still combustion which leads to localized air pollution concerns if combustion output is not cleaned before being released into the atmosphere, and trucking of the fuel could lead to localized heavy traffic in sensitive areas.

**Risks & Uncertainties:** For this to be a carbon neutral solution, procurement contracts must specify and verify that the amount of carbon released by creating and combusting the biomass is completely offset by the plants used for fuel.

**Behavior Change(s) Required:** Philosophically conflicts with forest expansion and sequestration efforts. While there are potential synergies with forest carbon storage (see co-benefits section) these are not guaranteed.

**Other Caveats:** Assurance through our procurement contracts that the biomass we purchase is a near net zero technology and providing transparent documentation.

**Educational Opportunities:** There are at least 3 classes on campus whose syllabi include biomass combustion process design and/or engineering. Penn State and Cooperative Extension also co-sponsor the statewide "Fuels for Schools" biomass heating program. A local facility would be of value for field trips and demonstrations with both audiences.

**Research Opportunities:** Development, processing and storage of crops for fuel. There are already active research programs on biomass torrefaction as a way to increase biomass energy density, reduce storage losses, and increase combustion efficiency.

**Co-Benefits:** Biomass generated from forest management activities designed to increase carbon sequestration could be a win-win.

**Authors:** Rob Cooper, Ron Pristash, Tom Richard, Consultant Burns & McDonnell

**Resources:**

- Dartmouth College (USA) positions itself as a green technology frontrunner – DBDH
- www.unionleader.com/news/environment/advisory-groups-formed-to-investigate-dartmouth-biomass-alternative/article _ d2750a8f-9117-5b81-98a2-2a233bb41673.html
- www.vnews.com/Column-Feeling-good-about-Dartmouth-s-proposed-biomass-project-29935596
- https://futureforestsandjobs.com/without-a-doubt-biomass-is-carbon-neutral-ohio-state-university-professor-supports-wood-bioenergy-in-new-study/

## I.2 BIOMASS BOILER – HARRISBURG

**Location:** Penn State Harrisburg

**Description:** Penn State Harrisburg (PSH) uses natural gas as the fuel source in its Heating Plant to distribute hot water to most of the buildings on its central campus. In 2020, a study was completed to address the obsolescence of much of the Heating Plant equipment. It was noted that if PSH continued to grow, the Heating Plant would approach its Firm Capacity limit. The study pointed out that the Heating Plant did not have a backup fuel system, emphasizing concern should something affect the incoming natural gas line. The study proposed installing a Biomass Boiler to replace two existing steam boilers that were at end of life.

**Emissions Reduction Potential:** 1,557 MTCO2e/year (1,250 MCF natural gas equivalent)

**Capital Cost:** $3.9 million

**Operating Cost Increase:** $33,061

**Financial Considerations:** The cost to replace the existing natural gas steam boilers with natural gas fired hot water boilers was $1.8 million. Savings from biomass fuel over natural gas are estimated to be in a range of $75,000-$80,000 annually. Maintenance contract costs increase by $36,000 over hot water boilers resulting in a net operating cost increase of $33,061.

ESP funding is based on a 10-year payback at 4.0% and would contribute about 25% of project costs. Including cost of carbon offsets could increase funding to about 1/3 of the project cost.

**Maturity:** Biomass boiler systems have been gaining popularity in the last 10 – 15 years and are becoming an option over other solid fuels.

**Scalability:** Yes, the technology is scalable to a level that could support the UP Campus.

**Advantages:**

- Aligns with University sustainability goals.
- Replaces obsolete systems with newer technology.
- Simplifies operations and maintenance.
- Increased reliability (provides back up source and increased firm capacity).
- Supports The Central Pennsylvania Research and Teaching Laboratory for Biofuels located at PSH.

**Disadvantages:**

- The Biomass Boiler cost was more than twice the cost of a natural gas option at $2.1 million.
- Even under the most ideal circumstances, these projects can still be cost prohibitive depending on funding resources and have the need for an alternate funding source for execution.
- Competition is increasing for localized biomass fuels.
- Increased infrastructure for truck unloading dumper, chip yard building and conveying, emissions control (Baghouse), conveyors, hoppers, feeders, grates, etc., pneumatic ash handling system.
- Biomass boilers are less efficient than natural gas fired boilers.

**Adaptability to the Future.** Yes, if fuel source is available.

**Social Justice Concerns:** Logging activities may be viewed critically. Since this is still combustion it leads to localized air pollution concerns if combustion output is not cleaned before being released into the atmosphere, and trucking of the fuel could lead to localized heavy traffic in sensitive areas.

**Risks and Uncertainties:**

- Risks of deploying new technologies could slow down project schedule or impede progress or performance.
- Inconsistent funding sources to support projects that support sustainability.

**Behavior Change(s) Required:** Maintenance and operations is very simple and could free up (or eliminate) positions at the heating plant.

**Other Caveats:** New and emerging technologies often come at a higher cost. All of the benefits should be weigh and a life cycle cost analysis be performed; OPP should investigate collaborating and seeking special grants and funding through various agencies. Energy engineers can help overcome resistance of engineers and architects to incorporate newer energy savings technologies.

**Educational and Research Opportunities:** Outreach opportunities in research and education would be through Penn State and the Central Pennsylvania Research and Teaching Laboratory for Biofuels located at PSH. Several biofuels could be tested, many students at PSH and across the Commonwealth would experience the living lab opportunities.

**Co-Benefits:** Carbon reduction, avoided energy, and maintenance savings.

**Information Sources:**

1. New Boiler Study, Burns & McDonnell 05/22/2020
2. AFS Proposal 02/13/2020

## I.3: CARBON CAPTURE AND SEQUESTRATION

**Location:** East Campus Steam Plant, University Park

**Description:** The carbon capture and sequestration (CCS) study for the ECSP includes consideration of two separate processes. The first process looks at the use of a chemical absorption system with an amine-based sorbent that would capture between 75% - 95% of the $CO_2$ from the ECSP flue gas stream which then would be concentrated to a pure (>99%) $CO_2$ product stream. The second process involves geological carbon sequestration in which the concentrated $CO_2$ stream is injected underground in geological rock formations for long term storage.

**Process:** The $CO_2$ capture portion of this study is based on chemical absorption using a monoethanolamine (MEA) based sorbent. Today there are two main MEA-based processes available for commercial $CO_2$ recovery plants: (1) the Fluor Daniel Econamine FG process and (2) the ABB Lummus Crest MEA process. This study considered the Fluor Daniel process.

### Fluor Daniel Econamine FG process

A continuous scrubbing system is used to separate $CO_2$ from a gaseous stream. The system consists of two main elements, an absorber, where $CO_2$ is absorbed into a sorbent and a regenerator (or stripper), where $CO_2$ is released (in concentrated form) and the original sorbent is recovered. The cooled flue gases flow vertically upwards through the absorber counter-current to the MEA absorbent. The MEA reacts chemically with the $CO_2$ in the flue gases to form a weakly bonded compound (carbamate). The scrubbed gases are then washed and vented to the atmosphere. The $CO_2$-rich solution leaves the absorber and passes through a heat exchanger, then is further heated in a reboiler using low-pressure steam. The weakly bonded compound formed during absorption is broken down by the application of heat, regenerating the sorbent, and producing a concentrated $CO_2$ stream. The hot $CO_2$-lean sorbent is then returned to the heat exchanger, where it is cooled, then sent back to the absorber. Some fresh MEA is added to make up for losses incurred in the process. The $CO_2$ product is separated from the sorbent in a flash separator, and then taken to the drying and compression unit. It is compressed to very high pressures so it can more easily be transported long distances to a designated sequestration site.

The carbon capture plant (CCP) would require approximately an additional 1-acre site at the East Campus location. The large footprint eliminates this technology for being implemented at the West Campus Steam Plant. The CCP also has a large vertical signature of 100-200 ft which may present issues on campus. The current estimated construction cost for the plant is in the $75 - $100 million range. The process is also energy intensive and would add significant annual operating costs: $300,000 in additional electric purchases at 500 KW (2,000 MTCO2e penalty) for plant auxiliaries; steam is utilized in the carbon capture process at 15-30 KPPH, and $1.5-2 million in added annual steam cost; six to eight additional plant staff to operate the plant day and night would add $600,000 -$800,000 in employee cost; and 30,000 KPPH steam consumption would cause the University to add boiler capacity sooner (7 years earlier based on 1% growth projection). The University would estimate a one-time $12-$15 million capacity reduction penalty (30 Years)

Once the carbon is concentrated at the East Campus plant it would then need to be piped to a suitable inject site for sequestration. The Pennsylvania Department of Conservation and Natural Resources completed a study of geologic carbon sequestration opportunities in the state. Thus, we know that appropriate sedimentary strata exist in northern Centre County as well as in nearby portions of adjacent counties, e.g., Clinton and Clearfield. Site specific studies still need to be accomplished, and the possibility of sequestration deep in the subsurface beneath the Nittany Valley should also be considered. Assuming that the Nittany Valley subsurface cannot be developed then consideration must be made for either 1) drilling an injection well, or 2) converting an existing production well. A newly drilled well into the Marcellus Formation on the plateau will cost on the order of $5-10 million. Dependent on where a suitable site is found the pipeline cost could be very large and take significant time to permit, construct, and maintain. The pipeline construction is estimated to cost $2-3 million per mile. A 2.5 MW compressor would add about $1.25-1.5 million in additional annual purchased electricity cost and if supplied by current grid power and not from renewables it would add 10,000 - 11,000 MTCO2e.

ECSP currently produces about 45,000 metric tons of $CO_2$ annually. If the ECSP plant were to implement this technology capturing 75% - 95% of the flue gas stream, 33,750 - 42,750 metric tons of $CO_2$ annually could be captured. The East and West Campus steam plants combined emitted roughly 110,000 metric tons of $CO_2$ in 2019. This process would reduce the total steam plants combined carbon footprint by 30-40%.

**Emissions Reduction Potential:** 33,750-42,750 MTCO2e/year gross reduction, consideration for energy input

**Capital Cost:**

- First Cost CCS Plant: $100 million
- First Cost transport Piping, injection well: $110 million

**Operating Cost:**

- Annual Labor increase: $600,000
- Annual Electric usage increase: 3.5 MW/year
- Annual plant Water increase: $50-75K/year
- Annual Steam Usage increase: 30 KKPH or 262.8 million pounds of steam per year, or $5.2 million

**Financial Considerations:** An economic profile for this will depend on funding sources, expectations on economic returns, and the ability for the University to monetize $CO_2$ sequestration tax credits (45Q). Our first step is to secure funding to conduct a Front-End Engineering Design Study (FEED) study. There may be sources of funding from DOE or other programs that can help fund FEED studies, but we would have to commit the time and expertise to secure them.

**Maturity:** Amine-based $CO_2$ capture systems are a proven technology that are commercially available today.

**Scalability:** 50% footprint of amine plant is too large for WCSP.

**Advantages:**

- Ability to use existing ECSP CT/HRSG & Boilers fired on low-cost natural gas.
- Avoids modifications to all buildings that are served by steam system.

**Disadvantages:**

- Large site footprint, capital and energy intensive, operation of a chemical process plant which adds complexity and operating cost. Visual impacts due to a height of 100-200 ft.
- Large footprint (1 acre) prevents this technology from being used at the West Campus Steam Plant which allows for only 50% carbon capture of system.
- Potential for protest / high risk associated with the operation of a chemical plant in the headwaters of a high-quality cold-water fishery stream (Spring Creek).
- Difficulty of permitting, ROW acquisition, and construction of a pipeline and drilling a well.

**Adaptability to the Future.**

**Social Justice Concerns:** Captured carbon needs to be stored somewhere – possible locations may be in already disadvantaged areas. Community engagement in any locations where a pipeline would go through or a well would be used/drilled would be necessary to ensure community concerns can be addressed. Cultural and natural resources need to be considered when considering this solution.

**Risks and Uncertainties:** Suitable sequestration sites near UP Campus; possible health and environmental impact of amine degradation products being released in the atmosphere; potential occupational risk of amines in carbon capture for power generation – PubMed (nih.gov).

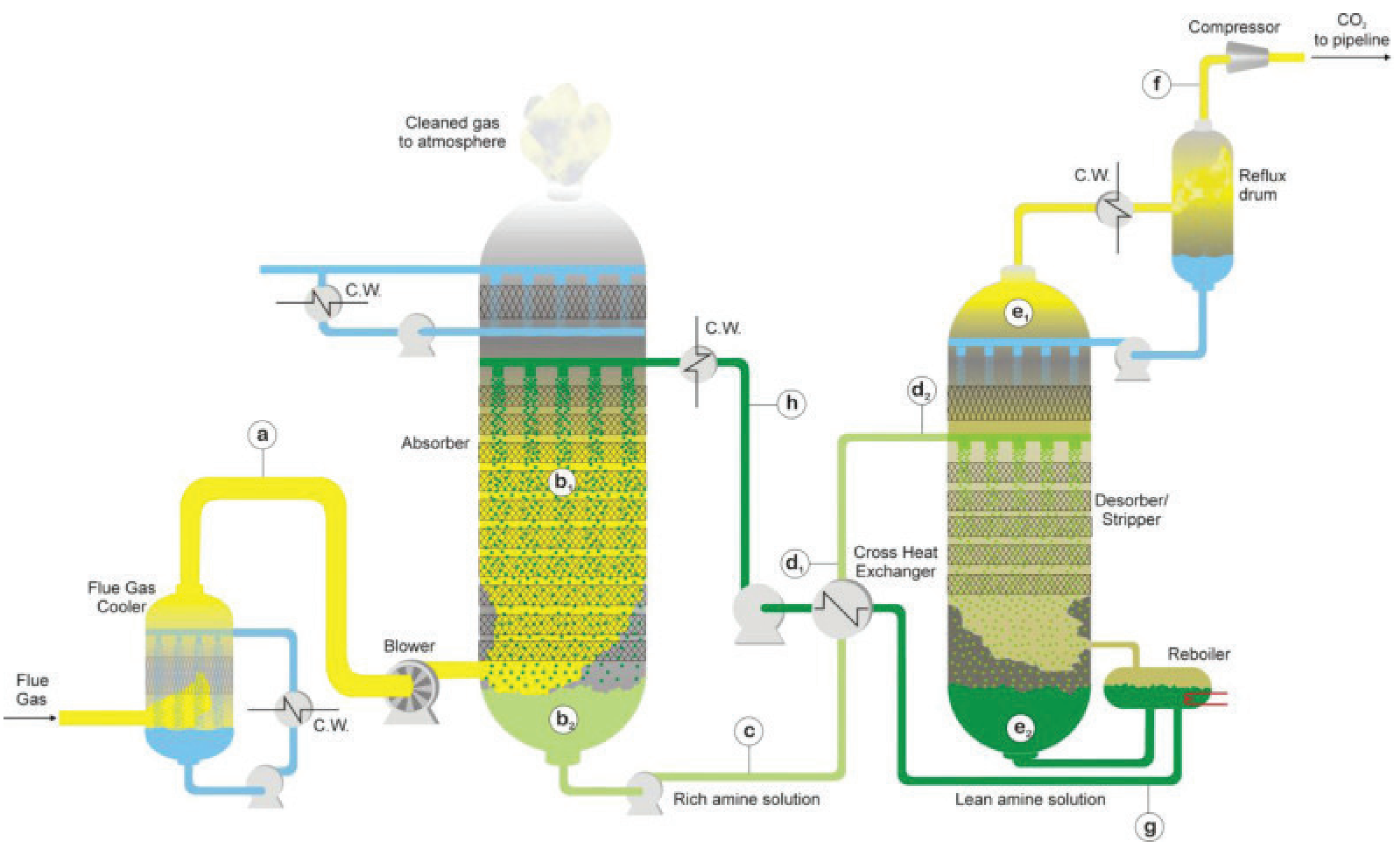



*Figure 28: Amine CCS Process Flow Diagram*

**Behavior Change(s) Required:** Carbon capture and storage has generally been seen to extend the life of fossil fuel facilities, which many environmental groups oppose due to other impacts of these facilities.

**Other Caveats:** Novel and efficient techniques for capturing carbon from industrial waste streams such as regenerative molecular baskets that can selectively absorb $CO_2$ from industrial exhausts, algal ponds and other biomass that selectively eliminate carbon from effluent streams show much promise. Utilization of the captured carbon to produce high-value products such as carbon electrodes for batteries or for efficient recovery of hydrocarbons through well-designed recovery processes that simultaneously sequester the $CO_2$ in subsurface rock formations could provide significant environmental and economic incentives. To realize geologic sequestration of carbon at industrial scale, there is an urgent need to identify mechanisms and create processes and materials that enable robust storage schemes for $CO_2$ and other fuel cycle materials. The storage schemes must perform reliably even when there is great uncertainty about properties of the subsurface formations. There is also a need to design energy-efficient carbon sequestration and energy harvesting techniques using biomass that works at the scale required for global greenhouse gas mitigation. Penn State has considerable expertise in all aspects of this complex challenge whether it be in the design of C capture systems, investigating novel techniques for injecting and monitoring $CO_2$ plumes in the subsurface, studying methods for commercial production of C materials or the design of biomass systems for capture, sequestration and energy production. The expertise extends to systems level analysis and optimization of CCS systems and understanding the risk and economics of those systems.

**Educational Opportunities:** The Fluor Daniel Econamine FG process on-site would provide students and faculty with living lab carbon capture & sequestration learning opportunities.

**Research Opportunities:** The Fluor Daniel Econamine FG process on-site would provide researchers with carbon capture research opportunities as the system could be constructed to test other carbon capture technologies.

**Co-Benefits:** If the carbon capture facility were attached to a biomass or RNG thermal plant instead of a fossil natural gas plant the sequestered carbon would be net-negative instead of net-zero. This could potentially offset a considerable amount of our Scope 3 emissions.

**Information Sources**

- https://www.sciencedirect.com/science/article/pii/S2300396015300653

## I.4: DEEP EARTH SOURCE GEOTHERMAL HEATING

**Location:** University Park

**Description:** The U.S. DOE estimates that deep source geothermal could potentially provide the United States with 15 million terawatt-hours-thermal (TWhth. The current U.S. annual energy consumption is 1,754 TWhth for residential and commercial space heating. The DOE further states that "this Enhanced Geothermal System (EGS resource is theoretically sufficient to heat every U.S. home and commercial building for at least 8,500 years." This study investigates deep Earth source geothermal heating at UP Campus location. Most of the information is this brief overview was gathered from a Cornell University Phase 1 study. Cornell has been developing this strategy for several years and it is one of the leading components to achieve their 2035 Carbon Neutrality target. In 2020, Cornell secured a $7.2 million DOE grant to cover some of the initial costs of drilling the 2-mile-deep exploratory borehole and create what Cornell calls "a state-of-the-art observatory" that will allow scientists at Cornell and other institutions to study the physical, geological and seismic characteristics of the rock far beneath the campus. The borehole, which will be drilled on Cornell property, will be used to assess the Earth Source Heat project's feasibility, and if it looks good financially and structurally, they can continue designing the geothermal circulation system. At a minimum, the ground temperature at depth will need to exceed 70°C (160°F)).

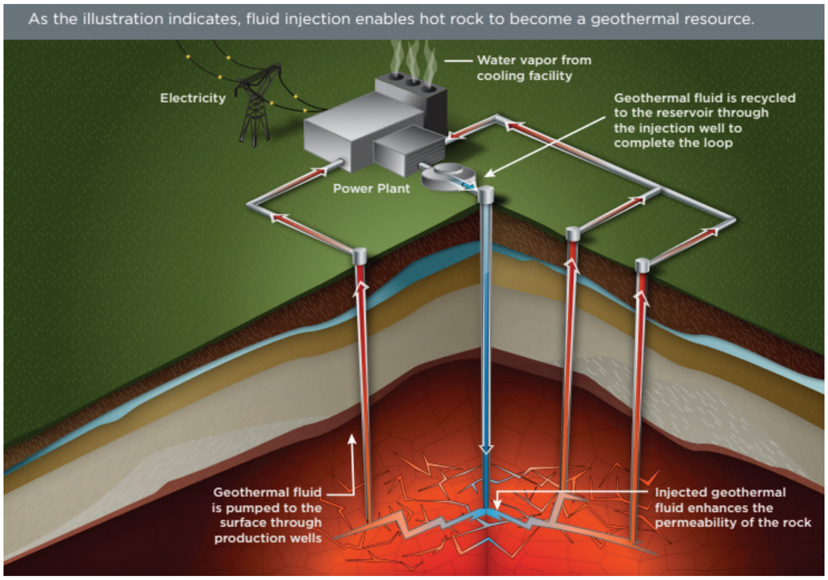
**Process:** Geothermal energy technology is comprised of four broad categories: Conventional Hydrothermal Resources, Enhanced Geothermal Systems, Super-Hot-Rock Geothermal and Advanced Geothermal Systems (AGS.

The UP study will examine the Enhanced & Advanced Geothermal Systems. The financial model will be run only for the AGS system since the economics are significantly more favorable.

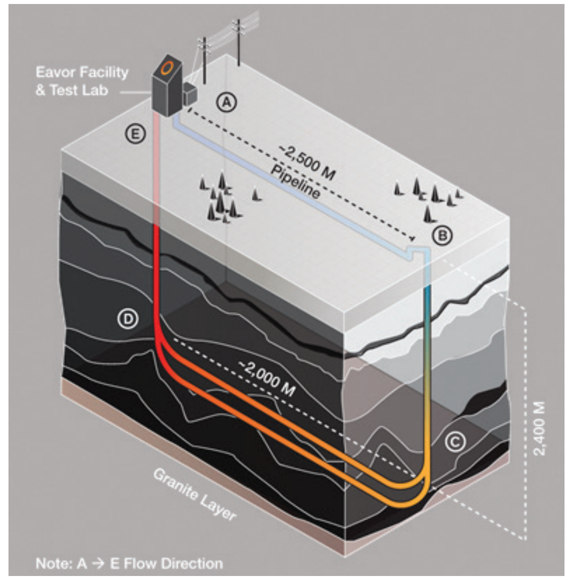
*Conventional Hydrothermal* – resources would be Iceland, California, Nevada, Alaska, etc.., locations that typically have pressurized hot water heated by the Earth's core that rises to become trapped under an impermeable caprock. These locations often reveal themselves on the surface through fumaroles or hot springs. Almost all the industrial scale geothermal currently running in the world falls under this category and utilizes this easily accessible high quality thermal energy. Conventional geothermal systems are limited to specialized areas where heat, water, and porosity come together just so.

*Super-Hot-Rock Geothermal* – Drilling deep into super-hot rock. The main goal of this process is electrical power generation. This process can achieve Supercritical temperatures for water and contain significantly more energy per unit mass.

*Enhanced Geothermal System (EGS)* – Consist of a deep depth man-made reservoir, created where there is hot rock but insufficient or little natural permeability or fluid saturation. In an EGS, fluid is injected into the subsurface under carefully controlled conditions, which cause pre-existing fractures to re-open, creating permeability. The increased permeability allows fluid to circulate throughout the now-fractured rock and to transport heat to the surface.

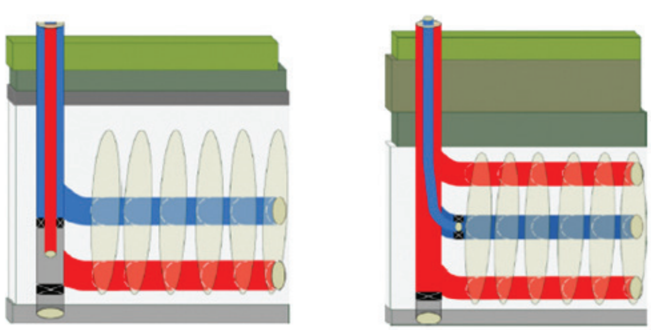



*Deep Earth Geothermal Illustration*

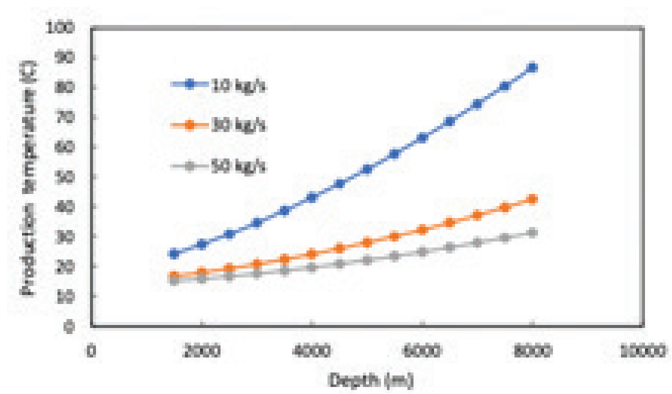



*AGS Illustration*

*Advanced Deep Geothermal System (AGS)* – Closed-loop geothermal systems have been around for decades, but a few startups have recently amped them up with technologies from the oil and gas industry. One such company, started by investors with experience in oil and gas, is the Alberta-based **Eavor**. In Eavor's planned system, called an "Eavor-Loop," two vertical wells around 1.5 miles apart will be connected by a horizontally arrayed series of lateral wells, in a kind of radiator design, to maximize surface area and soak up as much heat as possible. (Precise lateral drilling is borrowed from the shale revolution, and from the oil sands.) Because the loop is closed, cool water on one side sinks while hot water on the other side rises, creating a "**thermosiphon**" effect that circulates the water naturally, with no need for a pump. Without the parasitic load of a pump, Eavor can make profitable use of relatively low heat, around 150°C.



*AGS Enhanced Closed Loop Well with Multiple Laterals*



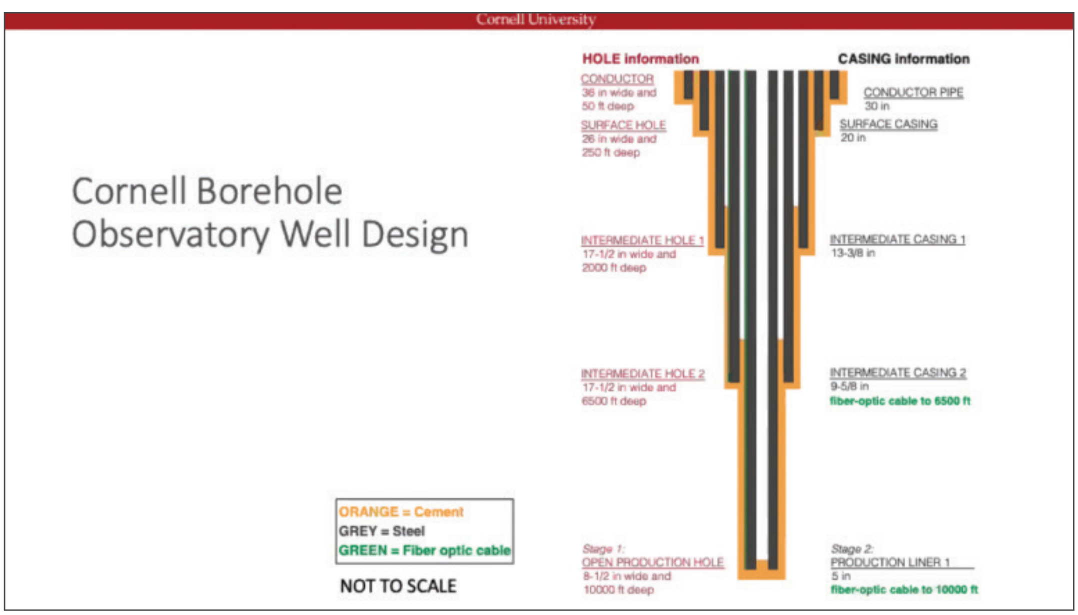

*AGS Well with 1000M Lateral Branch*

*Table 24: Predicted Well Production Mwh (Annual)*

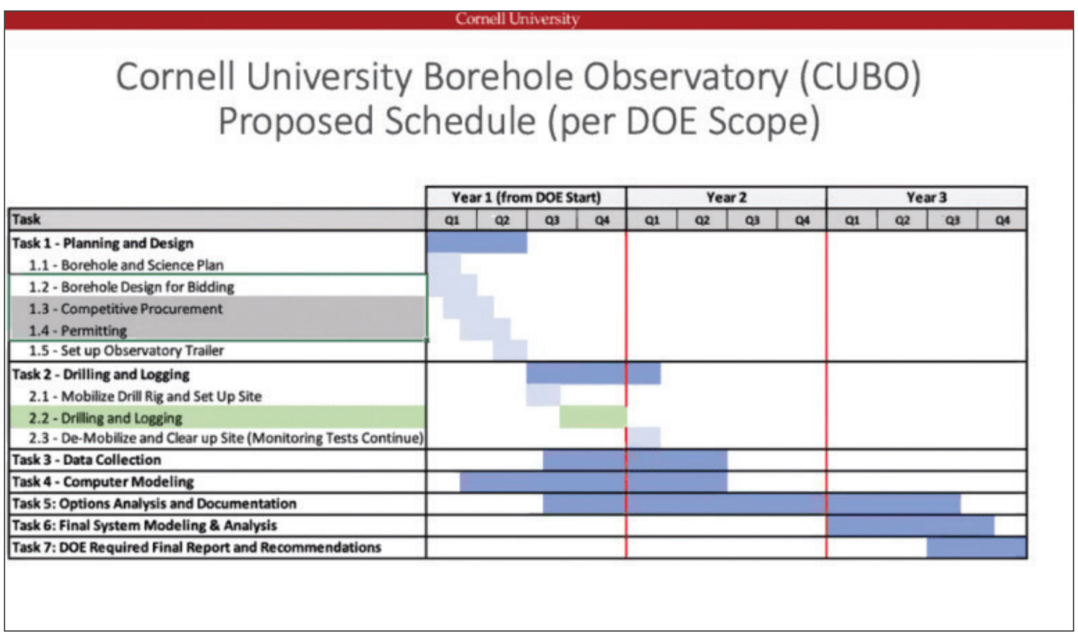
| Depth | Mass flow rate (kg/s) | Open Loop | Closed Loop | Lateral Branch | Enhanced Closed Loop | Pump Energy Use (REDA ESP ) |
|---|---|---|---|---|---|---|
| 4000 | 10 | 34,850.53 | 6,993.04 | 13,089.62 | 24,303.56 | 50.63 |
| | 30 | 92,183.22 | 7,625.60 | 14,758.01 | 34,447.08 | 152.27 |
| | 50 | 133,024.72 | 7,762.47 | 15,130.49 | 37,288.38 | 253.91 |
| | | | | | | |
| 6000 | 10 | 51,565.37 | 13,993.30 | 21,710.17 | 36,135.93 | 75.97 |
| | 30 | 142,327.73 | 15,843.73 | 25,374.90 | 55,452.48 | 228.44 |
| | 50 | 216,598.91 | 16,258.51 | 26,221.59 | 61,356.71 | 380.90 |
| | | | | | | |
| 8000 | 10 | 68,280.21 | 22,805.34 | 31,865.41 | 52,817.83 | 101.32 |
| | 30 | 192,472.24 | 26,762.69 | 38,547.23 | 88,595.40 | 304.54 |
| | 50 | 300,173.09 | 27,680.54 | 40,143.15 | 100,732.92 | 507.82 |

## *Cornell University Borehole Observatory (CUBO)*

The Cornell University Borehole Observatory (CUBO) will be about three feet wide at the surface, but progressively narrower as it presses deeper into the Earth. As designed, the CUBO well will have five layers of steel casing, with hefty amounts of concrete around the casings to ensure borehole integrity and to prevent impacts to surrounding groundwater.



The borehole would contain a fiber optic cable as part of the monitoring of the structural stability of the hole, as well as a very sensitive seismometer and a thermometer to check temperature as the borehole advances – to be successful, the ground would need to exceed at least 70°C (160°F). However, it's not just temperature that's important, but sustainability of the heat deep in the ground. While those involved in the project have a rough idea of what they expect, drilling through three generalized sedimentary rock layers before reaching a basement rock like that found in the Adirondacks, the truth is they aren't 100% sure how it's structured. They don't know how hot or fractured the rock is two miles down. They don't know how the existing subsurface fluids flow, what is potentially mixed in those fluids, or how introduced water would flow through the rock. They don't have a strong grasp of what the overall temperature gradient with depth looks like. These are features that are key in designing the Earth Source Heat system, and they're detailing that Cornell hopes to have a much better understanding of with the CUBO well. According to Steve Beyers, the Lead Facilities and Campus Services Earth Source Heat Engineer, "The CUBO well exploratory phase would be about three years. Implementation of the full-scale Earth Source Heat system could take another five years if the project proves to be feasible and remains viable, at which point we're around 2030." When Beyers was questioned on infrastructure cost his response was, "It will be a pretty penny, the focus is more on the CUBO facility for the next couple years, to make sure the system will even work before they start pricing out all the infrastructure."



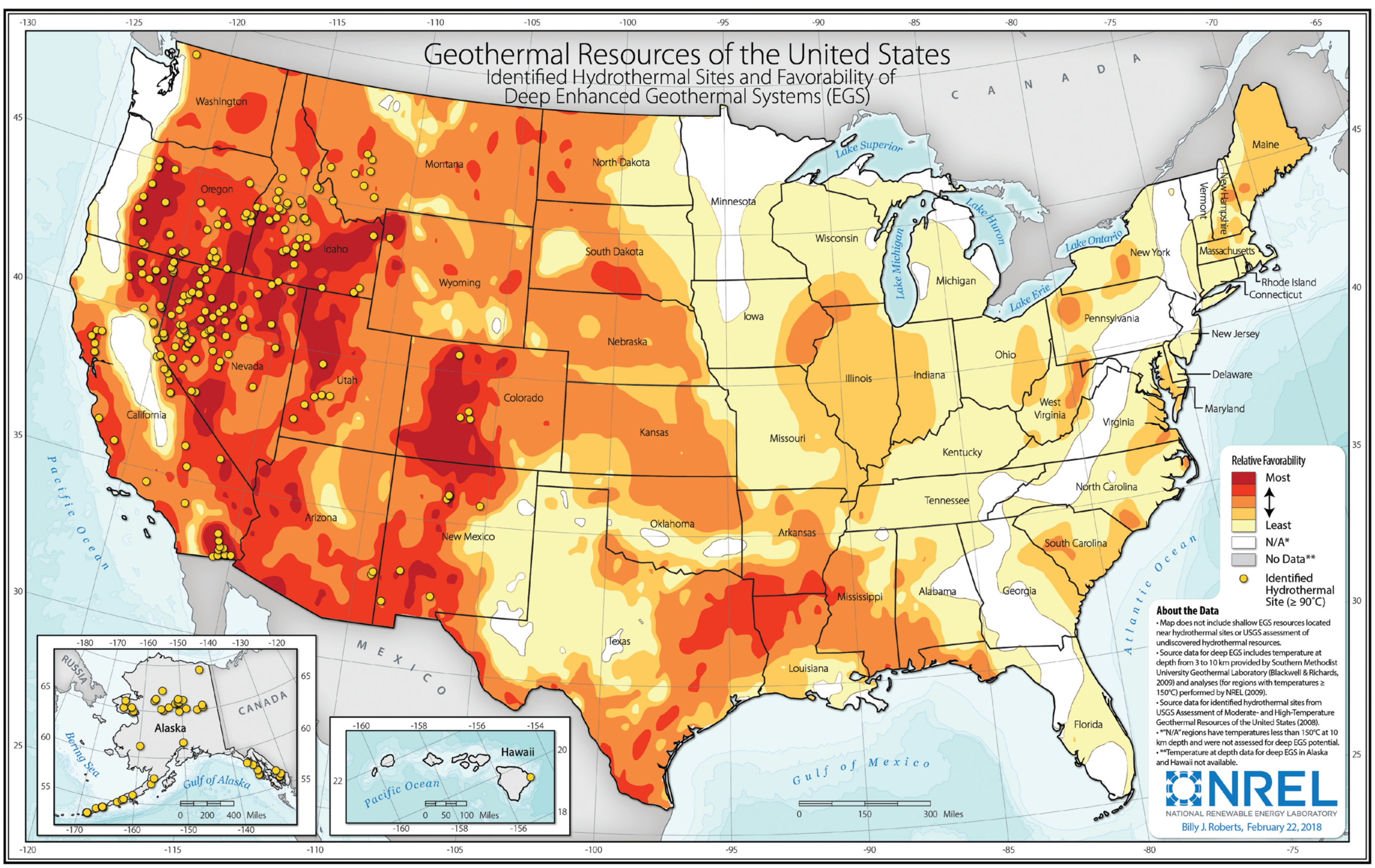
***PSU University Park Campus***

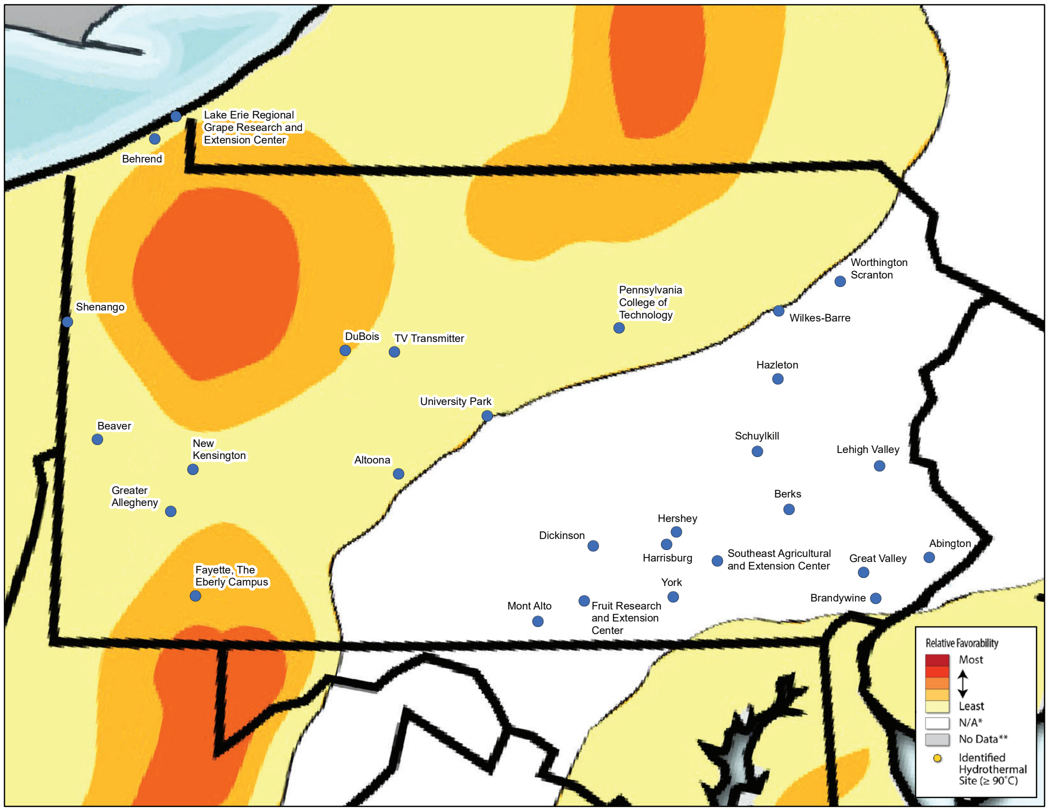
The National Resource Energy Lab (NREL in 2018 published a U.S. map identifying hydrothermal sites and favorability of deep enhanced geothermal systems. Cornell University in Ithaca, NY, is in a small area of the NREL map that shows a very favorable EGS potential. UP is located on the edge of Least Favorable (yellow) to N/A (white). N/A shown as white in the legend states "regions having temperatures less than 150°C at 10 km (6.25 miles) and were not assessed for deep EGS potential." Recent well costs are estimated at $5 million for a 2-mile depth and $20 mission per 6 mile depth.

In 2005, PSU had an engineering consultant evaluate two different applications at the University Park campus for deep source geothermal. The two applications were space heating and DHW use in East Halls and boiler feedwater heating at the WCSP. They evaluated drilling a 2-mile-deep Production well, producing 220°F saline and a 2-mile-deep injection well, 13,800 ft deep, returning 180°F saline. The consultant concluded at that time that deep source geothermal not be recommended for further consideration.

Disadvantages listed by the consultant:

- High initial cost of $11 - $13 million.
- Risk of contamination to wellfields.
- High maintenance.
- Risk of project failure resulting from potentially unfavorable geologic conditions (Not proven in eastern U.S.).






**Costs:** The Cornell phase 1 study goal is to meet, at a minimum, approximately 20% of their annual campus heat load (49,000 Mw per year heat output). This would be about 14% of the current annual heat load at UP. University Park Campus cost estimates are shown in **blue** under the Cornell cost estimate. This EGS system can then be scaled up to get a cost estimate for supplying 80%+ of UP needs. The study also evaluated an AGS Enhanced Closed Loop Well System. This system offers several advantages over the open well system. This system requires no make-up water or well stimulation, the closed loop significantly reduces contamination risk, and the system requires significantly less pump energy. The single well houses both the supply & return.

**Capital Cost (Open Well EGS):**

Well drilling & completion cost: $16 million

**Well drilling & completion cost: $35 million**

Well Stimulation: $1.25 million

**Well Stimulation: $2.5 million**

Submersible pipe and discharge line (well pumping infrastructure) & surface facility for pump power and control, heat exchangers, and chemical injection: $2.6 million

**Submersible pipe and discharge line (well pumping infrastructure) & surface facility for pump power and control, heat exchangers, and chemical injection: $8.0 million**

Pipeline connection to our existing district loop: $1.0 million

**Pipeline connection to our existing district loop: $2.5 million**

*Exploration Cost* – Cornell did not include separate Exploration Costs. The project's intent was to demonstrate the apples-to-apples cost comparison with other energy systems, and as such did not include exploration costs primarily related to research and development and not broad implementation. In our specific case, **we plan to use our "exploration" well ("Test Well") as our future supply or reinjection well**; other scientific work will be funded by appropriate research and donor funds, and are not considered part of "development" costs. ($10 million test bore

*Central Heat Pumps* – The total installed cost for these systems is calculated based on a unit price of $300,000 per MW unit capacity. **$6 million (PSU)**

*Engineering design costs* – **$9.0 million (PSU)**

**Total $54 million per module UP system scaled to 100%; $164 million + Exploratory Project Bore Hole $10 million = $174 million**

**O&M Cost (Annual)**
Maintenance: $265,000

Electrical Cost: 50,000 Mwh *** The electrical cost for circulating flow within the campus hot water distribution loop is not included, Cornell currently produces all campus power using a combination of gas turbine generators, steam turbines, hydropower turbines, and on-campus renewables***

Additional Purchased electricity (not generated on-site: 135,000 Mwh per year (CT's idle

Annual makeup water usage- and cost: Cornell did not include because they felt it was minimal.

**Emissions Reduction Potential:** 58,000 MTCO2e/year with PSU CT's in operation.

100,000 MTCO2e/year with the University gas boilers/ CT's as peaking & emergency backup.

**Capital Cost (AGS Enhanced Closed Well):**
Well drilling & completion cost: (10) 8000 m wells; with 1000 m horizontal laterals: $70 million total cost

Submersible pipe and discharge line connection to distribution system (well pumping infrastructure) & surface facility for pump power and control, heat exchangers, and chemical injection: $24 million

Exploration Cost: $10 million closed loop test bore

Central Heat Pumps: Our final LCOH estimates are all based on the use of "central" high-temperature heat pumps. The total installed cost for these systems is calculated based on a unit price of $300,000 per MW unit capacity. $10 million (PSU)

Engineering design costs: $5 million (PSU)

**UP System scaled to 80% + $119 million + Exploratory Project Bore Hole $10 million = $129 million**

Campus hot water system: $130.76 million

**O&M Cost (Annual)**
Maintenance: $400,000

Purchased electricity from idle CT's & STGs (not generated on-site): 135,000 Mwh per year

Additional Heat Pump Electrical Cost: 50,000 Mwh per year

Annual makeup water usage and cost: $0

Avoided Natural gas: 1,650,000 Dth

Hot water system has an O&M saving: $1.95 million

**Financial Considerations:**

U.S. DOE is looking to fund novel technologies for geothermal production. A single well concept is novel, and chances are high that it will attract federal funding. That funding could offset the cost for the exploratory borehole.

Other enterprises such as Google may also fund such projects that have initial investment of around $20 million dollars from other sources.

**Maturity:**

Deep geothermal heat production is quite well established. Good options exist for well tubulars, submersible pumps, carrier fluid design etc. The planned well will be above the basement rocks and so drilling contractors active in the shale plays will be able to drill the wells including the laterals. Technology for reaming the well bore exists. Novel heat-conducting proppants have also been somewhat studied. The single well closed loop design is novel and possibly some uncertainties exist until the well is put into production but analytical and numerical models for heat transfer for a single well configuration are available and have been used to come up with the preliminary estimates.

**Scalability:**

The project is scalable simply by drilling additional wells. Other campuses that are suitably located in good thermal gradient zones can also be served by deep geothermal wells. The Dubois campus has existing wells that can be converted for geothermal production. Funding may also be available from DOE for such "wells of opportunity."

**Advantages:**

- Utilizes natural heat available in the subsurface.
- Almost no environmental impact with the single well, closed loop option.
- No associated carbon emissions.

**Disadvantages:**

- Significant upfront capital cost.
- Significant operating cost because of electricity for pumps, etc.
- Requires retrofitting of UP thermal system to supply hot water instead of steam.

**Adaptability to the Future:** Future expansion can be accommodated either by drilling additional wells or if need be, deepening wells to tap the heat in the basement rocks.

**Social Justice Concerns:** None, if the site selected does not have cultural or other significant features.

**Risks and Uncertainties:** The biggest uncertainty is associated with establishing the temperature at depth. Several interpolated maps for thermal gradients in the central Appalachian region are available. These are based on the data along thousands of wells drilled into the Marcellus and Utica shales. However, UP is not near those wells and hence the uncertainty. Perhaps, that uncertainty can be mitigated by undertaking a thermal survey in one of the existing wells if they are located close to the UP campus. The other uncertainty is the heat transfer mechanisms in a single well configuration and the length of the horizontal section need to reach the desired temperature.

**Behavior Change(s) Required:** None

**Other Caveats:** This strategy requires the UP campus steam distribution system to be converted to a hot water system at a cost of $130.76 million. The hot water system also has an O&M saving $1.95 million. Significant cost savings are possible if we can negotiate turnkey projects to drill the well and tie it to the retrofitted hot water system.

**Educational Opportunities:** The geothermal facility can become a field training facility for operating and managing field production. Wells and surface facilities can be instrumented and connected to a control room that can be used for training purposes.

**Research Opportunities:** A lot of interest from companies and DOE on topics such as:

- Design of single well closed loop systems.
- Stimulation design and choice of proppants for improved heat recovery.
- Carrier fluid design.

**Co-Benefits:**

Drilling, coring and examination of the mineralogy using X-ray diffraction techniques can reveal whether there are critical mineral resources available in the vicinity of the wells. The presence of minerals like Strontium may be a huge incentive for DOE and other companies to invest in a project. Emphasis can then shift to geothermal production with simultaneous leaching of critical minerals.

Additionally, well drilling, facility retrofitting, etc. can spawn both direct and indirect spending that can create an economic benefit for the region.

**Information Sources:**

- Cornell University Report.
- Feasibility Report of a Deep Geothermal Single Well, Aberdeen Exhibition and Conference Centre, Report Published 23 Mar 2016.

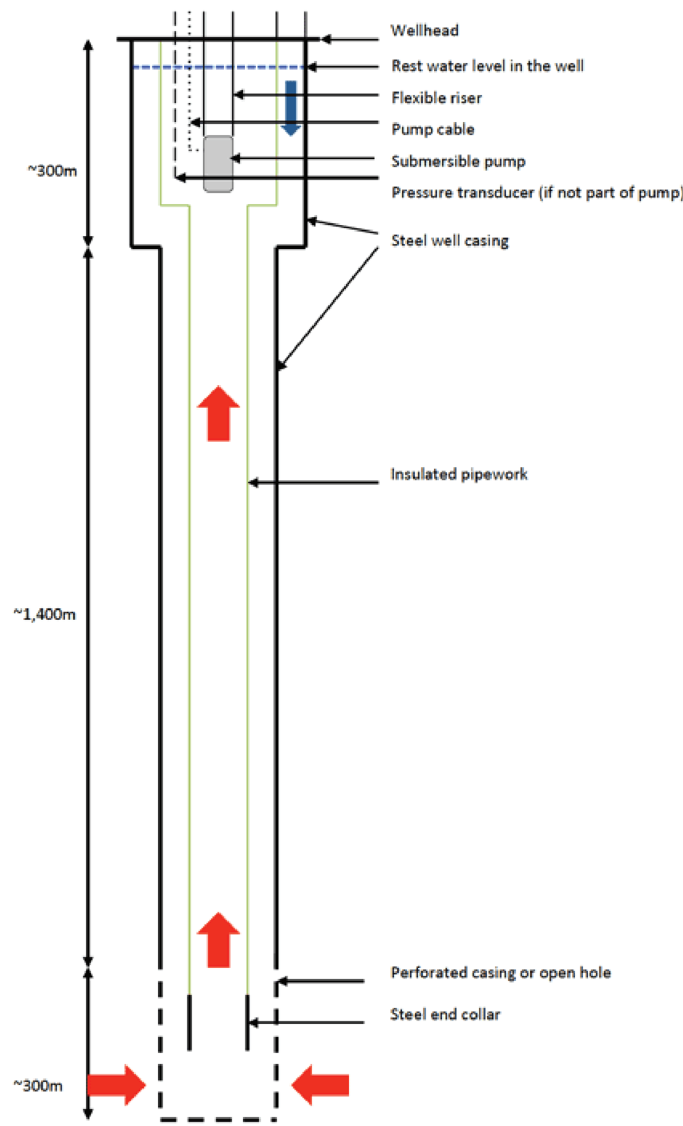
**Resources:**

- A short 5-minute information video from Cornell titled "THE FUTURE OF GEOTHERMAL ENERGY." https://energy.cornell.edu/news/earth-heat-source-cornell-engineering-future-geothermal-energy
- Eavor's AGS system. https://vimeo.com/301259525.

**Authors:** Ron S. Pristash, Arash Dahi Taleghani (PSU-EME), Sanjay Srinivasan (PSU-EME)

**Image:**

Configuration of a single well geothermal system. (Source: Feasibility Report of a Deep Geothermal Single Well, Aberdeen Exhibition and Conference Centre, Report Published 23 Mar 2016)



## I.5: DIRECT AIR CAPTURE

**Location:** University Park

**Description:** Direct air capture (DAC) is the process of capturing carbon dioxide directly from ambient air via a chemical/mechanical process. The captured $CO_2$ can be processed in two manners:

1. Sequester $CO_2$ into the ground (geosphere) via compression – potentially carbon negative.
2. Use the $CO_2$ to create synthetic fuels, "feed" greenhouse plants, carbonate beverages, make dry ice (e.g. Berkey Creamery) – carbon neutral at best.

There are two technological means of accomplishing direct air capture:

1. Liquid direct air capture: Air passes through a chemical solution (hydroxide solution); requires high grade heat to remove $CO_2$ during regeneration process (1600°F).
2. Solid direct air capture: Air passes through a solid sorbent filter; requires lower grade heat to remove $CO_2$ during regeneration process (175-250°F). At PSU, this heat would come from either an electric heater, steam from the central plant, or best case from recovered waste heat.

If pursued at Penn State, solid DAC (low temperature) would be the more feasible/economical route. The information below is based on low temperature solid DAC technology. Climeworks (Switzerland) and Global Thermostat (USA) are two companies that offer this type of DAC technology.

**Emissions Reduction Potential:** 35 MTCO2e per year per module (Climeworks DAC-1). Scales linearly with each additional module. Net emissions reduction using PSU utility emissions factors is 10 MTCO2e per year.

**Capital Cost:** According to Climeworks, one module (DAC-1) costs $1 million. This price does not include packaging, transport, construction of the plant, foundation work, or electrical/thermal connections. Using installation costs of 50% of capital cost, first cost = $1.5 million.

**Annual Operating Cost:** Not well documented since it is a new technology. Literature has shown assumptions at 3-4% of capital expenditure, i.e., ~$30,000 annually for one module. This seems very high, but the data is limited.

**Energy Inputs:** 17 mmBtu heat input/MTCO2e and 1,300 kWh electrical input/MTCO2e.

**Financial Considerations:** Carbon dioxide supplementation in greenhouses has potential to yield better growth at less cost (potentially cooler operating temps and less ventilation needed). Currently, the cost per metric ton of $CO_2$ is still too high to make the technology economically feasible.

**Maturity:** New technology but in very early commercial stage. Most DAC equipment/installs are currently proof-of-concept and not readily available for commercial sale/purchase.

**Scalability:** Extremely scalable.

**Advantages:** Location independent install, modular, captures distributed emissions; does not compete with land, food, or water resources; system can be designed to store C in the ground or produce pure $CO_2$ for sale/use.

**Disadvantages:** Unless carbon is compressed and stored into the ground, it is not a carbon negative system; expensive initial cost; requires waste heat from a plant (waste heat in a building not likely hot enough) or other heat input source; large energy input required due to low concentration of $CO_2$ in ambient air.

**Adaptability to the Future:** A necessary technology to remove historical emissions.

**Social Justice Concerns:** Direct air capture presents an opportunity to reduce carbon in the atmosphere in a local area, however the actual equipment is very industrial. This could be a beneficial technology to deploy in areas that are or have been polluted by fossil fuel-based industries and infrastructure.

**Risks and Uncertainties:** None.

**Behavior Change(s) Required:** Customer for captured $CO_2$ to adopt the new source. Fund a DAC install project that is not currently economically viable to solely stagnate or reduce GHG emissions.

**Other Caveats:** Cost of $CO_2$ capture – based on designs and carbon purity, the costs range drastically (literature details anywhere from $220 to $1,100/MTCO2e across diverse installs). Limited $CO_2$ sink capabilities in available greenhouses. Mike Uchneat (FC at Life Sciences building) stated that 7 growth chambers in Life Sciences building can manage $CO_2$ levels, but none currently do. The Life Science Greenhouse does not have equipment to supply $CO_2$. Untested market with products utilizing captured $CO_2$.

**Educational Opportunities:** Carbon dioxide adsorption process (applicable to HVAC IAQ as well).

**Research Opportunities:** Potential to operate greenhouses at cooler temperatures in the winter while supplementing carbon dioxide; effect of carbon dioxide depletion in greenhouses without supplementation; synthetic fuel production; algae bio-fuel reactor.

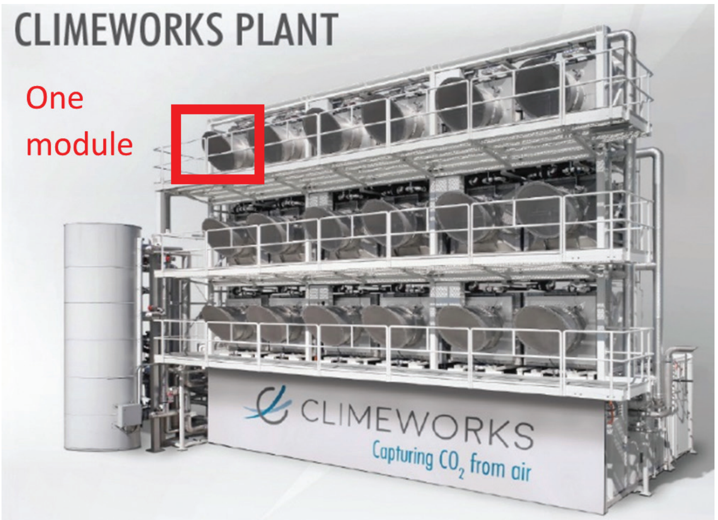
**Co-Benefits:** Potential to recover waste heat from steam/chiller plants to power the DAC system.

**Information Sources:**

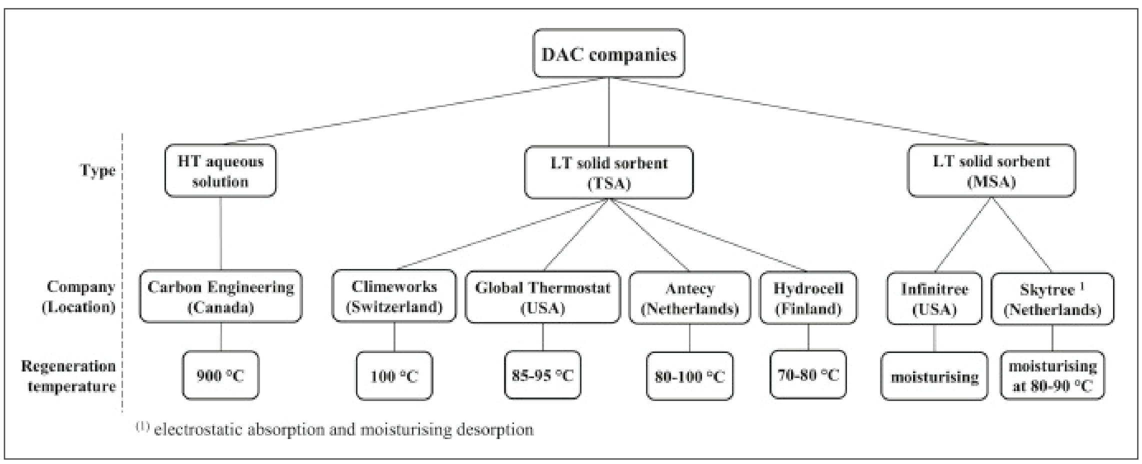

- Breyer, C., Fasihi, M., Bajamundi, C., Creutzig, F., 2019. Direct air capture of $CO_2$: A key technology for ambitious climate change mitigation. Joule 3, 2053-2065.
- Climeworks, 2018. Climeworks company presentation.
- Climeworks, 2017. Climeworks plant specification sheet.
- Fasihi, M., Efimova, O., Breyer, C., 2019. Techno-economic assessment of $CO_2$ direct air capture plants. Journal of Cleaner Production 224, 957-980.
- Frantz, J.M., 2011. Elevating carbon dioxide in a commercial greenhouse reduced overall fuel carbon consumption and production cost when used in combination with cool temperatures for lettuce production. HortTechnology.
- Kumar, A., Madden, D.G., Lusi, M., Chen, K., Daniels, E.A., Curtin, T., Perry IV, J.J., Zaworotko, M.J., 2015. Direct air capture of $CO_2$ by physisorbent materials. Wiley Online Library.
- Keufl, J., 2020. Pricing for climeworks demonstrator. Email communication.
- Marcucci, A., Kypreos, S., 2017. The road to achieving the long-term Paris targets: Energy transition and the role of direct air capture. Climatic Change 144, 181-193.
- Realmonte, G., Drouet, L., Gambhir, A., Glynn, J., Hawkes, A., Koberle, A.C., Tavoni, M., 2019. An inter-model assessment of the role of direct air capture in deep mitigation pathways. Nature Communications.
- Commercial install in Switzerland https://www.youtube.com/watch?v=63S0t4k _ Glw


**Author(s): Jake Bayus**

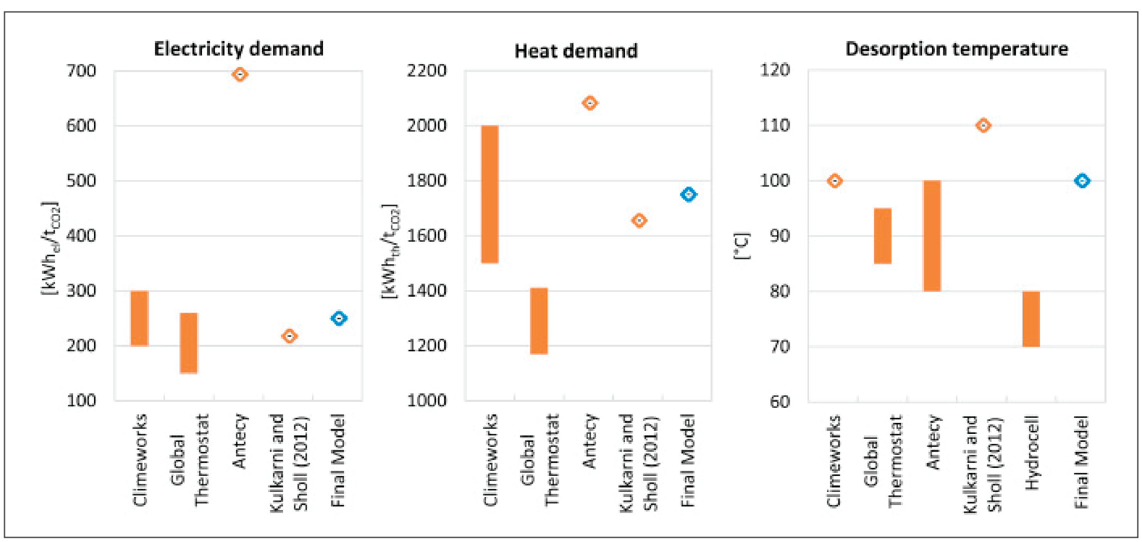
**Images:**



CLIMEWORKS PLANT
One module
CLIMEWORKS
Capturing CO2 from air

DAC companies
Type
HT aqueous solution
LT solid sorbent (TSA)
LT solid sorbent (MSA)
Company (Location)
Carbon Engineering (Canada)
Climeworks (Switzerland)
Global Thermostat (USA)
Antecy (Netherlands)
Hydrocell (Finland)
Infinitree (USA)
Skytree [1] (Netherlands)
Regeneration temperature
900 °C
100 °C
85-95 °C
80-100 °C
70-80 °C
moisturising
moisturising at 80-90 °C
(1) electrostatic absorption and moisturising desorption

Electricity demand
[kWhel/tCO2]
Heat demand
[kWhth/tCO2]
Desorption temperature
[°C]
Climeworks
Global Thermostat
Antecy
Kulkarni and Sholl (2012)
Hydrocell
Final Model

## I.6: ELECTRIC BOILERS

**Location:** University Park

**Description:** Electric Boilers can convert 100% of the electrical energy input into heat with no stack or heat transfer losses seen in combustion units. Without combustion, the operation of an electric boiler is quiet, clean, and produces zero on-site emissions. If these units are supplied with low cost 100% renewable electricity, the steam generated by these units would be 100% carbon free. Fuel lines/storage, economizers, stacks, draft fans, and complicated combustion control or emissions monitoring equipment are not required, saving on both capital expenditures and long-term life cycle cost. The units are very safe to operate with no flames, fumes, fuel lines or storage tanks.

This study examines the feasibility of operating three 61,000 lb/hr high voltage (25 KV-18.8 MW) electrode steam boilers at the East Campus Steam Plant located at the P Campus. Electrode boilers use the conductive and resistive properties to carry electric current and produce steam. The AC current flows from an electrode of one phase, through neutral, to an electrode of another phase and utilizing the water as the conductor. Since the water has electrical resistance, the current flow generates heat directly in the water itself. The more current that flows, the more heat (BTU's) generated, and the more steam produced. Because of this inherent feature low water protection is built in because the absence of water prevents any current flow and the electrode from producing steam. This unit can rapidly respond to full load in less than 60 seconds from hot start conditions. The unit has a stepless turndown adjustment from 0-100% which allows for significant more sizing flexibility than with a combustion unit.

**Emissions Reduction Potential:** The East and West Campus steam plants combined emitted roughly 110,000 MTCO2e in 2019. The three Electrode Steam Boilers would reduce GHG emissions by 63,000 MTCO2e/year (21,000 MTCO2e per unit at 60% load factor)

**Capital Costs:**
- First Cost Plant: $85-95 million
- First cost electrical upgrades: $50-75 million

**Operating Costs:**
- Annual Labor increase: No additional operational staff
- Annual Water Cost: No additional cost
- Annual Purchased Electric Cost Increase: 368,000 MWh – 428,000 MWh electricity cost for units (60-70%load factor)

**Financial Considerations:**
Maturity: High Voltage Electrode Steam boilers are a mature technology.

**Scalability:** Various boiler sizes available

**Advantages:**
- No stack, quiet and 100% efficiency.
- No additional plant operation staff required and can be operated remote.
- Very fast response time, less than 60 second to full load from a hot start.
- Works with existing campus steam distribution system.
- Safer both environmentally and operationally with no combustion or fuel storage/lines.
- Compact footprint allows unit(s) to be installed at ECSP or WCSP.
- Minimal to no environmental air permitting.
- High turndown.

**Disadvantages:**

- Energy intensive: 65-70 MW of imported power for three 61 KPPH units.
- Requires electric distribution system modifications.
- No backup fuel source.

**Adaptability to the Future:** Fits well with expected electrification of energy infrastructure.

**Risks and Uncertainties:**

- No backup fuel source.
- Research would be at increased risk due to increased risk from grid outages from storms, off-site car accidents, regional grid outages.
- For this to be a zero-carbon technology, the electricity used would need to be from renewable sources or a carbon-neutral source.

**Co-Benefits:** Local air quality benefits

**Authors:** Ron Pristash

## I.7: ELECTRIC VEHICLES

**Location:** University Park and Commonwealth Campuses

**Description:** The University owns vehicles of all sizes and types. This strategy is for electrification of vehicles that are used at the OPP Garage and Fleet Services, as a subset of vehicles that the University owns and operates. These locations were chosen because they have a single unit controlling many vehicles of different types. The assumption is that this scenario will give us an estimate of the scale of changes needed to electrify a set of vehicles, and that the learning from these cases will be useful in scaling this solution to the rest of the University.

The vehicles considered are a subset of vehicles owned and operated by OPP Garage and Fleet Services, that are available on the market now or within the next 5 years in electric versions (sedans up through cargo vans and trucks, and there is information readily available about their capabilities and costs. Increasing the charging infrastructure at UP is included in the model for this strategy.

Fleet Services owns and operates approximately 500 vehicles. The analysis here included 419 of these vehicles (buses and police vehicles were not included). OPP Garage owns and operates over 700 vehicles of widely varying types and sizes. The analysis here included 432 of these vehicles (large trucks, construction equipment, landscape equipment, tractors, large and small utility vehicles, and stationary equipment were not included). It was assumed that EVs would be purchased on a 5-year and 8-year rotation for Fleet Services and OPP Garage respectively.

To model the GHG emissions reduction potential and cost:

- The number of miles driven by each vehicle type in an average year was estimated based on data from Fleet Services and the OPP Garage
- A comparable EV replacement was selected for each type of vehicle as shown in Table 1. Both an up-front cost and the amount of electricity needed to travel the average distance of that vehicle type (using EPA-rated ranges and battery sizes) was then estimated.
- A replacement cost for an internal combustion engine (ICE) vehicle was also determined (from either public information or State contract pricing if available). The cost of the vehicle transition was modeled as the difference between the EV and ICE vehicle prices.
- Gasoline prices and electricity prices were modeled using current available data.
- It is estimated that the reduction in operating costs for EVs is approximately $100/year/vehicle based on experience with EVs at the OPP Garage (a national survey showed an estimated savings during the first 3 years of ownership of 30%).

The other costs associated with the conversion from gasoline to electricity is the vehicle charging infrastructure installation. Through conversations with OPP staff, an estimated combination of different levels of chargers were determined to be needed to accommodate the vehicles described. The different level of chargers charge vehicles at different rates and thus have different infrastructure needs. In general, it was assumed that vehicles could be charged overnight on level 1 chargers (which are the cheapest and the slowest charging), so almost a 1:1 vehicle to charger ratio was assumed. A mix of Level 2 and Level 3 chargers were also included, which charge at faster rates and are more expensive. Level 3 chargers are the most expensive, so it was assumed that they would be reserved for when either a very fast vehicle turnaround was needed or charging was neglected for whatever reason (no charger available, forgotten, etc). Level 2 chargers would be necessary for vehicles that are only parked for a single shift, for example, and not overnight. The cost per charger shown in Table 2 below is the up-front cost to install (including design, hardware, and installation). A lower cost was also included for maintenance/repair every 10 years (the life

*Table 25:The type and number of vehicles modeled at Fleet Services and the OPP Garage, and the EV replacement selected for that type.*

| Fleet Services | | | OPP Garage | | |
|---|---|---|---|---|---|
| **Vehicle Type** | **#** | **Elec Replacement** | **Vehicle Type** | **#** | **Elec Replacement** |
| Small sedan | 150 | Chevrolet Bolt | Minivan | 154 | Chrysler Portal |
| Large sedan | 53 | Ford Mach-E | Multipurpose 4WD | 9 | VW ID.4-like vehicle* |
| Minivan | 94 | Chrysler Portal | Small pickup truck | 76 | Ford Lightning |
| Service van | 56 | Ford E-Transit | Full-size van | 130 | Ford E-Transit |
| Pickup Truck | 7 | Ford 150 Lightning | Large pickup truck | 44 | Ford E-Transit** |
| Full-size 4WD | 26 | VW ID.4-like vehicle* | Box truck | 19 | Ford E-Transit** |
| Mid-size 4WD | 22 | VW ID.4-like vehicle* | | | |
| Large 4WD | 11 | Ford 150 Lightning | | | |

**4WD SUVs on the market currently are more 'luxury' vehicles (e.g., Volkswagen (VW), Tesla Y, Audi e-tron, Volvo XC40), however numerous vehicles are in development. Thus, it was estimated that a VW-like vehicle would be available in a less luxury version before 2025 with similar battery characteristics and price to the VW.*

***The Ford E-Transit battery size and range were used, however a cost estimate based on experience was used for the large pickup and box trucks.*

*Table 26: Number of chargers of each type estimated to be necessary to install on campus for the University-owned vehicles modeled.*

| Level charger | # vehicles/ charger type | Cost per charger |
|---|---|---|
| **1** | 1.3 | $1,400.00 |
| **2** | 9 | $2,500.00 |
| **3** | 112.5 | $75,000.00 |

of a common warranty). Additional up-front costs were also assumed to be necessary with an estimated value of $1.5 million for the total project, which would include underground work, installing transformers, and power distribution and service gear.

**Emissions Reduction Potential:** 2,700/year MTCO2e

**Capital Cost:** $12 million (OPP); $16 million (Fleet)

**Operating Cost:** $320,000/year savings (OPP); (616,000/year savings (Fleet)

**Financial Considerations:** EVs are currently more expensive than ICE vehicles. However, as more vehicles come to market the price continues to decline. It is expected that larger vehicle classes will have more of a price differential than smaller vehicles. However, total cost of EV ownership may be less since EVs do not require the same annual maintenance (e.g., oil changes, filter changes, radiator checks, etc.) as ICE vehicles. Also, the price of electricity at UP is low and the cost to charge an EV is less than purchasing gasoline for an ICE vehicle.

For this model, we assumed that the price difference between purchasing an EV and an ICE vehicle will reach parity by 2035. No State or Federal incentives were included in the model; however, it is expected that some grant or rebate funding may be available.

**Maturity:** EVs are on the market today, but not for all classes of vehicles. The smaller classes of vehicles are ahead of larger vehicles, however larger hauling vehicles and buses are ahead of utility vehicles like larger pickup trucks and shuttles. Lawn and landscaping equipment is available, however not considered in the current analysis. Larger farming and utility vehicles are in development.

**Scalability:** Electrification is being accomplished already in other countries, and some places in the U.S. This is an available technology and something that is proven to work in other places. Adding charging infrastructure in the PSU system could support scaling the electrification of private transportation as well.

The operating cost savings listed above include the difference between purchasing gasoline and electricity. The electricity rate used in the model assumes that a solar PPA is purchased to cover some of the electricity, thus making it slightly more expensive than market rate for electricity from the grid. The savings also includes the maintenance difference, assuming a $100/year difference between maintaining an ICE vehicle and an EV. If hybrid EVs are purchased, this full savings will not be realized due to needing to continue to maintain the ICE and purchase fuel.

**Advantages:**

- Reduces reliance on fossil fuel gasoline/diesel for transportation needs.
- Reduces maintenance requirements and cost.
- Reduces air pollution where vehicles are driven.
- Reduces noise where vehicles are driven.
- Increases available charging infrastructure.
- Could increase the acceptability of EVs to the public.

**Disadvantages:**

- Increases necessary infrastructure for electricity distribution on campus(es).
- Only driving within a certain distance will be supported at first due to range anxiety.
- If rental fleet vehicles are transitioned before renters are ready, this may reduce rentals from Fleet Services.

**Adaptability to the Future:** It is assumed that electrification of transportation is a necessary step in decarbonizing our society. A plan is necessary that allows future transportation needs to be considered when building out new infrastructure.

**Social Justice Concerns:** EVs rely on batteries, mostly lithium based. Lithium mining is a concern, as well as what happens during the disposal process and to the waste associated with the batteries.

**Risks and Uncertainties:** The goal of decarbonizing transportation could be achieved through electrification, but only if the electricity used to manufacture and charge the vehicles is also decarbonized. Currently the electricity used on PSU campuses is 25% renewable, thus there are fewer GHG emissions from EV usage. As the electricity sector of Penn State's and Pennsylvania's electricity grid continues to decarbonize, this will lead to continued emissions declines. However, if for some reason the emissions decline does not happen, the sector will not decarbonize effectively.

The infrastructure at the Commonwealth Campuses and outside of the OPP/Fleet Services area of the UP campus needs to be included in the electrification plan and process. The vehicles modeled here were mostly considered to be at UP, however Fleet vehicles and other University-owned vehicles do not reside only in one area of the campus, or only at UP campus. To create a plan to electrify our transportation system, we need to take the entire Commonwealth system into consideration.

**Behavior Change(s) Required:** A change in vehicle technology will require people to become accustomed to the new technology. When the Fleet rental vehicles are changed to electric, there may be a hesitancy to rent them until people get familiar with them. There will likely be range anxiety at first, so the vehicles may not be rented as much. An incentive structure may be needed to get people familiar with the vehicles and let them get comfortable with the logistics of charging. Another possibility is to purchase more plug-in hybrid EVs at first. This allows people to make a slower transition while the charging infrastructure is built up. Vehicles that are owned by Penn State and operated by

Penn State employees on and around campuses will need to get familiar with the technology as well, however routes and charging stops can be pre-planned based on the jobs that are done with the vehicles. These employees will likely need some training, however, to become familiar with the vehicles themselves. Because there is quite a bit of employee turnover in those areas, this training may need to be done on a regular basis.

**Other Caveats:** This evaluation includes only passenger and cargo/work vehicles. Other vehicle classes that should be transitioned away from fossil fuels are landscaping equipment, utility vehicles, stationary vehicles like generators and other equipment, construction vehicles, etc. A full electrification plan should be conducted, preferably after a full evaluation of the right-sizing of the current fleet.

*A note about travel distances for Fleet vehicles:* An analysis of Fleet rental vehicle destinations for 3 years (2007, 2010, and 2014) shows common locations to travel with a rental vehicle. The 'pool' vehicles that are rented account for only about 40% of the total number of Fleet vehicles located in Pennsylvania, however this gives an indication of rental vehicle usage. The total number of trips analyzed was 17,798 trips. Of these, 19.1% had listed locations of 'local' and another 56.2% (not including local trips) were to locations within Pennsylvania. Some other popular destinations were Harrisburg (9.5%), the Greater DC area (13.3%), Philadelphia (6.6%) and Pittsburgh (5.4%).

**Educational Opportunities:**

- Having EVs at the workplace could educate employees about their benefits and drawbacks.
- Living lab opportunities for in-class and out-of-class projects on vehicle electrification, battery systems, grid infrastructure, as well as the social aspects of uptake of new technologies, etc. Data could be made available.

**Research Opportunities:** Battery technology, battery recycling, EV technology and recycling, social systems and policies to support the EV transition, integration of vehicles with electricity grids for co-benefits, etc.

**Co-Benefits:**

- OPP personnel who operate tools could make use of the large vehicle battery to run their equipment. This could lead to efficiencies, as well as better working environments (less fossil fuel fumes, maintenance and mess).
- If the University invests in a large fleet of mobile batteries, it could be used as a backup system for the University's electricity grid, when vehicles and chargers are available to support it.

**Information Sources:**

- Ford® All-Electric Vehicles
- Chevy Electric Vehicle Lineup: EVs and EUVs
- The State of Vehicle Fleet Electrification (smartenergydecisions.com)
- Enterprise Fleet Management Case Study I Geotab | Geotab
- https://cleantechnica.com/2021/11/02/ev-maintenance-costs-are-30-lower-than-gas-vehicles-at-3-years-new-study-finds/
- https://www.carboncounter.com/#!/explore
- Routes to Lower Greenhouse Gas Emissions Transportation Future | U.S. EPA

**Acknowledgments:** Much appreciation for many conversations with Fleet Services (Rob DeMayo and others), OPP Garage (Bruce Cifelli), and OPP (Cyle Vogt and others)

**Author(s):** Meghan Hoskins

## I.8: ENERGY SAVINGS PROGRAM

**Location:** All Locations

**Description:** Implemented in 2003, the ESP is Penn State's premier energy reduction program that utilizes avoided utility costs to implement energy savings measures that include equipment, systems, and operational measures. This effort increases efficiency, reduces energy consumption, mitigates emissions and lowers maintenance costs. More than 200 projects have been funded through ESP or benefitted from contributions.

*The program is the single largest contributor toward the University's GHG emission reduction strategy to date.* The ESP can continue to play a major role in the climate action strategies aimed at helping Penn State achieve its aggressive GHG reduction goals.

This strategy looks at extending the ESP beyond the existing Capital Plan for an additional 10 years, with funding set at $12 million per year. These factors were derived as a best fit size from the IEP using savings performance of projects which were adjusted based on two significant targets. First, the lower limit of energy use by University buildings was evaluated to establish the maximum size of the ESP based on EUI targets. EUI is the Energy Use Intensity measurement in kbtu/sf, a benchmark widely used in the industry and well documented by the U.S. DOE's EnergyStar program. This evaluation uses 91 kbtu/sf, a 25% reduction from existing, as the lower limit for the 30 million square feet portfolio of University buildings. Second, the cost avoidance was expanded from the current practice of using utility costs only to include other operational savings. Most significantly are the costs of carbon offsets in an integrated scenario that is fully carbon neutral. This change addresses the current challenge of identifying projects that have sufficient energy cost avoidance to justify the investment.

**Emissions Reduction Potential:** ESP program, through energy management and conservation, has supported projects that have reduced the University footprint by over 200,000 MTCO2e.

The following is a breakdown of the current Capital Plan ESP (2018-2023) annual reductions:

| | University Park Building | Utilities Projects | Commonwealth* |
|---|---|---|---|
| **Total** | 6,545 MTCO2e | 28,086 MTCO2e | 4,774 MTCO2e |
| **Ave/proj** | 268 MTCO2e | 1872 MTCO2e | 191 MTCO2e |

**Includes ECM funded projects at CWC*

**Maturity:** The format and structure of the ESP and its projects have existed at PSU since 2003. The program is based on Energy Performance Contracting (EPC) which is the standard delivery method used by federal, state and institutional organizations to implement conservation projects.

**Advantages:**

- ESP is the largest contributing effort to emissions reduction for the University (over 200,000 MTCO2e).
- Projects are funded through Office of the Corporate Controller via a $79 million revolving fund.
- Utility funds are re-directed to fund projects, so there is little or no effect to the utility (campus or auxiliary) budget.
- As a long-time strategy, the ESP is very flexible to adjust as other things change, such as energy sources, funding availability, or building technology.

**Disadvantages:**

- Even under the most ideal ESP circumstances, these projects can still be cost prohibitive depending on funding resources and have the need for an alternate funding source for execution.
- ESP funding is a loan, not a budget. These loans include interest (at 4% interest rate), and annual repayments are required for each project/investment.
- Limit of $50,000 ESP funding per project (difficult to support smaller projects).
- No funding consideration for carbon reduction.

**Uncertainties:**

- Considerations
    - Unforeseen constructability limitations that could add costs to the project.
    - Abatement as responsibility of project.
    - Bringing outdated buildings up to current code alongside improvements.
    - Codes and standards.
- Risks of deploying new technologies could slow down project schedule or impede progress or performance.
- Inconsistent additional funding sources to support projects with longer payback period.
- Accurate metering and billing information.
- Energy savings not always captured at the meter.
- Utility and carbon offset price changes.

**Business Case and Financial Impact:** In the current Capital Plan, the ESP is funded at **$79,000,000**. At the end of the FY 19/20, the ESP committed project funds were **$129,789,083** with an expected return of **$99,610,074** in avoided energy costs (savings).

ESP has shown to be a best-in-class approach to reducing carbon emissions, and therefore has been evaluated as a continuing program. Using a next best approach so solve for the energy savings needed to have equal performance to other viable near-team strategies shows that additional operational cost avoidance can be included in the project finances to expand the range of projects available for implementation.

- Supports reducing the University deferred maintenance backlog, estimated at $1 billion.
- Installs more efficient equipment, systems, and controls.
- Reduces operating costs.
- Increased occupant comfort and satisfaction with building conditions.
- Provides deployment of new technologies, and opportunities to pilot technologies.
- Opportunity for safety improvements in buildings (light levels up to code/standard, egress lighting improvements, proper air changes in lab spaces, proper amounts of OA in spaces, etc.).
- Opportunity to assess scheduling in all buildings/facilities to adjust for changes of use to building spaces over time.

**Caveats:** The program is currently limited to six selected firms to deliver ESP projects. Program funding limitations restrict 'whole building' projects. The effort to meet PSU Standards and Code requirements increases costs and limits energy savings funding potential. Evaluating antiquated systems to ensure current compliance adds to audit, analysis, and installation costs.

**Educational Opportunities:** OPP employs student interns to support ESP projects and administration. Energy engineers work with professors either through classroom instruction or facility tours. The energy team often collaborates with and supports the Sustainability Institute.

**Research Opportunities:** OPP employs student interns to support ESP projects and administration. Where applicable, the energy team works with researchers in providing data, using the University as a living laboratory, or investigating new technologies.

**Behavior Change(s) Required:** ESP projects involve upstream modifications to equipment and systems. Opportunities exist to work with SI and others for complimentary downstream behavior modification curricula. (Direct Rebound Effect, familiarity with new products, OPP re-visit and review). Energy engineers can help overcome resistance of engineers and architects to incorporate newer energy savings technologies.

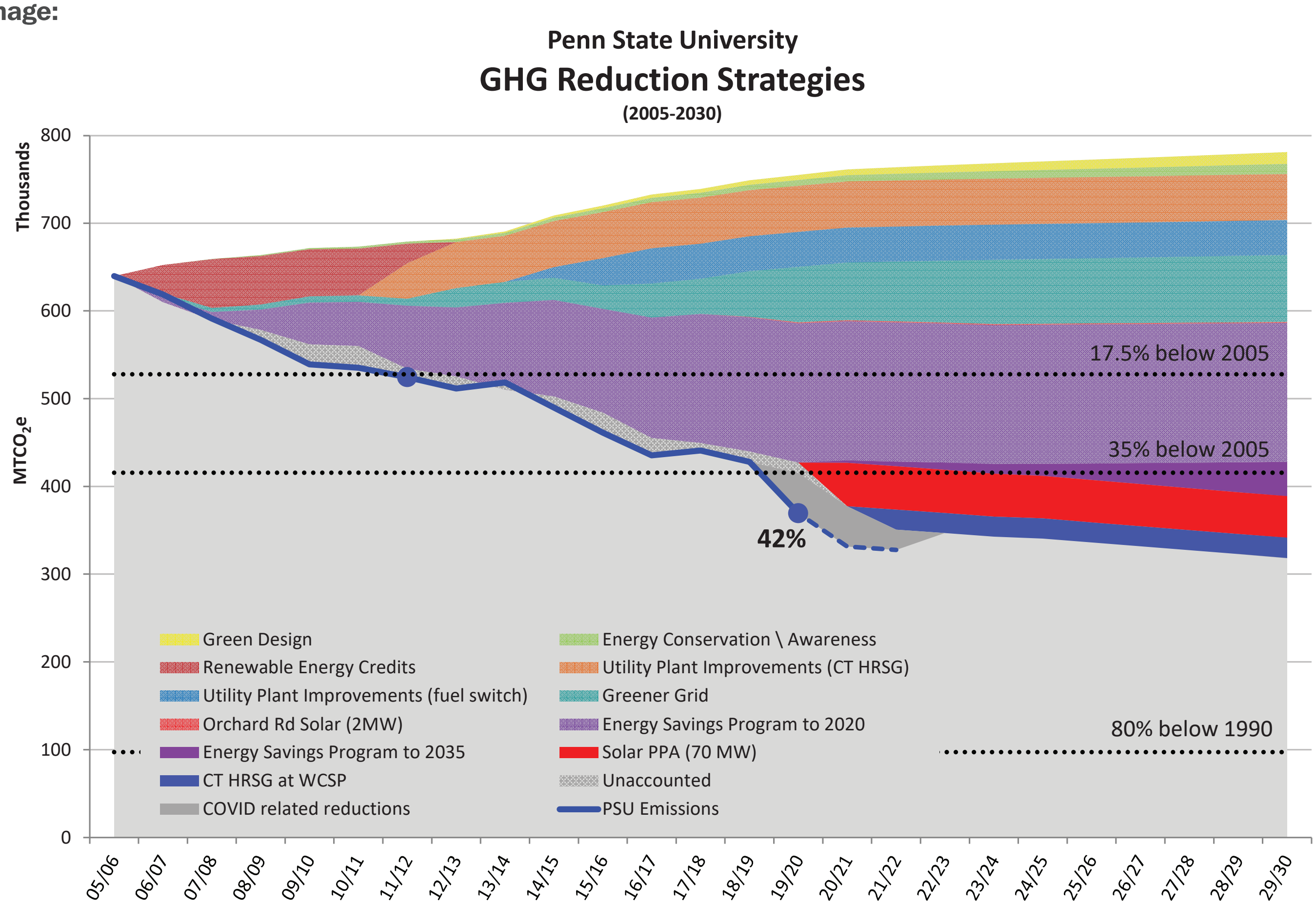
**Co-Benefits:** Carbon reduction, avoided energy, and maintenance savings, building occupant comfort, and reduced maintenance backlog.

**Visible Marker(s) of Success:**

- Annual report to Office of Corporate Controller
- GHG Emissions Reduction Strategy Chart (Purple Wedges)

**Authors:** Laura Miller, Jenn Messner, and Jacob Bayus

**Image:**



## I.9: FUEL CELL

**Location:** UP Water Reclamation Facility (WRF).

**Description:** According to the U.S. Department of Energy, a fuel cell uses the chemical energy of hydrogen or other fuels to cleanly and efficiently produce electricity. When hydrogen is the fuel, the only products are electricity, water, and heat. Fuel cells are unique in terms of the variety of their potential applications; they can use a wide range of fuels and feedstocks and can provide power for systems as large as a utility power station and as small as a laptop computer.

A fuel cell provides electricity through a chemical reaction instead of combustion. This evaluation involves the installation of one fuel cell at the University Park Water Reclamation Facility (WRF) where biogas would be used as the fuel source instead of natural gas to extract the hydrogen.

**Emissions Reduction Potential:** 2,796 MTCO2e/year based on (1) Doosan 450 Fuel Cell

**Capital Cost:** $1.9 million

**Operating Cost:** None.

**Financial Considerations:** Contracts vary slightly across manufacturers, but the design, installation and maintenance of the fuel cell was evaluated as a turnkey project. Typically, the fuel cell is received in an enclosed container with regular maintenance and full replacement (5-year is normal) included in the cost. A fuel cell contract period is usually 20 years.

A single installation of a 400 kW fuel cell will generate nearly 4,000,000 kWhs and produce 15,000 MMBtu of thermal energy that would be used at the new facility.

The use of existing biogas would offset any natural gas consumption. The project could be funded through ESP.

**Maturity:** Mature technology, emerging for smaller/commercial sizes.

**Scalability:** Commercial/industrial with utility scale substations.

**Advantages:**

- Maintenance contracts are included in the purchase package.
- Fuel cell manufacturer provides delivery, oversight and commissioning.
- Fuel cell would be designed to use on-site biogas.

**Disadvantages:** Current study is 5 years old and needs refreshing based on the new WRF. At that time, relocation of underground facilities was required.

**Adaptability to the Future.** Yes. A fuel cell is refurbished every 5 – 10 years. During the process additional fuel cells can be added as defined increments. Some manufacturers may also be able to adapt the reforming process to accommodate newer fuels as well.

**Social Justice Concerns:** Affordability at a smaller scale.

**Risks and Uncertainties:** Availability of the digester methane. Placement of a fuel cell has not been determined with new facility layout. Viability of thermal energy may have changed since the study was completed. The Spark spread works best with low natural gas/higher electric costs.

**Behavior Change(s) Required:** WRF operations would not be required to perform maintenance. No testing, but perhaps minor monitoring would be necessary.

**Other Caveats:** Assumptions are based on the old WWTP layout and flared biogas.

**Educational Opportunities:** The WRF is a secure facility plus the fuel cell remains under ownership and operation of an outside vendor so educational opportunities are limited to data sharing.

**Research Opportunities:** Not an ideal research opportunity as manufacturers requires no or very limited access to the fuel cell to comply with warranty and maintenance.

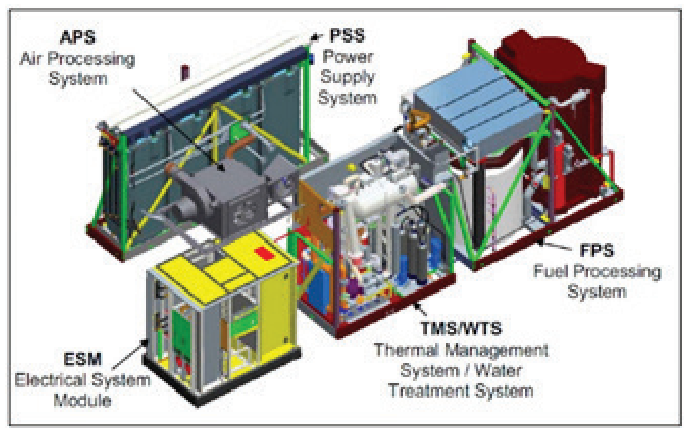
**Co-Benefits:** Carbon reduction and elimination of continual biogas flaring.

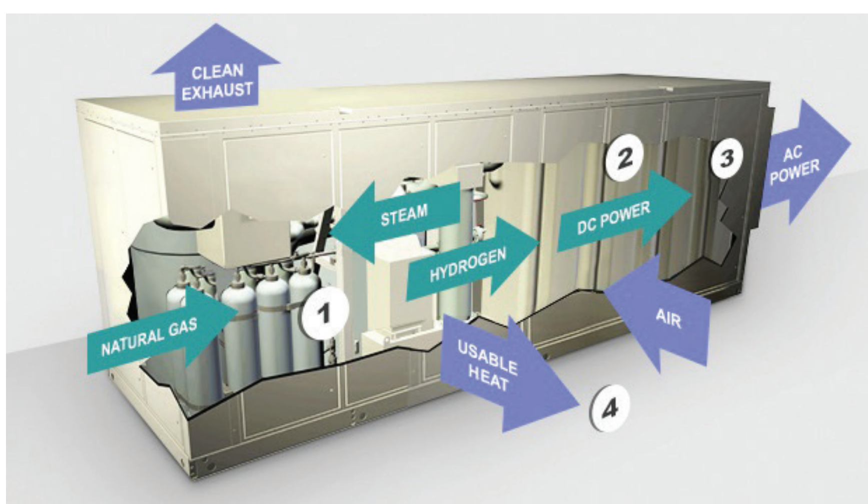
**Information Sources:**

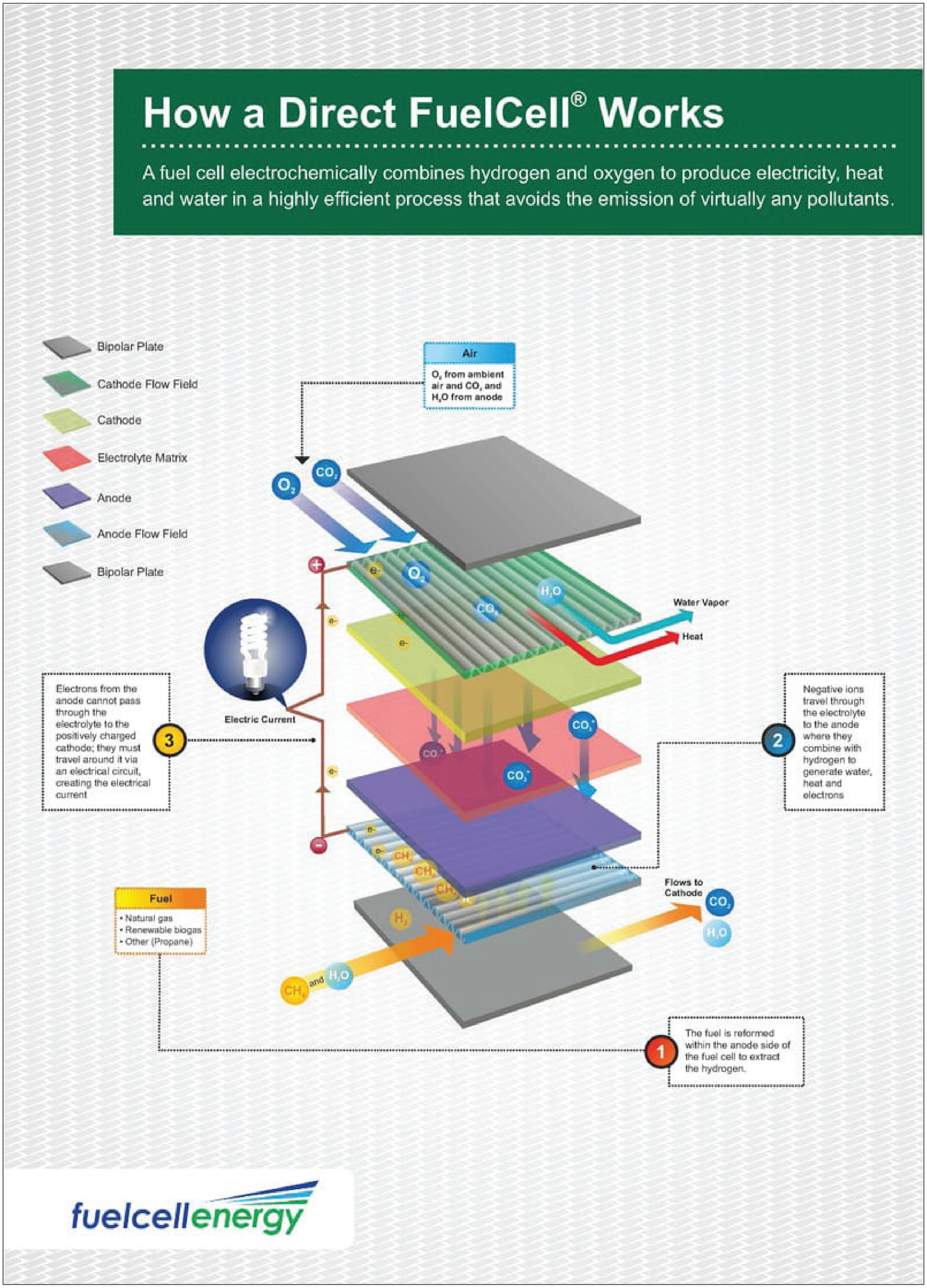
- https://www.energy.gov/eere/fuelcells/fuel-cells
- https://www.fuelcellenergy.com/benefits/how-a-fuel-cell-works/
- Doosan Corporation
- FuelCell Energy

**Author(s):** Laura Miller

**Images:**




*(1) https://www.fuelcellenergy.com/benefits/how-a-fuel-cell-works/*

## I.10: GREEN HYDROGEN

**Location:** University Park

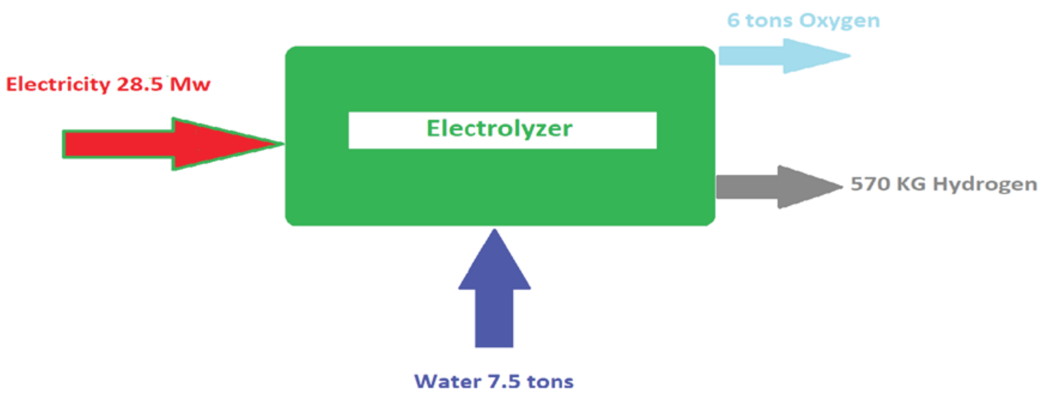
**Description:** There are four color classifications for hydrogen production which are grey (or brown), blue, green, and pink. *Grey hydrogen* is made using fossil fuels, which emits $CO_2$ in the process. *Blue hydrogen* is made in the same way but utilizes carbon capture technology to prevent the $CO_2$ from being released, enabling the captured carbon to be sequestered deep underground or utilized in industrial processes. *Pink hydrogen* is made carbon free generated through electrolysis using nuclear energy. *Green hydrogen* is the cleanest process, producing zero carbon emissions. It is produced using electrolysis powered by renewable energy sources to produce a clean and sustainable fuel. Over 99% of the hydrogen currently produced utilizes fossil fuels. According to the International Energy Agency (IEA), less than 0.1% of hydrogen currently produced in the world is through water electrolysis. Forbes recently published an article that seven of the biggest green hydrogen project developers in the world have come together to launch the Green Hydrogen Catapult Initiative with a goal to increase the production of green hydrogen 50-fold in the next six years. The new initiative aims to cut the cost of green hydrogen to less than $2/kg, which would help to cut emissions from the world's most carbon-intensive industries including steel-making, shipping, chemicals production, and power generation. Analysis in the article suggests that $2/kg is a potential tipping point that will make green hydrogen and its derivative fuels competitive in multiple sectors. It is estimated that green hydrogen could supply up to 25% of the world's energy needs by 2050 and become a U.S. $10 trillion addressable market by 2050, according to Goldman Sachs.

This study examines the feasibility of producing green hydrogen on-site at the P campus and utilizing this carbon free fuel source in specialized hydrogen boilers referred to as a Dynamic Combustion Chamber™ (DCC™) manufactured by Hydrogen Technologies Inc (HTI). These boilers would produce steam for campus heating, electric generation, and process needs.

**Process:** Hydrogen is the most abundant element found in the universe comprising three quarters of its total mass. However, with this seeming endless supply there are no natural occurring hydrogen deposits found on Earth. Hydrogen has to be extracted from other compounds by a chemical process.

*Green Hydrogen* – Why produce the green hydrogen on site? Hydrogen gas has a very low density which makes it hard to store and move around. Storing and transporting the highly flammable hydrogen gas is not easy; the hydrogen gas needs to be cooled to -253˚C to liquefy it, or it needs to be compressed to 700 times atmospheric pressure so it can be delivered as a compressed gas. Producing the hydrogen on-site to meet demand with an electrolyzer eliminates these two major fuel handling hurdles.

*Electrolyzer* – Green hydrogen is made through a process known as electrolysis. Here, a device known as an electrolyzer splits water into its constituent elements of hydrogen and oxygen using electric current. The only byproduct of the process is oxygen. There are four types of water electrolyzers: Alkaline, polymer electrolyte membrane (PEM, anion exchange membrane (AEM, and solid oxide. The electrolyzer is very energy intensive, and efficiencies range from around 60-80%, according to Shell. It is estimated that electrolyzer costs could fall by half by 2040, from currently around $840 per kilowatt of capacity, the IEA said in 2019. The 62,000 lb/hr of steam generated by Hydrogen Technologies Inc (HTI Dynamic




Combustion Chamber (DCC)™ process consumes 568 kg/hr of hydrogen at full load. Using an electrolyzer with hydrogen production averages of 50 kWh per kilogram of hydrogen, it would require a 28.5 MW of electricity to produce 570 kg of hydrogen per hour. Using the $840 per kW capacity puts a 30 MW electrolyzer cost at $25.2 million. The illustration shown above shows the hourly inputs and outputs of the electrolyzer.

*Water Usage* – The electrolyzer will use 20 kg (10 kg Consumptive) of water as makeup for every kilogram of hydrogen that is produced using an electrolyzer that has an efficiency of 75%. The 570 kg of hydrogen per hour that is required for 62 kpph Boiler would use 72,000 GPD or 216,000 gallons per day for 3 units at full load. PSU UP water is at the E&G rate of $12.07/1,000 gallons. The Susquehanna River & Boat Commission (SRBC) would require additional fees for $0.34/1,000 gallons on consumptive use. Based on 60% load factor (47.3 million gallons per year total for all three units combined) this is $600,000 per year water cost. The use of PSU reuse water needs to be investigated.

*Electrical* – Preliminary estimate for the electrical investment needed to import an additional 100 MW into campus of $50-75 million. Operating at an annual average of 60-70 MW/hr and if the University was able to purchase renewables at $.035 kW/hr this would be an increase in annual purchased electrical cost of $18,400,00-$21,500,000. Steam generated and run through BPST would reduce purchase electric cost $500,000-$1,000,000.

*Boiler* – The function of the Dynamic Combustion Chamber ™(DCC™) process is to generate either hot water or steam, without producing any carbon based or NOx emissions. The process uses hydrogen and oxygen as fuel, reacts them in the DCC™ under a slight vacuum, and extracts thermal energy with the use of common industrial thermo-fluid heat transfer components. It is fundamentally a steam condensing boiler. The scalable process is based on combining pure hydrogen and oxygen to form water molecules. This reaction releases 61,000 British Thermal Units (BTUs) per pound of hydrogen. It is this energy, operating in the ultra-violet range that is used to heat water and generate steam. The heat is extracted across typical stainless-steel heat exchangers commonly used in industrial applications. After the reaction, the fuel, now water, is collected in a closed loop system to be electrolyzed and returned as a fuel source. All equipment, engineering processes and control systems are based on proven industrial equipment and standard operating procedures.


*Credit: www.hydrogentechnologiesinc.com/#home*

The HTI condensing boiler process: 1) emits no carbon or NOx particles when burning pure hydrogen; 2) requires no combustion atmospheric air-eliminating parasitic loads from fan; 3) delivers a boiler thermal efficiency of >97%; and 4) operates quietly compared to traditional boilers.

**Emissions Reduction Potential:** The East and West Campus steam plants combined emitted roughly 110,000 metric tons of $CO_2$ in 2019. Annual GHG Reduction: 21,000 MTCO2e/boiler (60% load factor). Total for 3 units 63,000 MTCO2e (dependent on operational model).

**Capital Costs:**

- First Cost Plant: $210-250 million (Purchase cost (3) electrolyzers ($76 million) & 3 Hydrogen Boilers ($25-30 million), balance of plant work ($10-15 million), distribution ($5 million), new 50,000 sqft Building, engineering, design,and construction.
- First cost electrical upgrades: $50-75 Million (100 MW imported to campus)

**Operating Costs:**

- Annual Water Cost: $600,000 for all 3 units (216,000 GPD x .6 Load factor)
- Annual Purchased Electric Cost Increase: $18.4-21.5 million; $0.35 kWh electricity cost for 3 units (60-70% load factor)

**Maturity:** Green hydrogen production is in its early stages of development. As previously mentioned only 0.1% of world hydrogen production is currently made by electrolysis. Green hydrogen requires inexpensive, large-scale, renewable energy.

**Scalability:** The system is scalable.

**Advantages:**

- No stack, quiet and efficient 97% operation.
- No additional plant operation staff.
- Works with existing campus steam distribution system.
- Easy to permit with closed loop combustion, no NOx, only byproduct is water from boiler and oxygen from electrolyzer.

**Disadvantages:**

- Large site footprint (2 acres) – each 30MW electrolyzer requires a 80’ x 140’ building area
- Energy intensive – 90 MW of imported power for three 62 KPPH units
- Water intensive – 46.8 million gallons per year for three units based on 60% load factor.

**Adaptability to the Future:** Abundant supplies of water as source fuel, possible use of reuse water.

**Social Justice Concerns:** Use of pressurized hydrogen may lead to safety concerns from the perspective of the community. Transportation of the fuel, by vehicles or pipelines, has inherent risk of accidental combustion. Intense water usage is also a concern.

**Risks and Uncertainties:** Green hydrogen is banking its future on large scale low-cost renewable electricity. Could reuse water instead of potable water be used in the electrolyzer. This study is just a snapshot of the current time, tremendous amounts of capital is being invested worldwide into research that could lead to rapid advancements in green hydrogen technology.

- H2Pro's dollar-a-kilo green hydrogen: a 20-year leap in clean energy? (newatlas.com)
- Hydrogen Shot | Department of Energy

**Behavior Change(s) Required:** This system does not require any changes to the distribution or steam generation equipment at the ECSP.

**Educational Opportunities:** The green hydrogen production process on-site would provide students and faculty with living lab electrolysis and hydrogen boiler learning opportunities.

**Research Opportunities:** The green hydrogen production process on-site would provide students and faculty with living lab electrolysis and green hydrogen boiler research opportunities.

**Information Sources:**

- www.news.psu.edu/story/661450/2021/06/16/research/computers-help-researchers-find-materials-turn-solar-power-hydrogen?utm _ source=newswire&utm _ medium=email&utm _ term=661836 _ HTML&utm _ content=06-17-2021-22-51&utm _ campaign=Penn% 20 State%20Today

**Author(s):** Ron Pristash

## I.11: LARGE SCALE SOLAR POWER PURCHASE AGREEMENT

**Location:** All Locations

**Description:** Purchase another solar (or mix of renewables PPA like the Franklin County PPA. OPP has reviewed the current economics and rate potential for an additional PPA estimates the rate for the next PPA to be in the $0.055 - $0.06/kWh range ($0.058/kWh has been the assumption used for modeling purposes. The size and term length of the PPA depends on several factors including investments in electricity reduction and potential conversion of thermal systems from natural gas to electric. For example, the PPA scale must be reduced if solar is installed on Commonwealth Campuses to avoid purchasing too much electric in total. As a stand-alone opportunity targeting all Scope 2 emissions not mitigated by the Franklin County PPA, the next solar PPA can be sized at approximately 120 MW-ac providing 150 million kWh/year. At $0.058/kwh, the PPA purchase would result in a net increase in cost of $5.3 million on a net present value basis.

**Emissions Reduction Potential:** The solar PPA will offset grid purchases of fossil fuel generation reducing GHG emissions by 50,000 MTCO2e/year.

**Capital Cost:** There is no capital cost associated with a PPA purchase. The estimated capital cost of the installation for the project owner/developer is $100 million.

**Operating Cost:** The PPA counterparty will be responsible for operating the solar generation project and incorporates such cost into the PPA price. The owner's operating cost is estimated to be $25,000/year with an inverter replacement cost at year 15 of approximately $500,000.

**Financial Considerations:** The solar project underlying the PPA must be owned by a third party that is an approved wholesale entity on PJM. Penn State does not have the option to own the project.

**Maturity:** Solar PV generation is a mature and highly commercialized technology with a proven successful track record.

**Scalability:** Solar PV installations are highly scalable but are dependent on the availability of land. Additional land and solar generation capacity could be easily added to the PPA (or under another PPA). Reducing the amount of solar generation capacity in the PPA will be costly during the PPA's term.

As technology changes, Penn State could work with the project owner to transition to newer, more efficient equipment if an economic benefit is available during the term of the PPA.

**Advantages:**

- No up-front capital cost.
- Proven technology and value proposition.
- Provide tangible additionality in support of our commitment to carbon reduction.
- If locally developed (like Franklin County project) the solar system can be leveraged by students, teachers and researchers.
- Fixed PPA price of electricity per kwh generated can hedge against future price increases in market electricity.

**Disadvantages:**

- Depending on the location and land type, large-scale solar projects can face public scrutiny and resistance.
- The commercial in-service date and kwh generation may be several years after the date the PPA is signed.
- PA projects create high value RECs which can increase the price of the PPA.
- A REC conversion from PA RECs to national Green-e RECs may be required to minimize price.

**Adaptability to the Future:** Solar PV systems can be upgraded as technologies improve. Panels can be converted at any time to higher efficiency versions when economically beneficial.

**Social Justice Concerns:** Land payments and local tax revenue would go to rural landowners, schools and first responders. Many of these projects provide job opportunities to rural and economically disadvantaged areas.

Depending on the location of the installation, local air quality can be improved, especially if fossil fuel-based electricity generation can be replaced with renewables. It may also help farmers keep their land as farmable and not needing to sell.

**Risks and Uncertainties:**

- Panels are globally sourced and subject to supply chain and political influences.
- Incentives may decline over time.
- Equipment costs are subject to inflation and may increase over time; however, higher costs may be offset by gains in efficiency.

**Other Caveats:** Some PSU brand concern related to how the project owner (or the developer) designs and constructs the project and manages public interaction during permitting.

**Educational Opportunities:** Students and faculty can have some limited access to the project but full access to operational data for living labs and other learning.

**Research Opportunities:** Students and faculty can have some limited access to the project but full access to operational data for research.

**Co-Benefits:**

- The local power grid will use less fossil fuel benefiting the local community's environmental quality.
- Local PA labor will be used to install and maintain the systems.
- PA solar businesses will continue to grow and support the growth of renewable energy.

**Author(s):** Gregg Shively, Mike Prinkey

## I.12: MICRO-NUCLEAR REACTORS

**Location:** University Park

**Description:** Nuclear power has historically not been considered as a viable option at the University due to the scale of established nuclear reactor designs. Although the Breazeale Nuclear Reactor has been utilized for research on the UP campus for over 60 years, utilizing nuclear power for heat or electricity production has traditionally required an investment that was limited to utility-scale installations.

Recent developments in advanced nuclear reactor designs (at the modular and micro-reactor scale have changed the potential for use of nuclear power at a scale that could be attractive to Penn State (e.g., many of the smaller reactors can produce as low as 1 megawatt of electricity where before, the scale was in gigawatts. These smaller reactors could be capable of providing a reliable, carbon-neutral, and low maintenance source of both heat and electricity while being free from variable fuel prices. The largest challenges to adoption remain the initial capital costs and the maturity of the technology. It should be noted that many of these designs are readily adapted to the production of both thermal and electric power, which could provide attractive solutions, for our UP power needs.

Companies such as NuScale, GE Hitachi Nuclear Energy, and Westinghouse have been developing both modular and micro-reactors for future implementation. Modular reactors such as the NuScale SMR and the GE Prism reactor typically range between 60-100 MWe per unit and upwards of 300 MWe for GE's BRX 300, with multiple units being placed in parallel to provide scalable electricity for remote communities. Several micro-reactors from various vendors appear to be capable of fitting the needs of Penn State.

One such micro-reactor that was investigated can provide up to 5 MWe of electricity (with 10 MWt of thermal residual power) or up to 15 MWt of thermal power and is primarily being developed for forward-deployed military installations as a mobile and reliable power source that is free from a fuel logistics train. Another micro-reactor design can produce 10 MWe of electricity (with 10 MWt of thermal residual power) or up to 30 MWt of thermal power, and it is targeted toward both mobile military applications as well as large scale replacement of on-site and power plant energy production.

### Modular Reactor Designs

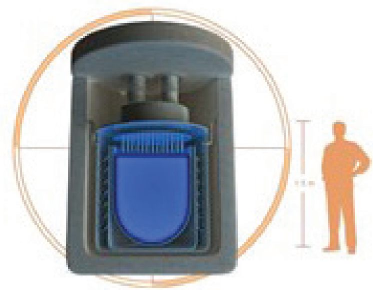
There are two challenges with bringing any of the modular reactors currently under development to Penn State. First, these reactors are just above the scale that could be used at the UP Campus. Currently, the smallest modular reactor can produce 60 MWe of electricity, but even at its peak, the UP Campus uses only 50 MWe of electricity. Current agreements with West Penn Power on interconnections and the University's reluctance to be regulated under the PUC as a power provider would require adjustments to Penn State's relationship with West Penn Power and regulators. These considerations are limiting factors with regards to the ability to place a modular reactor on campus as the power source for the University and the surrounding communities. Second, these reactors have significant site constraints including the need to be near a thermal heat sink (river or ocean), and sizable footprints for exclusion areas which could be as large as 40 acres. In concert with the cost ($2-10 billion dollars per unit), these constraints limit the applicability of modular reactors at any Penn State campus.

## Micro-Reactors

Smaller reactors, known as micro-reactors, do not have the same limitations as the Modular reactors. Micro-reactors (which can be configured in a modular fashion) are typically air-cooled, produce less than 50 MWe of electricity, and require small footprints for installation and exclusion areas. One challenge with utilizing some of the micro-reactors is that they are being designed for producing electricity with very little waste heat. Alternatively, there are other reactor designs that can modulate between thermal and electric power production (with residual waste heat available during peak electricity production). One of the University's critical needs is a consistent and reliable heat source – from which electricity is produced as a waste product.

The most promising fission-based reactors still face the hurdle of obtaining a license from the Nuclear Regulatory Commission (NRC), a process that has proven to be expensive and time-consuming (with variation in both dimensions). For both reactors mentioned above, their firms have commercialization plans that project a commercially licensed reactor, ready for deployment by 2028.

If Penn State were to pursue bringing micro-nuclear reactors to the UP campus, in addition to the companies needing to receive approval from the NRC for the reactors, the University would need to secure a site license for the reactors. It is possible that Penn State could pursue a strategy like the University of Illinois and seek to place these reactors at UP under a research license, which would require research activities to be the primary reason for bringing the reactors but would not preclude using the reactors to produce thermal and electric power for the UP campus.



Pursuing a nuclear power solution to our thermal (and electric) power needs would depend on non-engineering factors including economic factors, regulatory cooperation, and public relations support. Any of these challenges would significantly influence the decision to implement nuclear power. However, continued pressures to develop carbon-neutral heat and electricity sources along with the need for predictability and stability in the power grid are important considerations that could positively influence and help support and speed the implementation of nuclear power. In addition, it should be mentioned that 40% of Pennsylvania's electricity production is generated by nuclear power compared to 30% of natural gas and 21% of coal (Pennsylvania PUC report August 2019).

**Scenarios:** The following investigates the use of two different types of micro-nuclear reactor(s) on the Penn State UP campus. The reactors produce both carbon free electricity and thermal heat energy that can be distributed to the campus as steam or hot water. Operational safety has been the major focus of modern design and both reactors that were evaluated are being designed to shut down and self-cool for an indefinite period, with no operator action required, no additional water, and no AC or DC power needed.

*Vendor 1* is currently developing a next-generation, very small micro-reactor for decentralized applications. This micro-reactor's innovative design is a combination of space reactor technologies and 50+ years of commercial nuclear systems design, engineering and innovation. The small size of the unit allows for standard transportation methods for on-site deployment. The reactor core is designed to run for three or more years, eliminating the need for frequent refueling. The key benefits of this micro-reactor are attributed to its solid core and advanced heat pipes. The heat pipes enable passive core heat extraction, allowing autonomous operation and inherent load following capabilities. Vendor 1's design and implementation of novel components has led to a reactor system that avoids some of the major conventional accident conditions in present-day commercial reactors. Accident conditions specifically avoided include loss of primary coolant flow, loss-of-coolant accidents on the primary side; positive reactivity injection due to water ingress into the core;  high-pressure ruptures and ejections; and positive  reactivity injection due to control rod ejection, and station blackout. These advanced technologies together make  this micro-reactor a pseudo "solid-state" reactor with minimal moving parts.

*Vendor 2* is developing a micro molten salt reactor (MSR). The fluoride salt, Uraniumfueled reactor has multiple layers of safety features. The reactor does not require high pressure to prevent coolant from boiling off. In fact, even though it operates at around 700°C, the salt coolant cannot get hot enough to boil. If the reactor loses power, the fuel salt freezes, safely containing fission products. This unit is very flexible and can switch from maximum electrical generation with some thermal to full thermal mode when needed. This reactor is designed to run three years without the need for refueling. Vendor 2 has also developed a novel process that can efficiently convert nuclear waste into valuable products, including rare earth elements, medical isotopes, industrial isotopes, precious metals, and new fuel for advanced reactors. With appropriate approval and licensing, Vendor 2 could close the fuel cycle to offer a truly clean and green circular economy.

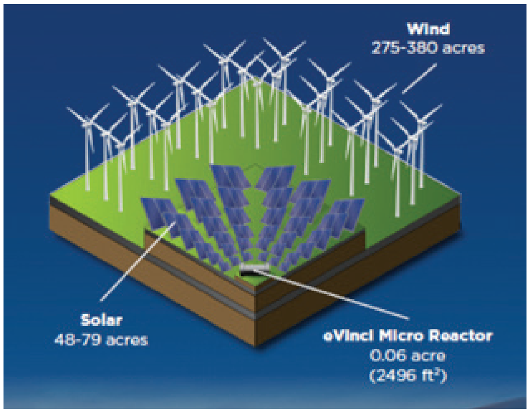
We evaluated the use of three (3) Vendor 2 reactors and evaluated the use of a single unit (1) and two-unit (2) reactors for Vendor 1. The difference in unit quantities for the two brands was based on the campus seasonal electric/thermal fit and cost. Vendor 2's reactors are capable of 30 MWt in pure thermal mode and 10 MWe in electricity with 10 MWt thermal production. Vendor 1's unit is capable of 15 MWt in pure thermal and 5 MWe in electric mode with 7 MWt thermal. The reactors if capable were modeled in primary electric or maximum thermal mode dependent on seasonal conditions. The building site requirements for both manufacturers include an enclosed 2-acre site with a 30,000 sq ft building to house the reactors.

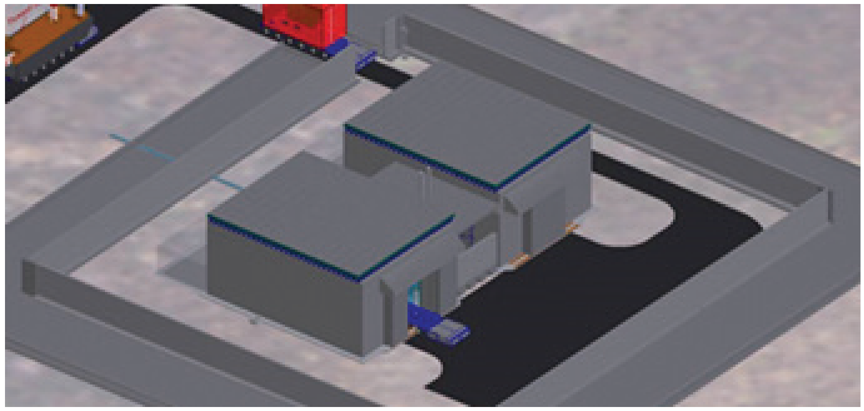
**Emissions Reduction Potential:**

- Vendor 1: 30,000 MTCO2e/year
- Vendor 2: 100,000 MTCO2e/year

**Capital Cost:**

- Reactor Cost per Module:
    - $30 million each Vendor 2 for 3 Units = $90 million
    - $60 million each Vendor 1 for 2 Units = $120 million
- Building & Site Work: $35 million for both systems
- Permitting: $17 million for research permit, or $37 million full industrial permit
- Electrical work: $50 million for both systems



**Operating Cost:**

- Refueling: (Costs not listed due to confidentiality requirements)
  - Vendor 1: Every 10 years
  - Vendor 2: Every 3 years
  - Licensed Operators: $750,000/year
  - Maintenance Contracts: None expected

**Financial Considerations:** Financial evaluation of technology very soft due to a projected commercial availability of 2028, at the earliest.

**Maturity:**

- Small nuclear reactors have not yet been used in a commercial setting.
- Both vendors have plans that would bring their reactors into commercial deployment by 2028.

**Scalability:** Depends on unit thermal/electrical configuration, but in theory both systems could be scaled at UP and potentially be used at other (larger) campus locations.

**Advantages:** 100% carbon-free electric and thermal energy, competitive to favorable economics, relatively small building footprint. The ability to provide a reliable, baseload power base, with the ability to modulate electricity production. The ability to provide resilient power to the UP campus, even in the face of a failure of the wider power grid.

**Disadvantages:** There could be public opposition to placing an advanced nuclear reactor on the UP campus (even though these reactors are very different and much safer than traditional light-water reactors, which still operate very safely). Nuclear energy still produces waste which needs to be dealt with in a responsible manner.
The molten-salt post-processing technology developed by Vendor 2 offers a potential path for reducing or even eliminating the nuclear waste from their reactors. The existing fission reactors use Uranium, which has a limited supply (although other designs could use alternative fuel sources, such as Thorium which is abundant enough to supply the Earth's energy needs for hundreds of thousands of years into the future). However, it should be noted that companies are already addressing supply chain challenges with Uranium fuel using high assay low enriched Uranium fuel cycle with low grade reactive waste.

**Adaptability to the Future:** Advanced micro-reactors offer a scalable solution for providing carbon-free energy (both thermal and electric) for a wide range of needs including hydrogen generation, medical radioisotope fabrication and process heat. Penn State could play a pivotal role in helping advance and socialize the use of advanced micro-reactors in the U.S. and globally.

**Social Justice Concerns:** The mobility of these micro-reactors offers the possibility of bringing sources of power to remote locations, without having to build costly infrastructure (e.g., roads, pipelines, or a power grid) allowing large portions of the planet's population the benefits that come from having access to reliable, inexpensive power. If done correctly, the post-processing of fuel offers a potential avenue for not only producing power while producing little (to no) nuclear waste, it also offers the potential to consume nuclear waste from existing light-water reactors. In addition, micro reactor small footprint addresses land use concerns with other land intensive options.

**Risk and Uncertainties:** The cost and timelines to get license for both the reactor designs and the site license could be costly and take an extended amount of time. Many of these companies are young and all of them still must prove their technologies.

**Behavioral Change Required:** The UP campus and surrounding community would have to become educated on the risks and benefits of advanced micro-nuclear reactors and become comfortable with the perceived risks of siting an advanced nuclear reactor on campus, realizing that these risks are not the same as the risks associated with other existing light-water nuclear reactors.

**Other Caveats:** There is a need to consider how putting an advanced micro-nuclear reactor would impact Penn State's insurance and risk management considerations.

**Educational Opportunities:** The micro-reactor facility would offer PSU faculty, staff and students a diverse set of opportunities for education: instrumentation and control, multi-physics validation, reactor prototype testing, micro-grid operations, cybersecurity, hydrogen production for transportation and energy storage, and other energy intensive, high-value products.

**Research Opportunities:** The micro-reactor facility would offer PSU faculty, staff and students a diverse set of opportunities for research: instrumentation and control, multi-physics validation, reactor prototype testing, micro-grid operations, cybersecurity, hydrogen production for transportation and energy storage, medical radioisotopes, high temperature materials, and other energy intensive, high-value products.

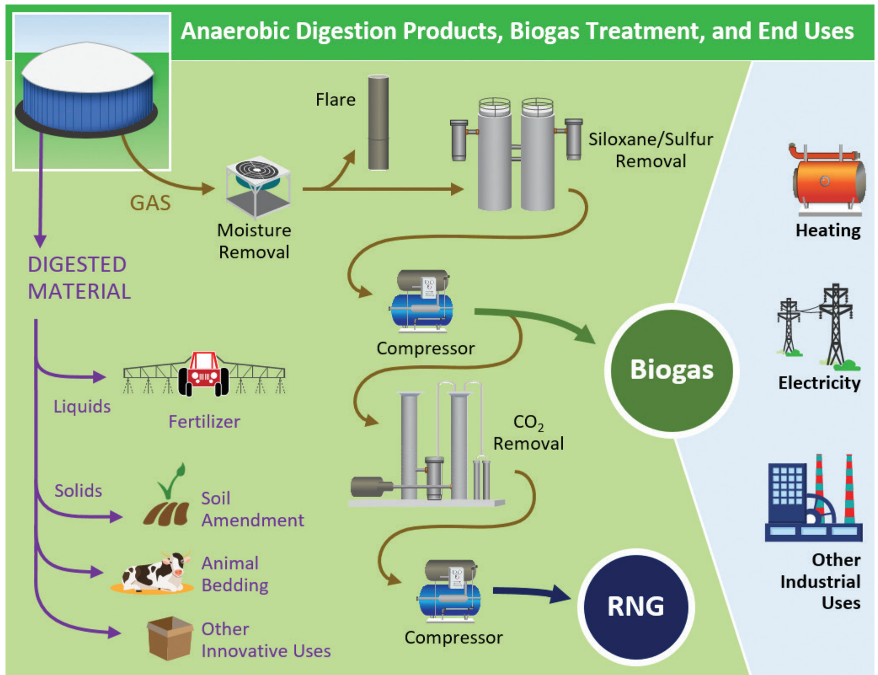
**Co-Benefits:** Penn State has a long history of working with nuclear energy with deep connections across the industry and regulatory community. As a result, the University is uniquely positioned to help advance nuclear energy as a part of a global solution for creating a carbon-free economy.

**Author(s):** Rob Cooper, Ron Pristash, John Liechty, Jean Paul Allain

## I.13: RENEWABLE NATURAL GAS

**Location:** University Park

**Description:** Renewable natural gas (RNG) is a term used to describe biogas that has been upgraded for use in place of fossil natural gas. The biogas used to produce RNG comes from a variety of sources, including municipal solid waste landfills, digesters at water resource recovery facilities (wastewater treatment plants), livestock farms, food production facilities and organic waste management operations.




As a substitute for natural gas, RNG has many ends uses:

- in thermal applications,
- to generate electricity,
- for vehicle fuel, or
- as a bio-product feedstock.

RNG can be used locally at the site where the gas is created, or it can be injected into natural gas transmission or distribution pipelines.

Raw biogas has a methane content between 45-65%, depending on the source of the feedstock, and must go through a series of steps to be converted into RNG. Treatment includes removing moisture, carbon dioxide and trace level contaminants (including siloxanes, volatile organic compounds, or VOCs, and hydrogen sulfide), as well as reducing the nitrogen and oxygen content. Once upgraded, the gas has a methane content of 90% or greater. Typically, RNG injected into a natural gas pipeline has a methane content between 96-98%.

Natural gas in any form (fossil or RNG) is less carbon-intensive than the other fossil fuels it typically replaces, including conventional transportation fuels (e.g., gasoline, diesel) in most cases and coal or petroleum for generating electricity. RNG provides an additional benefit over fossil natural gas because it generally has a lower total carbon footprint, after accounting for emissions from fuel production, transport and use. RNG's carbon footprint is even lower if a project can also take into account directly reducing $CH_4$ emissions from the organic waste used to produce the fuel.

If Penn State were to own the offsets for a dairy-based RNG facility, the standard State of California calculation for dairy offsets are about 5 times the $CO_2$ emissions for fossil natural gas. If you buy 20% of your fossil natural gas as RNG from a dairy digester you have offset all your emissions. The reason is the substantial methane emissions from conventional dairy manure management. Landfills are regulated to not release methane, so their offsets are much less, and in this case apparently zero.

As of 2019, the offering price for renewable natural gas from landfills was 5 times our current price for fossil natural gas.

Penn State is not interested in paying 5 times its energy cost ($16 per MCF RNG vs $3 per MCF NG). Even 5 times for 20% would almost double our total natural gas cost: 0.20 x 5 + 0.80 x 1 = 1.8 the current cost (or an increase of $5.6 million/year) but would get us to net zero for the steam plant.

**Emissions Reduction Potential:** 100,000 MTCO2e/year

**Capital Cost:** $0

**Operating Cost:** $0

**Financial Considerations:** Low or zero-interest loans for farm digesters potentially available from PennVEST, the Pennsylvania environmental bonding authority charged with financing cleanup of the Chesapeake Bay. From a Penn State perspective, low initial capital costs but high operating costs may change the cost/benefit over time.

**Maturity:** Mature technology with billions of MJ available from livestock operations and landfills, but not yet available at our location.

**Scalability:** Supply through the natural gas grid allows distributed scale-up and seamless substitution on campus. Could be used for peak demand exclusively or full load.

**Advantages:**

- Doesn’t require plant upgrades or building modification.
- Could stimulate new technology development, investment, job creation, and environmental benefits.
- New infrastructure would be off-site.
- Could be structured as a public private partnership to ensure a guaranteed price for carbon offsets for a fixed time period (e.g., 10 or 15 years).
- Technology is “shovel ready” and could be implemented in the near future.
- Implementation locally could allow Penn State to help reduce GHG emissions where we live.
- Monitoring Pennsylvania farms would allow us the ability to verify the validity of our offsets and implementing state-of-the-art monitoring for teaching and research.
- GHG reduction due to carbon intensity score ranges from 3-5 times compared to displaced pipeline fossil natural gas.

**Disadvantages:**

- Increases annual operating cost by $5.6 million per year
- The multiplier effect of the carbon offset will go away at some point in the future. (If we can structure the public private partnership to coincide with length of the multiplier effect, this could be offer us a clear way of matching benefits with risks.)

**Adaptability to the Future.** Large near-term offsets are available from the reduction in livestock GHG emissions. These offsets should eventually be sunset as the “business as usual” dairy manure systems transition. As new low-carbon thermal systems ramp up, procurement of RNG could scale down to peak load as desired.

**Social Justice Concerns:** Those objecting to livestock operations due to animal welfare, immigrant worker, or other concerns may see this as enabling a bad system. Fugitive methane leakage at farm sources, project life cycle, waste streams, and land use impacts must all be addressed, and still may be viewed critically.

**Risks and Uncertainties:** Unsure when Columbia (our local natural gas distributor) will provide this option themselves, cooperate with us, or if we should build a separate system.

**Behavior Change(s) Required:** RNG is chemically identical to the fossil natural gas that is our current fuel, so no equipment or behavioral changes are required by the campus community. Procurement contracts and project development off-site will require training and adoption of new business models by farmers and gas grid operators.

**Other Caveats:** No known caveats or compatibility conflicts with other Penn State solutions.

**Educational Opportunities:** Penn State already has a farm digester that burns the biogas on site for electricity. This local demonstration is already used for classroom teaching and stakeholder field days.

**Research Opportunities:** Major research opportunities in the agricultural sector, including a current $4 million USDA grant already awarded to Penn State to work with farms in Pennsylvania. Major corporations (Smithfield, Land-o-Lakes, Dominion Energy) and startups (Compact Membrane Systems) already stakeholders doing research on this approach with Penn State.

**Co-Benefits:** RNG from livestock facilities has a strong positive impact on rural economies and reduces greenhouse gas emissions. Implementation will significantly reduce greenhouse gas emissions reductions in the agricultural sector and provide water quality benefits for Pennsylvania rivers and the Chesapeake Bay.

**References:**

- https://www.greenbiz.com/article/7-things-know-about-renewable-natural-gas

**Author(s):** Rob Cooper, Tom Richard, John Liechty

**Images:**

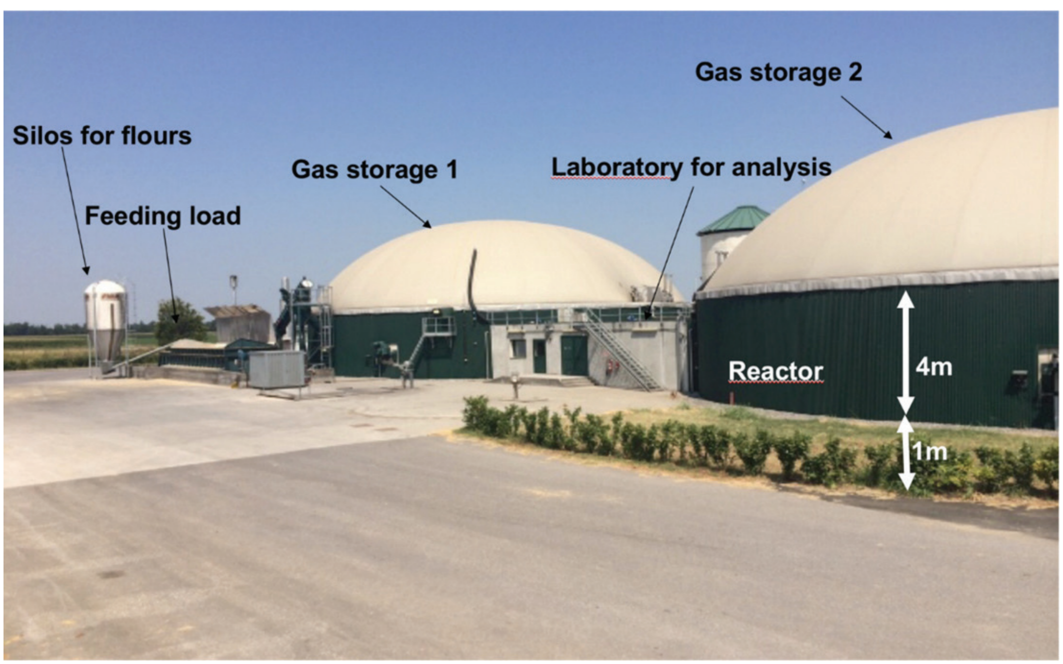



*Figure 29: Typical dairy farm digester.*

## I.14: SHALLOW WELL GEOTHERMAL UTILIZING HEAT PUMPS

**Location:** Commonwealth Campuses

**Description:** Utilizing heat pumps or heat pump water-to-water chillers to produce space heating and cooling for Commonwealth Campus buildings with ground coupling to closed-loop shallow well geothermal heat exchangers. This project is a progressive step towards electrification and energy efficiency that includes the conversion of natural gas fired and electric resistance heating systems in buildings to heat pumps. This project is based on a few sample projects, and general rule of thumb values for both capital costs and energy savings. This is a scalable project but was modeled as a full conversion of all Commonwealth Campus buildings.

**Emissions Reduction Potential:** 15,751 MTCO2e/year, IEP total of 520,000 MTCO2e. Much higher potential when paired with renewable electricity generation.

**Capital Cost:** $333 million total. Based on assumptions from reference study at $45 per square foot for 7.4 million square feet of Commonwealth Campus buildings.

**Operating Cost:** Energy costs are projected to be reduced by the elimination of natural gas while maintaining electric costs like existing costs. This assumption is rooted in the increase in electric use for heating being offset by a reduction in electric use by decreasing heating and cooling loads served by the equipment as part of the project as well as more efficient cooling operation. These decreases come from project related changes to building envelope, ventilation, and automation.

Maintenance costs are assumed to be cost neutral for this preliminary level study, considering that most of the existing heating and cooling equipment will be replaced with new significantly lowering the maintenance backlog.

**Financial Considerations:** Large capital costs are projected for this project, while lower operating costs are projected for the decrease in fuel use.

**Maturity:** Projects of this type are mature and have been the approach utilized by several large universities to decarbonize their campuses while addressing significant maintenance and capital backlogs in their utility systems. Stanford is the most well-known and documented system. Other conversions have happened at Ball State, UBC, and Princeton.

**Advantages:**

- Highly efficient and low temperature heating operations reduce total energy consumption significantly.
- Conversion to electricity allows significant carbon emission reductions when paired with renewable energy sourced electricity.
- Projects utilize equipment and technology that the University already uses and is familiar with.
- Lessons learned from other university conversions helps to lower first cost.
- Eliminates maintenance and reporting on underground natural gas piping systems.

**Disadvantages:**

- Requires capital intensive heating and cooling equipment replacement.
- Large underground footprint of shallow closed loop geothermal heat exchange field.
- Increased electric grid reliance.

**Uncertainties:**

- Capital cost estimates are based on rule of thumb metrics, significant cost risk is possible.
- Electricity supply from renewable sources is becoming more in demand driving price increases and price volatility.
- Building requirement assumptions that could limit efficiency.

**Caveats:** The business case assumes the integration of the project with the currently planned expansion of the central chilled water system, such that the heat recovery portion only incurs the cost of the equipment and the shallow geo system, while the plant building and cooling plant infrastructure are excluded.

**Educational Opportunities:** OPP employs student interns to support utility projects and administration. Energy and Utility engineers work with professors either through classroom instruction or facility tours. The energy team often collaborates and supports the Sustainability Institute.

**Research Opportunities:** Where applicable the energy team works with researchers in providing data, using the University as a living laboratory, or investigating new technologies.

**Behavior Change(s) Required:** Geothermal heat pump system involve upstream modifications to equipment and systems, with minimal behavior change required. Opportunities exist to work with SI and others for complimentary downstream behavior modification curricula. (Direct Rebound Effect, familiarity with new products, OPP re-visit and review.

**Co-Benefits:** Reduction of deferred maintenance backlog in building heating and cooling systems. Removal of University-owned underground natural gas piping that carries a safety concern and monitoring program.

**Visible Marker(s) of Success:** Reduction of on-site Fossil fuels consumption.

**Author(s):** Mike Prinkey

**Geothermal Heat Pump Conversion Probable Capital Cost**

| Measure | Description | Cost/ft$^2$ |
|---|---|---|
| Geothermal Conversion | Installation of Geothermal wells & loop piping, removal of steam systems (boilers & piping), conversion of AHUs to 2 pipe, installation of new FCUs & AHUs [Campus Wide] | 34.0 |
| Controls Upgrade | Upgrade of front end software, new in-room communicating thermostats, programming/commissioning [Campus Wide] | 5.2 |
| Soft costs | Design, permitting, project management, contingency | 5.9 |
| **Total** | | **45.0** |

**Geothermal Heat Pump Conversion Probable Energy Savings and Operating Cost**

| | | Geothermal + Controls Only | |
|---|---|---|---|
| Pre | kWh/yr | 102,351,145 | |
| | Therms/yr | 318,844 | |
| | Cost/yr | $9,856,900 | |
| | EUI (kBtu/ft$^2$) | 51.4 | |
| | CUI ($/ft$^2$) | $1.33 | |
| Post | kWh/yr | 102,351,145 | |
| | Therms/yr | 0 | |
| | Cost/yr | $7,680,621 | |
| | EUI (kBtu/ft$^2$) | 47.1 | |
| | CUI ($/ft$^2$) | 1.04 | |
| Savings & % Reduction | kWh/yr | 0 | **0%** |
| | Therms/yr | 318,844 | **100%** |
| | Cost/yr | $2,176,279 | **22%** |
| | EUI (kBtu/ft$^2$) | 4.3 | **8%** |
| | CUI ($/ft$^2$) | 0.29 | **22%** |

## I.15: SHALLOW WELL GEOTHERMAL UTILIZING HEAT RECOVERY CHILLERS

**Location:** University Park

**Description:** Utilization of heat recovery or heat pump water-to-water chillers to produce hot water for the UP Campus district heat system. This project is a progressive step towards electrification that includes the conversion of the steam distribution system to a low temperature hot water system, allowing the use of hot water generated at or below 140˚F. The electric powered heat recovery chillers would discharge cooling to the campus district chilled water system first, and then to a shallow closed loop geothermal heat exchange field. This is a scalable project that was modeled in many sizes, but two sizes are presented here.

- The first size is a single 2000 Ton heat recovery chiller operating year around between the cooling and heating systems, utilizing heat shift loads in the buildings to supplement the wintertime cooling load profile (HW CHWX).
- The second size is 6000 Tons, with three (3) 2000 Ton heat recovery chillers, utilizing the same heat shift cooling load, plus a closed loop ground heat exchanger sized for 4000 tons of seasonal heat exchange (HW SW Geo).

**Emissions Reduction Potential:** 30,000 MTCO2e/year (HW CHWX) to 50,000 MTCO2e/year (HW CHWX) as a stand-alone. Much higher potential when paired with renewable electricity generation.

**Capital Cost:** $140 million (HW CHWX) to $170 million (HW SW Geo), where both projects include the steam to hot water distribution conversion at $131 million.

**Operating Cost:** Increased electric costs as a replacement for the natural gas which will include higher use at cooling plant and lower on-site co-generation that will need to be replaced by grid electricity. Changes in campus electric and natural gas were calculated as follows (each compared to baseline):

| | | |
|---|---|---|
| **ST to HW:** | **473,000 dth savings** | **21M kwh additional** |
| **HW CHWX:** | 908,000 dth savings | 64M kwh additional |
| **HW SW Geo:** | 1,483,000 dth savings | 114M kwh additional |

Maintenance costs in the cooling or heating plants will transition, but will not significantly change, assumed zero at this study level. Maintenance for the geofield were assumed at $265k/year based on a scale up from the East Halls study.

**Financial Considerations:** Increased operating costs due to higher fuel cost, and the new demand created when Penn State enters the market could drive fuel costs higher

**Maturity:** Projects of this type are mature and have been the approach utilized by several large research universities to decarbonize their campuses while addressing significant maintenance and capital backlogs in their utility systems. Stanford is the most well known and documented system. Other conversions have happened at Ball State, UBC, and Princeton.

**Advantages:**

- Highly efficient and low temperature heating operations reduce total energy consumption significantly.
- Conversion to electricity allows significant carbon emission reductions when paired with renewable energy sourced electricity.
- Projects utilize equipment and technology that the University already uses and is familiar with.
- Lessons learned from other university conversions helps to lower first cost.
- Day and night thermal utility plant operation could be combined from current separated operation.

**Disadvantages:**

- Requires capital intensive steam to hot water conversion.
- Large underground footprint of shallow closed loop geothermal heat exchange field.
- Increase electric grid reliance and lowers on-site power generation capability.

**Uncertainties:**

- Capital cost estimates are based on rule of thumb metrics, significant cost risk is possible.
- Electricity supply from renewable sources is becoming more in demand driving price increases and price volatility.
- Building requirement assumptions that could limit efficiency.

**Caveats:** The business case assumes the integration of the project with the currently planned expansion of the central chilled water system, such that the heat recovery portion only incurs the cost of the equipment and the shallow geo system, while the plant building and cooling plant infrastructure are excluded.

**Educational Opportunities:** OPP employs student interns to support utility projects and administration. Energy and Utility engineers work with professors either through classroom instruction or facility tours. The energy team often collaborates and supports the Sustainability Institute.

**Research Opportunities:** Where applicable the energy team works with researchers in providing data, using the University as a living laboratory, or investigating new technologies.

**Behavior Change(s) Required:** Utility electrification projects involve upstream modifications to equipment and systems, with minimal behavior change required. Opportunities exist to work with SI and others for complimentary downstream behavior modification curricula. (Direct Rebound Effect, familiarity with new products, OPP re-visit and review).

**Co-Benefits:** Reduction of deferred maintenance backlog in steam distribution system, increased cooling capacity, enables other low temperature energy sources that are currently not usable

**Visible Marker(s) of Success:**

- Reduction of on-site fossil fuels consumption.

**Author(s):** Mike Prinkey

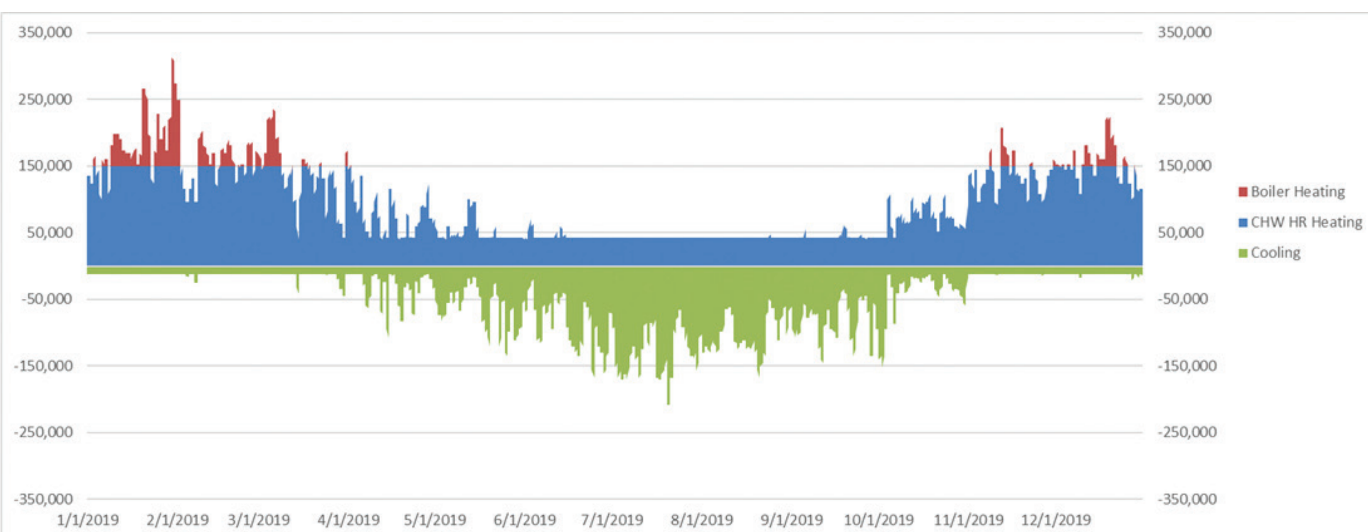


*Table 7 – Preliminary Construction Cost Estimate*

| **Penn State - Preliminary Construction Cost Estimate** | |
|---|---|
| ***Geothermal HVAC Plant Line Item*** | ***Estimated Budget per Item*** |
| **Well Field (180 Vertical Bores)** | $1,440,000.00 |
| **Pumps and Trim** | $205,000.00 |
| **Exp Tank & Air Seperator** | $110,000.00 |
| **HVAC Controls** | $225,000.00 |
| **HVAC Water Treatment** | $9,500.00 |
| **Hydronic Piping** | $425,000.00 |
| **Hydronic Piping Insulation** | $180,000.00 |
| **Plumbing** | $40,000.00 |
| **Heat Pump Chiller (640 Ton Modular System)** | $480,000.00 |
| **Solar Themal Array (75 Collectors)** | $75,000.00 |
| ***SUBTOTAL*** | ***$3,189,500.00*** |
| | |
| **Electrical - Plant Components** | $95,500.00 |
| **Electrical - 3000A Service Upgrade** | $195,000.00 |
| **Electrical - (2) 2500 kVA Transformers** | $120,000.00 |
| ***SUBTOTAL*** | ***$410,500.00*** |
| | |
| **General Construction** | $150,000.00 |
| ***SUBTOTAL*** | ***$150,000.00*** |
| | |
| **Total Plant Construction Cost** | **$3,750,000.00 +/- ($500,000.00)** |

## I.16: SOLAR INSTALLATIONS

**Location:** Commonwealth Campuses

**Description:** Install ground mounted solar generation on available land at Commonwealth Campuses. OPP has conducted a preliminary review of the potential for behind-the-meter solar projects identifying available land on campuses to host approximately 20 MW providing an estimated 25 million kWh/year of renewable electricity. The electricity can be net metered by the local utilities to offset an equivalent amount of electricity that would have otherwise been purchased from the PJM grid. The reduction in purchased electricity will save $1.7 million/year with a Net Cost impact on a Net Present Value basis of $1.8 million.

**Emissions Reduction Potential:** The solar generation will offset grid purchases reducing GHG emissions by 7,000 MTCO2e/year.

**Capital Cost:** The installation cost (equipment, engineering and installation) is estimated to cost $2.00-$2.75/watt depending on the size of the installation. The total capital cost is estimated at $50.8 million for the 20 MWs identified.

**Operating Cost:** The electrical systems and solar equipment will need to be maintained at an estimated cost of $0.80-$1.50/kW depending on the size of the installation. The annual operating cost for the installed 20 MWs is estimated at $220,000/year.

**Financial Considerations:** The solar projects identified should be packaged together and taken to bid in the aggregate to obtain the lowest install and operating costs. The projects may be eligible for ESP funding or could be structured as PPAs to finance the capital and allow the financing party to monetize federal tax incentives the University does cannot access.

**Maturity:** Solar PV generation is a mature and highly commercialized technology with a proven successful track record.

**Scalability:** Solar PV installations are highly scalable but are dependent on the availability of land. The University could evaluate additional land opportunities that are proximate to our campuses and are University-owned or friendly third parties (such as donors and alumni. Pennsylvania net metering rules allow land that is within 2 miles of the metered usage to be net metered under the same rules as land that is at the metered usage location.

Additionally, pending community solar legislation may provide additional opportunities for campuses to utilize solar that is outside a 2-mile radius of campus.

**Advantages:**

- Provides on-site generation from a renewable energy source.
- Low operating cost.
- Proven technology and value proposition.
- Provide tangible evidence of Penn State's commitment to carbon reduction.
- Can be leveraged by students, teachers and researchers.
- Located on owned land which avoids external permitting and public approvals.
- Fixed price of electricity generated by the system can hedge against future price increases on the external power grids.

**Disadvantages:**

- Occupies open land for up to 40 years challenging campus expansion planning.
- Ownership may need to be shared with a third party to monetize incentives that reduce capital costs.
- May not be an aesthetically pleasing addition to campus design.

**Adaptability to the Future:** Solar PV systems can be upgraded as technologies improve. Panels can be converted at any time to higher efficiency versions when economically beneficial.

**Social Justice Concerns:** Installations would be contracted with local labor and equipment can be sourced from companies that practice socially responsible manufacturing. Equipment for solar generation is manufactured globally at varying costs with U.S., Europe, Canada, South Korea and China providing much of the equipment used today.

**Risks and Uncertainties:**

- Panels are globally sourced and subject to supply chain and political influences.
- Incentives may decline over time.
- Equipment costs are subject to inflation and may increase over time; however, higher costs may be offset by gains in efficiency.
- Campus expansion will be more difficult if land has been developed for solar generation.

**Educational Opportunities:** Students and faculty can access on-campus installations for living labs and other learning.

**Research Opportunities:** Students and faculty can access on-campus installations and performance data for research.

**Co-Benefits:**

- The local power grid will use less fossil fuel benefiting the local community's environmental quality.
- Local labor will be used to install and maintain the systems.
- PA solar businesses will continue to grow and support the growth of renewable energy.

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## I.17: SOLAR THERMAL AND HOT WATER STORAGE

*Note: This strategy was not modeled due to time constraints*

**Name:** Solar Thermal (Solar Heating) and Hot Water Storage

**Location:** Commonwealth Campuses

**Description:** Solar heating is a low-carbon thermal solution that uses solar collectors, often flat plate collectors, to transfer heat from solar radiation to internal collector fluid loops and then to water in a secondary loop. Like solar PV panels, flat plate solar collectors perform best when facing south and tilting up 30-40º. The systems can be built for both individual buildings and district heating purposes and can be designed to operate alongside conventional boiler systems. Depending on thermal needs and available space, solar thermal collectors can be installed on rooftops, in fields, or above parking lots, garages, etc. The collectors must be installed locally, relatively close to the building or district system it feeds. Large solar thermal systems may require thermal energy storage, which can be conventional tank, aquifer, or borehole storage systems or newer technologies like Aalborg's seasonal pit thermal energy storage.

**Emissions Reduction Potential:** 10,000 - 40,000 MTCO2E/year

**Capital Cost:** Roughly $700,000 - $1,000,000 per MW

- Cost of storage systems are an additional $0.4 - 8.0 per kwh.

**Operating Cost:** 1-2% of capital costs

**Financial Considerations:** Capital costs associated with project construction. Low operational costs. Reduces exposure to risk of fluctuating natural gas prices.

**Maturity:** Technology is mature and has been deployed on rooftops around the world. Denmark is home to an estimated 75% of the world's large solar heating capacity, having 110 solar heating plants in operation at the end of 2016. Pit thermal storage systems have been available at the neighborhood scale since 1995 (Furbo et al., 2018).

**Scalability:** Solar thermal projects are designed to fit specific thermal loads and are limited by the ground or rooftop space available at a campus. For this reason, the technology would be most effective at campuses with relatively smaller thermal loads and open space.

**Advantages:**

- Could operate in tandem with existing boiler systems.
- Could operate in tandem with heat pumps.
- Could be used to "preheat" water to increase efficiency of existing boilers.
- Projects could use same mounting systems as solar PV projects.
- Compliments efforts to move campuses away from steam and onto hot water.
- Can provide entire campuses with source of district heat.
- Reduces dependency on natural gas and risk exposure to price fluctuations.

**Disadvantages:**

- Uses land or roof space that may have other potential uses.
- Ineffective at large urban campuses and UP due to land constraints.
- Large district heating projects likely require storage systems.
- Storage systems generally require larger land footprints.

**Adaptability to the Future:** Solar thermal has the potential to compliment multiple long-term efforts to reduce carbon emissions and improve energy efficiency; including steam to hot water distribution, electric boilers, heat pumps, renewable natural gas.

**Social Justice Concerns:** None.

**Behavior Change(s) Required:** None. Operates more efficiently and can be implemented better with hot water distribution systems as opposed to steam. Inclusion of storage system requires maintenance.

**Other Caveats:** None.

**Educational Opportunities:** Because projects are on campus, there is opportunity for students to take part in the planning, construction, and management of solar thermal. This would be an early introduction to a potentially scalable and cost-effective technology in the future.

**Research Opportunities:** Project design and implementation and opportunity to study coupling with other thermal strategies and PV systems.

**Co-Benefits:** Reduction and elimination of natural gas combustion has health benefits to campus and community health.

**Visible Marker(s) of Success:** Major reductions in natural gas purchases at a campus. Engagement with energy, construction, or architectural engineering students.

*Figure 31: Aalborg's Pit Thermal Storage System (12 pits) Beside Collectors.*

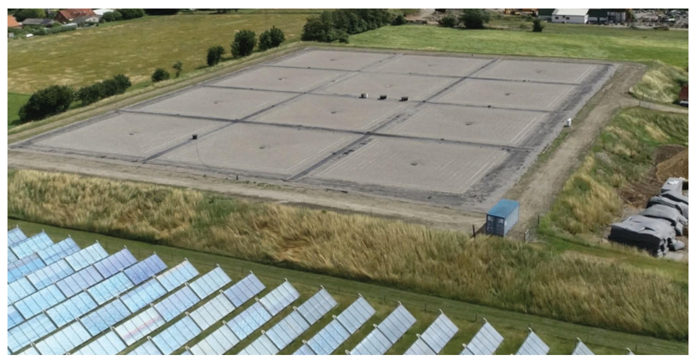

*Figure 30: Flat Plate Solar Collector Plant.*

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*Table 27: Cost and Technical Estimates for 1MW Project in PA (Aalborg).*

Some key figures for a roughly 1 MW (thermal) solar plant:

| # | Technical Items | Value | Unit | Comments |
|---|---|---|---|---|
| 1 | Thermal peak capacity | 1.05 | $MW_{th}$ | |
| 2 | Max. daily production | 7.18 | MWh | |
| 3 | Total solar collector gross area | 1,294 | $m^2$ | |
| 4 | Approx. land/rooftop footprint | 2,100 | $m^2$ | |
| 5 | Annual heat generation | 1,154 | MWh | |
| 6 | Annual specific heat generation per unit area | 892 | $kWh/m^2$ | |
| | | | | |
| | *Climatic Characteristics – State College, PA* | | | |
| 7 | Annual Global Horizontal Irradiance | 1,368 | $kWh/m^2$ | |
| 8 | Annual Direct Normal Irradiance | 1,265 | $kWh/m^2$ | |
| 9 | Annual Diffuse Horizontal Irradiance | 662 | $kWh/m^2$ | |
| 10 | Average annual ambient temperature | 50.5 | °F | |
| | | | | |
| | *Financial Items* | | | |
| 11 | Est. Capital Expenditure per unit area | 470 | $USD/m^2$ | Turnkey price for small pilot plant approx. 1,500 $m^2$ of collector area (*excl. thermal storage*) |
| 12 | Est. Capital Expenditure per unit area | 420 | $USD/m^2$ | Turnkey price for large scale installations larger than 10,000 $m^2$ of collector area (*excl. thermal storage*) |
| 13 | Est. Operational Expenditure | - | - | Expected to be 1%-2% of CAPEX yearly (mainly for running the circulation pumps) |

## I.18: STEAM TO HOT WATER DISTRIBUTION SYSTEM

**Location:** University Park

**Description:** Historically, steam with its high energy density seems to be the perfect vehicle to carry energy across large distances while using minimal electricity. For this reason, most buildings built at the beginning of the 20th century were developed around a steam distribution system. Today, many university campuses are a testimony to this heritage. However, with the goals to increase efficiency, reduce maintenance cost, lower GHG emissions, and utilize high efficiency/low-carbon energy sources, many universities are now looking at converting their aging steam distribution systems to low/ultra-low hot water distribution systems.

Steam is often produced to transport energy over large distances, when it arrives at the point of use, the temperature is always higher than what is needed to heat. Steam also flashes when brought back to atmospheric pressure, creating additional energy and water losses that weigh down network efficiency. Maintenance of steam systems is critical to ensure uninterrupted operation: steam traps need regular maintenance, condensate pumps and tanks must be replaced at regular intervals, and pressurized distribution and condensate piping will inevitably spring leaks. Operation of a steam network is also a critical and complex task that requires a skilled technical staff. Given all these factors many universities today are converting their (Generation 1) steam distribution systems to new low temperature (Generation 3) or ultra-low temperature systems (Generation 4). By converting to a hot water system these campuses are seeing a significant savings in both consumption, O&M cost, and GHG emissions. Moreover, a low-temperature hot water system allows integration of additional high-efficiency / renewable energy heating technologies such as heat pumps, solar thermal, heat recovery chillers, and geothermal. Below is a table showing the progression of heating distribution systems over the last century:

- **Generation 1** (1900's): Steam Distribution Systems (UPCampus)
- **Generation 2** (1930's): (230F-450F) High Temperature Hot Water Systems (Olmsted AF Base (PSU Harrisburg Campus))
- **Generation 3** (1980's): (160°F-230°F) Low- Medium Temperature Hot Water (Harrisburg Campus Today)
- **Generation 4** (2015): (120°F-140°F) Ultra Low Hot Water

**Universities that recently converted from steam to hot water:**

- ***Stanford University*** – In 2015, Stanford (15M sq ft) completed a conversion of its first-generation steam system to a third-generation hot water system, resulting in overall cost savings (20%), water savings (18%), and GHG reductions (50%).
- ***University of British Columbia*** – In 2015, UBC (15M sq ft) completed a conversion of its first-generation steam system to a third-generation hot water system, resulting in operational and energy cost savings ($5 million/year), thermal efficiency improvement (24%) and GHG reductions (22%).
- ***University of Rochester*** – In 2004, Rochester (12M sq ft) initiated a process to convert its first-generation steam system to a third-generation hot water system (70% completed as of today), resulting in thermal losses savings (24%).
- ***University of California, Davis*** – In 2017, UC Davis (11M sq ft) initiated a process to convert its first-generation steam system to a third-generation hot water system, hoping to save an estimated 30-50% in distribution losses, avoid spending $98 million of planned maintenance costs on the aging steam system, reduce O&M costs by 42%, while cutting GHG emissions by 30% and getting closer to its 2025 net-zero commitment.

The heating system at UP consists of two plants, the West Campus and East Campus Steam Plants. Steam is sent out to campus at two pressures 13 psig and 150 psig through an interconnected piping system. The distribution piping is all located underground in a combination of walkable tunnel, shallow tunnel, engineered pipe-in-conduit, and direct buried in an insulating powder.

In 2019, Penn State hired an outside engineering firm to perform a high-level screening analysis of the potential to convert the campus from a steam to heating hot water distribution system. The results of the study indicate that the conversion to heating water is cost effective and a more detailed study should be initiated.

**Emissions Reduction Potential:** 24,500 MTCO2e/year

**Capital Cost:** $130 million

**Operating Cost:**

- Avoided steam system repair cost: $67 million
- Annual Operational Savings: $3.3 million

**Maturity:** District heating hot water systems have been around since 1930's. The technology is proven and commercially readily available

**Advantages:**

- No steam manholes (currently over 230 manholes on campus), expansion joints, anchors, guides steam traps, pressure reducing stations, condensate pumps, lines, and vents.
- No condensate losses.
- Installed cost is about one-half to one-third the cost of steam.
- Energy efficiency would allow heating growth curve to extend 7+ years.
- Can be phased over 10-15 years to spread cost.
- Operator and technician safety, no climbing in/out of manholes to isolate lines and no dangerous cold line startup conditions.
- Able to utilize existing boilers & generation equipment at both campus steam plants.
- Future proof works well with many new potential low-carbon energy sources that produce low grade heat. Heat recovery chiller, solar thermal, fuel cells, geothermal, etc.
- Ability to be weaved around objects to assist with installation.

**Disadvantages:**

- Initial cost
- Building conversion cost
- Disruption of campus
- Process steam uses

**Risks and Uncertainties:** Proven technology and most future renewable energy sources utilize low grade heat that compliments a hot water system. Most campuses with hot water systems use the term "Future Proofing." Controlling capital costs of the installation to minimize additional costs associated with unknown conditions must be addressed during planning phase to successful manage cost risks.

**Behavior Change(s) Required:** This system does not require any changes to the steam generation equipment at the WCSP & ECSP.

**Other Caveats:** Required system for all of the low temperature thermal solutions, such as heat recovery chillers, shallow well geothermal, or solar thermal.

**Educational Opportunities:** The hot water distribution process on-site would provide University students and faculty with living lab learning opportunities.

**Research Opportunities:** The hot water distribution process on-site would provide students and faculty with living lab research opportunities.

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