# Options for Achieving a Carbon Neutral Campus by 2035

## Analysis of Solutions

Cornell University Senior Leaders Climate Action Working Group
September 2016

Cornell University

# Cornell University Senior Leaders Climate Action Group

## Committee Membership

(Co-Chair) Lance Collins, the Joseph Silbert Dean of Engineering
(Co-Chair) KyuJung Whang, Vice President for Infrastructure, Properties and Planning (IPP)
Beth Ahner, Professor of Biological and Environmental Engineering and Senior Associate Dean, College of Agriculture and Life Sciences
Jeffrey Bergfalk, Doctoral Candidate, Mathematics
Robert Bland, Associate Vice President for Energy and Sustainability
Edwin A. Cowen, Professor of Civil and Environmental Engineering and the Kathy Dwyer Marble and Curt Marble Faculty Director for Energy, David R. Atkinson Center for a Sustainable Future
Robert Howarth, the David R. Atkinson Professor of Ecology and Evolutionary Biology
Barbara Knuth, Senior Vice Provost and Dean of the Graduate School
David Lodge, the Francis J. DiSalvo Director of the David R. Atkinson Center for a Sustainable Future
Ryan Lombardi, Vice President for Student and Campus Life
Joel Malina, Vice President for University Relations
Alan Mathios, the Rebecca Q. and James C. Morgan Dean of the College of Human Ecology
Mark Milstein, Clinical Professor of Management and Director of the Center for Sustainable Global Enterprise at the Samuel Curtis Johnson Graduate School of Management
Mary Opperman, Vice President and Chief Human Resource Officer
Tishya Ravichander Rao ’18, Urban and Regional Studies in the College of Architecture, Art and Planning
Bill Sitzabee, Associate Vice President for Engineering and Project Administration
Paul Streeter, Vice President for Budget and Planning
Sarah Zemanick, Director of the Campus Sustainability Office

## Additional Contributors

Steve Beyers, Service Team Leader, Facilities Services Engineering, IPP
Sarah Brylinsky, Sustainability Communications & Integration Manager, Campus Sustainability Office
William Schulze, Robinson Professor in Applied Economics and Management

# Contents

# Executive Summary

In March 2016, Provost Michael Kotlikoff charged the Senior Leaders Climate Action Group (SLCAG) to analyze viable energy alternatives for the Ithaca campus to achieve carbon neutrality by 2035. Reducing energy demand while adapting to renewable energy sources will require innovative technological solutions, a significant increase in capital investment in renewable energy sources, and broad support and engagement from all members of the campus community.

Sustainability is a signature area of excellence at Cornell University. Its faculty, students, staff and alumni have a wealth of knowledge, and tapping into their expertise will be critical to meeting these ambitious campus goals. The choices Cornell makes today to power a carbon-neutral campus tomorrow will involve real costs. These investments would insulate Cornell from unknown future volatility in fossil fuel markets and associated carbon fees. Nevertheless, they must be carefully considered in the context of the University's need to advance its full academic mission, including the ability to offer the best and most cost-effective education for its students, and the creation of new knowledge that advances society and serves the citizens of New York state. It is a delicate balance.

In addition to assessing the single bottom line of proposed solutions, this report uses social costs as a measure of the true impact of University carbon use in Ithaca and beyond. It also introduces a new greenhouse gas assessment to account for the impact of methane leakage from natural gas purchased by Cornell. On the time scale for achieving our carbon neutrality goal, reducing the impact of leaked methane has the highest impact on reducing climate change. It is important to note that this report is not a definitive plan of action; rather, it is a set of recommendations for discussion, and will require input from the campus and the surrounding community. Proposed solutions include:

- Invest immediately in reducing energy demand through support for and advancement of our energy conservation programs;
- Make preliminary investments in transitioning to a low-carbon footprint campus energy supply;
- Set goals and explore options to secure external funding;
- Pursue energy solutions in partnership with local and regional entities;
- Adopt rigorous building energy standards and project approval processes during retrofits, deferred maintenance projects, and new construction to create only "high-performance buildings" on campus;
- Prioritize development of infrastructure to support a campus fleet of clean-fuel vehicles and replace the existing fleet accordingly;
- Evaluate Earth Source Heat and ground source heat pumps as heating solutions;
- Strive for 100 percent of the campus electric supply to come from renewable sources;
- Seek campus-wide behavioral change through programs such as Think Big, Live Green and other campus engagement programs; and
- Ensure all students graduate with basic climate literacy.

Potential timeline for implementing options discussed in this report:

| Today | | 2022 | 2027 | 2035 |
|---|---|---|---|---|
| - Energy conservation<br>- Building standards<br>- Campus engagement<br>- Climate literacy<br>- Fleet solutions | - Earth Source Heat (ESH) test well<br>- Heat pump evaluations<br>- Renewable power projects | - Begin full ESH, if viable or alternate GSHP option<br>- Revise Climate Action Plan, including new energy path forward | - Fully implement campus heating solution<br>- Advance other carbon reduction efforts | - Reach carbon neutrality with full participation from the campus community |

We believe the campus, local community and region are partners in helping to reduce our carbon footprint, and we must consider and pursue solutions that ensure a thriving, resilient and sustainable future for Ithaca, New York state, and, where possible, the world.

This report analyzes opportunities for Cornell's Ithaca campus to achieve carbon neutrality in campus energy by 2035. It builds on the ongoing *Climate Action Plan* and the *Acceleration Working Group Report (2014*) among other planning documents, and can be considered a new tool for decision-making. To date, Cornell has already achieved a 30 percent reduction in campus emissions. The future path to carbon neutrality will require Cornell to pursue:

1) building and infrastructure efficiency through energy conservation (campus energy demand)
2) solutions that reduce our carbon footprint for heating, cooling and electricity (campus energy supply)
3) reducing emissions from commuting and business travel (transportation)
4) creating a culture of sustainable behavior and advancing climate literacy (campus engagement)

Because campus building energy needs comprise at least two-thirds of the University's carbon footprint, this report focuses on solutions for campus energy demand reduction and renewable supply, numbers one and two above, complemented by campus engagement and climate literacy programs, number four. Some proposed solutions must be maintained or initiated today, while others can be explored in the coming decade.

**Today**, every member of the campus community must be empowered to make changes in the way we do business in order to reduce our energy demand, while gaining the climate literacy necessary to understand and value the costs and opportunities of making sustainable changes. Cornell must continuously reduce the campus energy demand by strengthening energy conservation and green building standards across campus, and by introducing decision-making processes that value the true cost of carbon during purchasing, planning, building, retrofitting and other operational areas.

**Over the next five years,** the University must make decisions about how to invest in reducing the carbon footprint of the campus energy supply. The University should continue to pursue preliminary tests for a promising solution to campus heating needs – Earth Source Heat – while also ensuring the campus will be positioned to pursue an alternative, proven heating solution, such as ground source heat pumps, should Earth Source Heat prove infeasible. Investments in reducing emissions from transportation also should be undertaken immediately.

To assist in moving forward on both short- and long-term solutions, this report provides the following tools:

1. **Solutions for Evaluating Projects:** This section introduces a framework for understanding the true cost of carbon emissions as part of the financial evaluation for projects at Cornell. The three components are:
   a. Applying a "social cost of carbon" to each ton of greenhouse gas (GHG) emissions;
   b. Introducing a "quadruple bottom line analysis" to evaluate the costs and benefits of projects; and
   c. Evaluating the climate impact of Cornell's purchased natural gas, by assessing methane leakage from natural gas production and distribution.

2. **Solutions for Today:** A proposed set of solutions that reduce and maintain reductions to campus energy needs through green building, energy conservation, transportation and engagement solutions.

3. **Solutions for Tomorrow:** A menu of options for supplying the heating, cooling and electricity needs of the campus with low-carbon technologies.

Each step on the path to neutrality must consider the unique potential – and commitment – for Cornell to serve as a model for transitioning to a sustainable campus. Campus energy neutrality, like other climate efforts, will require engagement from every member of the community. The passions of students, faculty and staff in research opportunities, multidisciplinary teaching, and living laboratory projects should be considered actively in the next phase of decision-making.

## Technologies Explored in the Report

The options for the campus energy supply described in this report include:

| | |
|---|---|
| *Air Source Heat Pumps* | Electrically powered equipment that transfers heat from outdoor air using a refrigerant system with compression and condensing; |
| *Biomass Combustion* | Burning renewable biomass resources (wood or non-food agricultural products) directly in solid-fuel boilers to generate heat; |
| *Biomass Gasification* | Converting renewable biomass resources (wood or non-food agricultural products) into gas to burn in order to generate heat and electricity; |
| *Earth Source Heat* | Accessing the renewable heat stored in the basement rock below the Earth's surface by circulating water through well sets and heat exchanger equipment located at the surface – commonly known as an enhanced geothermal system; |
| *Ground Source Heat Pumps* | Electrically powered equipment that transfers heat from the ground using a refrigerant system with compression and condensing. Unlike Earth Source Heat, ground source heat pumps use horizontal or vertical wells no more than 400-500 feet deep; |
| *Nuclear* | Utilizing the energy released from splitting atoms (nuclear fission) in a small modular reactor to generate heat and electricity; and |
| *Wind, Water, and Solar* | Developing facilities to convert the energy in wind, solar irradiance and moving water into electricity using turbines or solar photovoltaic panels. |

## Baseline for Financial Comparison: Business as Usual

Business as usual is not a "solution," as it does not advance Cornell toward carbon neutrality. That said, it is the obvious baseline from which to compare the costs and benefits of campus energy solutions presented in this document. Cornell University has an annual equivalent cost for heating and powering the campus of $42 million, not accounting for any costs of carbon, as explained in *Solutions for Evaluating Projects* on page 8.

# Our Challenge

## Cornell's Carbon Footprint Today

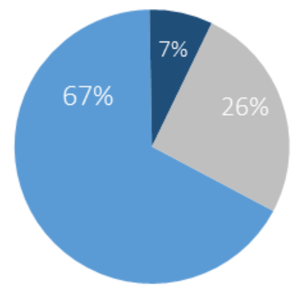
Cornell is responsible for a carbon footprint of approximately 214,000 metric tons of CO2 equivalent (MT CO2e) annually, before accounting for upstream methane leakage (estimated to be an additional 580,000 MT CO2e, see page 9). Carbon neutrality means reducing these emissions to net zero[1].

Campus energy needs account for nearly two-thirds of Cornell's carbon dioxide footprint, and even more of Cornell's total carbon footprint when upstream methane leakage is included. Solutions for carbon-neutral energy should strive to meet the current equivalent, which is a combined 179,000 MTCO2e (Figure 1) from power produced and purchased.

Figure 1:

Cornell Ithaca Campus

**2014 Greenhouse Gas Inventory**




213,650

Total Net Emissions

(MT CO2e)

| | |
|---|---|
| **Campus Energy** | **179,303** |
| • Produced Power | 161,806 |
| • Purchased Electricity | 17,497 |
| • **Transportation** | **62,142** |

Broadly, Cornell's challenges to finding energy solutions include:

- Designing a heating system that can handle the high energy demands of the state-of-the-art research labs and facilities at Cornell, and the extreme weather demands in Ithaca that will likely grow with climate change;
- The current low cost of fossil fuels, which makes it difficult to justify renewable energy projects based simply on a return-on-investment analysis. For example, Cornell's natural gas rate is currently half the national price average;
- Modifying capital planning and financing processes across the University to consider the true cost of carbon emissions; and
- Reducing the energy demand of campus buildings and increasing the number of high-performance buildings.

There are also many benefits to pursuing the solutions proposed in this report, beyond mitigation of the Cornell campus impact on climate change. These include:

- Advancement of Cornell's academic mission through research, teaching and public engagement focused on the social, environmental, technological, health and economic aspects of achieving carbon neutrality;
- Fulfillment of Cornell's land-grant mission to New York state by increasing regional energy independence;
- Enhancement of the Cornell brand as a campus demonstrating practical ways to reduce carbon from energy use in spite of the challenges listed;
- Pride and satisfaction among all members of the Cornell community in "walking the talk" on sustainability;
- New revenue streams from external fundraising and energy conservation savings; and
- Reduced financial exposure to increasingly unstable energy markets and compliance regulations.

Finally, it is important to note that in every area of Cornell's carbon impact, faculty, staff, and students across campus, in all disciplines, are making contributions and decisions that directly impact energy and resource use and, therefore, Cornell's overall carbon footprint. The solutions described in this report are both technical and require engagement from the people across campus who use energy for their campus research, teaching, work and residential needs. Achieving climate change literacy for all campus community members will be essential in order for Cornell to meet its neutrality goal with understanding and support from the community, in a manner aligned with its educational and research mission.

[1] Note that total emissions for the university are lower than the sum of categories listed here. Cornell claims about 27,795 of emissions deductions each year from forest management and exported electricity.

# Solutions for Evaluating Projects
## Accounting for the True Cost of Carbon

The three topics in this section provide a framework for ensuring the University can "value" the true impact of climate change costs and mitigation strategies. Adjustments to the way Cornell evaluates costs when considering projects will ensure climate impacts are properly accounted for against the cost, and risk, of business as usual.

### The Social Cost of Carbon

Climate change has and will lead to detriments to human health and well-being in many ways, including the spread of disease and decreased food production, coastal destruction, social and economic disruption from extreme and unpredictable weather, and from natural events such as fires, droughts and floods. The social cost of carbon calculates the economic toll of these impacts and allows the University to compare the costs of implementing neutrality solutions against the costs of using fossil fuels that contribute to climate change. It also allows Cornell to evaluate the future cost or risk of carbon charges. The report applies an average charge of $58 per metric ton of CO2e emissions to offsets for all direct emissions in all financial scenarios, and to the methane leakage models described below. This number was derived from recommendations by the U.S. Environmental Protection Agency and in consultation with Cornell researcher William D. Schulze. See *Appendix A: Suggested Economic Parameters for the Carbon Neutral Campus Alternatives Report* for further details.

### Using a Quadruple Bottom Line

The traditional measure of project viability for the campus is based on a single, financial bottom line. A method more in line with sustainable decision-making uses a quadruple bottom line that considers four impact areas:

1. Does the solution help Cornell fulfill its academic mission and **purpose**?
2. Does it meet the needs of **people** on campus, in the community and in the world?
3. Will it enhance overall **prosperity** for the campus and our region?
4. Does it support a sustainable **planet**?

Table 1: Quadruple Bottom Line Framework

| | |
|---|---|
| Purpose | *Supports Cornell's Mission*<br>How does the solution align with Cornell's educational and land-grant missions? Does it create research and teaching opportunities? Is it aligned with existing programs? Will the solution attract research funding? Does it increase Cornell's reputation as a global institution addressing climate change and finding solutions to challenging research questions across disciplines? |
| People | *Supports Community Goals and Potential*<br>Is the solution a useful, scalable option to share with others? Does it help regional carbon reduction efforts? Does it create jobs? Does it increase or decrease quality of life through visual, infrastructure, transit or community resource development? |
| Prosperity | *Supports Financial Stability*<br>What are the short-term, long-term, and socialized costs to the project? Does a solution mitigate future costs or uncertainties? Will this solution allow Cornell to plan for today and its future in an economically feasible way? |
| Planet | *Supports Environmental Needs*<br>How does this solution ensure that Cornell fulfills its commitments to environmental sustainability and mitigating climate impact? What is the carbon-reduction impact of this solution? Are there additional environmental and ecological benefits or risks related to land use, water, biodiversity, air quality or waste? |

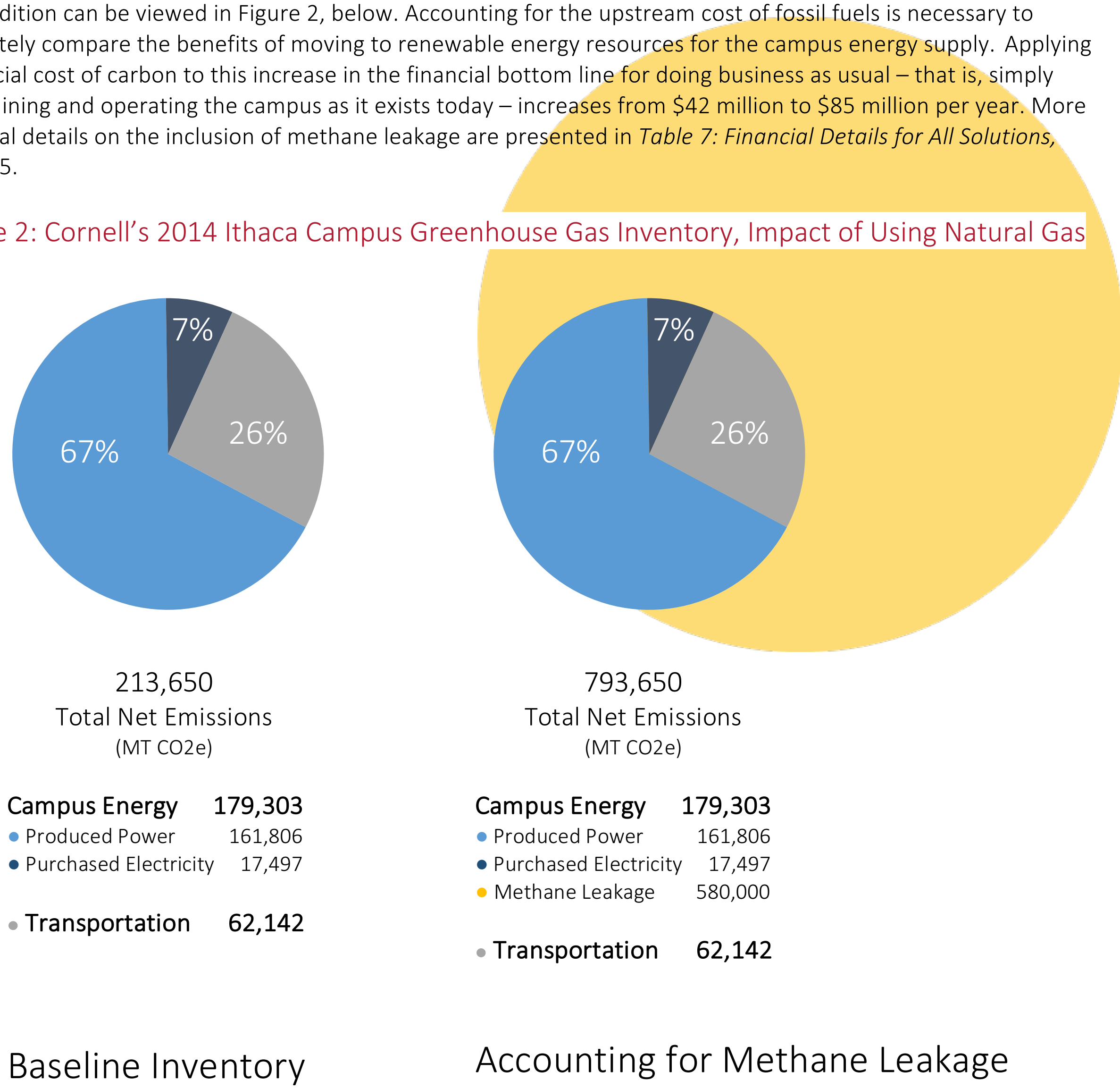
*Quadruple Bottom Line, cont.*

For the purpose of this report, members of the committee used a quadruple bottom line analysis in addition to assessing the overall financial cost and technical feasibility of proposed solutions that can be seen in *Table 7: Financial Details for All Solutions*, page 15. Quadruple bottom line ratings in each section use a color-coded system. (● = High Benefit, ● = Neutral, ● = Negative/Low/No Benefit). Cornell must further develop, and adopt, quadruple bottom line thinking across departments and decision-making at all levels.

## Assessing the Climate Impact of Natural Gas

In order to account for the full impact of fossil fuel use to meet campus energy needs, it is important to consider the impact of methane leakage during production of the natural gas purchased by Cornell. Natural gas production and delivery systems, particularly in the Northeast United States, have a high percentage of methane leakage. The impact of methane on climate change is calculated to be 86 times higher than that of carbon dioxide over a 20-year period, making it an important area of impact to consider. Accounting for the impact of methane leakage adds 580,000 metric tons of carbon dioxide equivalent (MTCO2e) to Cornell's existing energy footprint. A comparison of this addition can be viewed in Figure 2, below. Accounting for the upstream cost of fossil fuels is necessary to accurately compare the benefits of moving to renewable energy resources for the campus energy supply. Applying the social cost of carbon to this increase in the financial bottom line for doing business as usual – that is, simply maintaining and operating the campus as it exists today – increases from \$42 million to \$85 million per year. More financial details on the inclusion of methane leakage are presented in *Table 7: Financial Details for All Solutions,* page 15.

Figure 2: Cornell's 2014 Ithaca Campus Greenhouse Gas Inventory, Impact of Using Natural Gas



# Solutions for Today

## Campus Energy Demand and Community Engagement

Although the campus square footage has grown by 20 percent since 2000, energy demand has remained flat. Maintaining and even improving on this trend of increased energy efficiency over the next 20 years will be critical for meeting the carbon neutrality goal.

## Building Solutions

All campus buildings can be built, maintained, and operated to minimize energy use and greenhouse gas emissions. Smart, energy-efficient buildings will minimize disruptions in service, reduce energy costs and the need for new sources of energy supply, and reduce wear and tear (and therefore maintenance expenditures) on the campus energy infrastructure.

1) Build High-Performance Buildings

   High-performance buildings reduce costs and emissions by using less energy and by using energy more efficiently. Although in some cases the up-front costs for such buildings may be higher, the planning, project approval, and design process for new construction and renovations can and should analyze long-term benefits and savings, and use the quadruple bottom line (Table 1, page 8). This solution proposes principles, analysis and standards that the provost, deans, and unit leaders can use to understand and justify the benefits of high-performance buildings in the context of their own needs and the institution's energy footprint. The U.S. Green Building Council notes a poor correlation between energy-efficient design and per square foot building costs – for example, energy-efficient facades are frequently cost effective, while some efficient windows are expensive. Nonetheless, a conservative assumption can be made that $20 per square foot additional up-front investment would achieve 20 percent lower energy use for campus renovations.

2) Conserve Energy in Existing Buildings

   Cornell's energy conservation efforts to date have been successful in reducing energy use in existing buildings by modernizing building envelopes, building automation and control systems, heat recovery systems and lighting systems. Conservation-focused preventive maintenance on these systems further reduces usage and maintains performance.

   The ongoing Energy Conservation Initiative has negated the energy impacts of new buildings constructed over the past 15 years through capital improvement projects in existing buildings that retrofit their systems with the latest features. These projects include lighting retrofits, heat recovery from exhausted air, and installing occupancy sensors and programmable automated building controls. All projects to date have had a return on investment of five to seven years. Campus studies show that significant cost-effective opportunities still abound. Table 2 illustrates a hypothetical scenario (based on actual results to date) where $50 million is invested to reduce the campus heating load by 10 percent, and electricity needs by 5 percent, generating a significant financial savings. A longer payback period than is currently supported by the university, up to 15 years, would be needed to capitalize on the significant remaining opportunities.

   The Energy Conservation Initiative projects are complemented by continuous "re-commissioning" by a team of building-control technicians who routinely check and optimize building systems to maintain peak performance and further reduce energy use. Without this maintenance, building performance can degrade significantly over a period of just a few years. The current program has a $1.5 million annual cost but saves more than $3 million a year in energy use. Table 2 illustrates a hypothetical scenario of increasing the staff and budget equivalent to $1 million per year, netting over $0.3 million in annual savings and a sustained 5 percent reduction in heat and cooling.

Table 2: Campus Energy Demand Reduction Illustrative Scenarios

| Solution | Up-front Capital Cost | Annual Operating Cost | Annual Equivalent Cost* |
|---|---|---|---|
| Energy Conservation | $50M (over 10 years) | $(3.4M) (Savings) | $(0.4M) (Savings) |
| Conservation Maintenance | - | $(0.3M) (Savings)** | $(0.3M) (Savings) |

*Annual Equivalent Cost = Annual Operating Cost + Capital Cost spread over 30 years
**Investing an additional $1M/yr in conservation maintenance generates enough energy savings for a net $0.3M/yr in savings

## Transportation Solution

In addition to the energy needs for campus buildings and infrastructure, Cornell is also responsible for the energy needs of campus vehicles and the emissions associated with commuting. Many of the solutions for reducing carbon in the energy supply outlined later in this report present opportunities to introduce more clean-fuel vehicles to the Cornell fleet and make such vehicles a viable option for commuting to campus.

### 1) Increase Electric Vehicle Capacity

This analysis looked at expanding electric vehicle charging stations on campus to support a clean-fuel fleet, and incentivizing use of such infrastructure by the Cornell community. A scenario such as that presented in Table 3 below has the potential to reduce emissions from transportation by about 2 percent for every 500 fleet/commuter vehicles converted to clean fuel. Cornell owns about 700 vehicles and accounts for emissions from about 9,000 commuter vehicles. There are multidisciplinary opportunities for collaboration with faculty on clean-fuel projects, and the potential to further existing partnerships with local and regional governments and NGOs for grants for infrastructure and community engagement. A pending Comprehensive Transportation Plan will provide further analysis of solutions for reducing transportation emissions and increasing support for alternative modes of transportation.

Table 3: Electric Vehicle Charging Station Illustrative Scenario
Charging stations to support 500 vehicles

| Solution | Up-Front Capital Cost | Annual Operating Cost | Annual Equivalent Cost |
|---|---|---|---|
| Electric Vehicle Charging Stations | $1.5M | $0.1M | $0.2 million |

## Campus Engagement Solutions

Cornell will need to engage and educate students, faculty and staff on their collective role, and opportunities for innovation, research and improvement to reduce energy use and greenhouse gas emissions. High-performance buildings rely on occupants who understand the impact of their personal behaviors and who use their buildings to maximum efficiency. Occupant interaction with building systems also provides unique learning and research opportunities.

### 1) Campus Resource User and Building Occupant Engagement (Think Big Live Green)

The Think Big Live Green (TBLG) campaign engages members of the Cornell community as collaborators in creating a sustainable campus through the College Engagement Program, student EcoReps, faculty and staff Green Ambassadors, Green Office Certifications, Green Lab Certifications, and the Campus Building Dashboard. TBLG has produced significant, sustained energy savings. The proposed solution, illustrated in Table 4, includes an additional $50,000 in the TBLG budget per year, to achieve an energy reduction of 1 percent and a savings of $500,000 annually, based on actual results to date. Think Big Live Green supports research on the initiation and maintenance of behavior change.

### 2) Campus Climate Literacy Engagement

Cornell should ensure that all students, and ideally all members of the campus community, have a basic literacy in climate change, including an understanding of their influence on climate and climate's influence on them and society. An educated community will implement campus conservation programs and innovate new solutions. This solution draws on a 2014 proposal by the Climate Action Plan Acceleration Working

Group that would require an investment of $100,000 per year and an additional staff person to manage a variety of climate curricular and literacy initiatives. Funding would be used for mini-grants and software/ programming to expand the integration of climate learning goals into the student and campus experience.

Table 4: Impact of Engagement Investments

| Solution | Annual Implementation Cost | Benefits |
|---|---|---|
| Think Big, Live Green | Current resources + $50,000 additional budget | $500,000 (Saving), 1% energy reduction per year |
| Campus Climate Literacy | $100,000 + 1 new FTE staff | Engaged campus, maintain baseline |

# Solutions for Tomorrow

## Meeting Campus Energy Supply

The University has already greatly reduced its carbon dioxide footprint by transitioning away from coal, by combining heat and power generation at the Central Energy Plant, and by providing for the cooling needs of the campus using the Lake Source Cooling plant. However, the natural gas used to fuel the Central Energy Plant is still a fossil fuel – and contributes to climate change, particularly because of high methane emissions. Cornell will need to consider low-carbon alternatives to meet the heating and power needs of the campus. It is assumed that cooling needs will continue to be met through Lake Source Cooling in all scenarios.

This section presents five full and partial solutions:

A. Solutions for heating <u>and</u> powering
B. Solutions for heating only
C. Solution to power, through wind, water, and solar
D. Options for offsetting emissions
E. Non-feasible options

See *Appendix B: Assumptions for all Campus Energy Solutions* for full pricing, technology, operational and future forecast assumptions. A detailed review of the assumptions can be found in the *2016 Climate Neutral Campus Energy Alternatives Report (CNCEAR)*. CNCEAR analyzed the technical concept and cost for each solution. Table 7 on page 15 provides a summary of the financial needs projected for each solution for meeting campus energy supply. The table breaks down the capital cost, annual cost, and cost of offsets needed for each of the following solutions in this section of the report.

## Solutions for Heating and Powering the Campus

The following solutions – numbers one through six – present opportunities for Cornell to reduce the carbon intensity, and/or increase the efficiency of campus energy systems by meeting both the heating and power needs.

### 1) Earth Source Heat Combined with Wind, Water, and Solar and Biomass

Earth Source Heat (ESH) is an emerging technology that proposes to utilize the heat energy deep beneath the Earth's surface to generate district heating and possibly some electricity. A combined solution is proposed here that would use biomass to meet peak heating needs; and wind, water, and solar to meet campus electrical needs. See *Appendix D: Biomass Peaking with Earth Source Heat Solutions* for more detail on biomass peaking. Biomass gasification was found to be the most financially feasible solution for this analysis, though biomass combustion could be explored with further research and financial modeling. This total solution is overall ranked with high feasibility and quadruple bottom line ratings due to high carbon reduction, academic and research potential, and overall suitability to regional climate and geographic constraints.

Earth Source Heat is an unproven, yet promising, technology for Cornell to reduce emissions in the largest source of its carbon inventory. The experimental nature of this technology creates the opportunity to attract research and development funding through a consortium of public and private partners. Should Cornell successfully demonstrate Earth Source Heat, it could also play a role in developing a new industry. Furthermore, research questions remain about the impacts and sustainability of using biomass for peaking and will require further evaluation before full implementation. Should Earth Source Heat prove unfeasible, other solutions could be pursued in time to meet the carbon neutrality goal. Those options would need to commence by 2025 if the University is to achieve neutrality by 2035.

2) Earth Source Heat Combined with Wind, Water, and Solar
This solution assumes Earth Source Heat would be sized to meet the campus peak load, with electricity needs met through wind, water, and solar projects. This solution offers the similar benefits as solution one (Earth Source Heat combined with wind, water, solar and biomass), and is equally feasible. There are tradeoffs to consider between the two solutions in up-front capital costs and annual operating costs, in addition to resolving research questions about the impacts and sustainability of using biomass for peaking that will require further evaluation before full implementation of either solution.

3) Ground Source Heat Pumps Combined with Wind, Water, and Solar
Ground source heat pumps use a refrigeration cycle and electric power to exchange heat with the Earth, relatively close to the surface, extracting heat from relatively cool ground for heating during the winter. Ground source heat pumps provide a heating solution that will increase electricity needs for the campus. This technology will be used on the Cornell Tech campus. Ground source heat pumps, combined with wind, water and solar, is the next-best solution after Earth Source Heat, should Earth Source Heat prove infeasible. If ground source heat pumps were developed as a district system, it would require a large geothermal well-field constructed on adjacent campus land. A location for this well field does not require open space; well fields are commonly placed under parking areas. Ground source heat pumps can also be deployed during building renovations on a building-by-building basis, or as smaller district heating systems linking a subset of buildings. Before full implementation of this solution, further analysis of the costs and funding implications for the other approaches is needed.

4) Air Source Heat Pumps Combined with Wind, Water, and Solar
Air source heat pumps require refrigeration and electric power to exchange heat with the ambient air. This report analyzes a scenario where heat pumps would be centrally located at up to four facilities. Building-by-building deployment and funding during renovation and new construction may also be considered for this technology.

Overall, it is not as strongly recommended as ground source heat pumps due to overall feasibility of the technology in very cold weather resulting in costly increases in electricity demand at campus-scale. The use of either heat pump technology would eliminate the need for the Central Energy Plant. Electricity use would increase, making a combined solution with wind, water and solar necessary.

5) Nuclear
This report analyzed the feasibility of a small modular reactor. It is the only stand-alone technology that can generate all of the heat and electricity needed for the campus. Concerns include timing of the technology availability (suitable for institutional application), permitting challenges, disposal of nuclear waste, local acceptance and approvals, and environmental assessment challenges. If nuclear energy were to be pursued, further analysis of the potential for alternate micro-reactor technology and continued use of the existing steam distribution is recommended.

6) Business as Usual, with Purchased Offsets
In this scenario, Cornell continues on a path of purchasing electricity from the grid, which includes a high percentage of natural gas to power the Central Energy Plant for both heating and energy needs, and purchases of offsets to balance carbon emissions. Though this solution provides the least disruption to existing campus systems, it has potentially high risk from unknown future carbon offset market costs, and has a substantially higher overall price tag with little or no benefit to People and Purpose bottom lines.

## Table 7: Financial Details for All Solutions (in millions)

| Solutions for Campus Energy Supply, Financial Details | | | Up-Front Capital Cost | Annualized Capital Cost | Annual Operating Cost | Annual Offsets Cost | **Annual Equivalent Cost** | Accounting for Methane Leakage: Annual Offsets Cost | Accounting for Methane Leakage: **Annual Equivalent Cost** | QBL Analysis: Purpose | QBL Analysis: Prosperity | QBL Analysis: People | QBL Analysis: Planet |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | (AEC = Annual Cost + Capital Cost spread over 30 years) | | | | | | | | | | |
| Business as Usual (for comparison, not a solution) | | | $42 | | $42 | | | | | | | | |
| *Heating & Powering Solutions* *No offsets needed* | 1. | Earth Source Heat, WWS, Biomass | $700 | $47 | $24 | - | **$71** | - | **$71** | 🟢 | 🟡 | 🟡 | 🟢 |
| | 2. | Earth Source Heat, WWS | $730 | $50 | $22 | - | **$72** | - | **$72** | 🟢 | 🟡 | 🟡 | 🟢 |
| | 3. | Air Heat Pumps, WWS | $930 | $62 | $28 | - | **$90** | - | **$90** | 🟡 | 🔴 | 🟡 | 🟢 |
| | 4. | Ground Source Heat Pumps, WWS | $920 | $55 | $26 | - | **$81** | - | **$81** | 🟢 | 🔴 | 🟡 | 🟢 |
| | 5. | Nuclear | $700 | $42 | $34 | - | **$76** | - | **$76** | 🔴 | 🔴 | 🔴 | 🟡 |
| *All offsets needed* | 6. | Business as Usual + Carbon Offsets | - | - | $42 | $10 | **$52** | $43 | **$85** | 🟡 | 🔴 | 🔴 | 🔴 |
| *Heating Solutions* *Offsets for Electricity* | 7. | Earth Source Heat, Biomass | $430 | $31 | $36 | $2 | **$69** | $10 | **$78** | 🟢 | 🔴 | 🟡 | 🟢 |
| | 8. | (Only) Earth Source Heat | $470 | $36 | $34 | $2 | **$72** | $10 | **$80** | 🟢 | 🔴 | 🟡 | 🟢 |
| | 9. | (Only) Air Source Heat Pumps | $490 | $28 | $47 | $4 | **$79** | $17 | **$92** | 🔴 | 🔴 | 🟡 | 🔴 |
| | 10. | (Only) Ground Source Heat Pumps | $600 | $34 | $40 | $3 | **$77** | $13 | **$87** | 🔴 | 🔴 | 🟡 | 🟡 |

As a simplification for comparison, the up-front capital cost in Table 7 assumes all financing would be provided by Cornell in a single year of implementation (2027). In reality, any solution would be phased in over a number of years – at least a decade – giving the University time to secure funding in stages. If Cornell can capitalize solutions with external funds, annual operating costs drop <u>below</u> business as usual.

<u>Annual Equivalent Cost</u> is a combination of the annual costs and capital cost (up-front cost) spread over 30 years. The AEC costs are *instead of* (not in addition to) Cornell's current business as usual cost provided for comparison. AEC is an easy number to use for comparing solutions, since each solution varies widely in proportion of capital and operating costs, but does not account for realities like project phasing (building segments slowly over time, with potentially better pricing as it becomes more available), or the prospect of external funding sources. It includes residual value and capital expenditures during the life of the analysis period. Existing debt is not included in business as usual.

<u>Up-Front Capital Cost</u> is the price to *install* each solution, including any updates to campus systems while <u>Annual Operating Cost</u> is the price to *operate and maintain* the system each year. The <u>Annual Offsets Cost</u> is the price to *purchase offsets for remaining emissions* from purchased grid electricity. It assumes a social cost of carbon for purchased offsets (not mission-linked offsets) as discussed in *Solutions for Evaluating Projects*.

The accounting for methane leakage Annual Equivalent Cost and Annual Offset Cost columns show the increase in cost if Cornell accounts for upstream methane leakage, and a sample quadruple bottom line analysis provides a ranking of 🟢 = High Benefit, 🟡 = Neutral, 🔴 = Negative/Low/No Benefit as prepared by the Senior Leadership Climate Action Working Group

## Budgetary Context

Solutions for heating and powering the campus that eliminate carbon sources (see Table 7, items 1-5) involve capital investments that could exceed $700 million. An investment of this magnitude would not be possible within the operating budget, and new debt on this scale would significantly constrain and reduce the amount of debt capacity available for investment in other high-priority academic and infrastructure support capital needs, including existing space renovations on the Ithaca, Weill Cornell Medicine and Cornell Tech campuses. Moreover, the estimated debt service on a loan of $700 million, which is more than $40 million per year, is equivalent to 2-3 percent of the total annual operating cost or approximately 17 percent of the current amount spent on faculty salaries. An internal investment of this magnitude would cause significant pressure and trade-offs within the operating budget, and would not be possible to build into the utility costs of the academic units without large offsetting cuts. Consequently, solutions that have the potential for significant external funding should be considered more feasible and given priority.

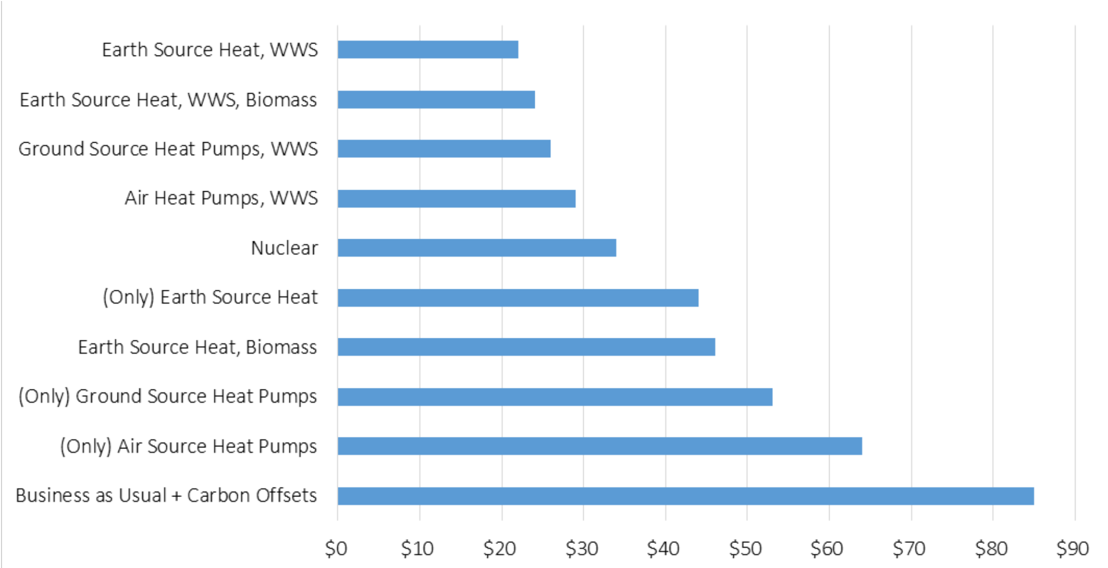
Table 8 imagines a scenario in which external funding is secured for a portion of capital costs. For instance, if the University could secure $480 million in external funding, the solution is on par with the cost of running the campus today – with all of the additional benefits of achieving the campus carbon neutrality goal.

### Table 8: Financial Comparison Scenario for Earth Source Heat, WWS and BAU

| Financing Scenario for Solution #2 | Capital Cost – External | Capital Cost – Cornell | Annual Operating Cost | **Annual Equivalent Cost** |
|---|---|---|---|---|
| Business as Usual Today | | | $42 | $42 |
| 2. Earth Source Heat, WWS | $480 | $250 | $22 | $42 |

Figure 3 further demonstrates this principle by illustrating that the annual operating costs of full solutions that replace the business as usual, natural gas fueled energy generation with renewable sources are, in fact, the least expensive. Solutions that have the potential to attract significant external funding for capital costs, therefore, have the potential to be cost effective for the university.

Figure 3: Annual Operating Costs of Solutions ($ Millions / Year)




## Solution for Powering the Campus (Wind, Water, and Solar)

Assuming that 50 percent of grid-sourced power will come from renewable resources by 2030 as per the New York Clean Energy Standard, Cornell will need to either purchase offsets for the remaining 50 percent or create renewable-energy resources. The annual electric needs of the campus will be dependent on the heating solution – for instance, ground source heat pumps may increase the campus electricity need by 43 percent. All solutions except nuclear in *Section A: Heating and Power*, assume use of the following proposed wind-water-solar solution. See *Appendix C: Assumptions for Wind, Water, and Solar* for further detail on financial assumptions made here.

The proposed solution for creating new renewable energy resources assumes Cornell will maintain existing hydro facilities with no new water development, and supply the additional need through 50 percent wind and 50 percent solar sources. Wind, water, and solar are proven technologies with readily available implementation. Sited properly, they have a relatively benign environmental and community impact. Community concerns about siting facilities, particularly wind turbines, and storage capacity to mitigate the intermittency of these resources remain a challenge.

- *Wind*: To be economical, turbines must be sited for maximum power generation, which in New York state typically requires siting on high ridges or along expansive water bodies. Tompkins County has marginal wind resources. Projects should explore off-shore sites along Lake Erie or Lake Ontario, or windier ridges in other parts of the state.

- *Water (Hydroelectric Power):* No significant additional hydropower resources are proposed for this scenario. Cornell has an existing hydroelectric plant in Fall Creek that has been recently upgraded to deliver about 6,000 MWh per year, or about 2.7 percent of the campus annual electric needs, and should be continually operated.

- *Solar*: Including projects currently underway, solar photovoltaics (solar PV) will supply the equivalent of 7 percent of campus electric needs by the end of 2016. The upcoming expiration of federal tax incentives, reduced state incentives, and interconnection challenges are making it difficult to develop solar projects in the near future, though a changing regulatory environment emerging in New York state may improve feasibility.

## Solutions for Heating the Campus, Only

The following options meet the heating needs for the campus and therefore provide only a percentage of carbon-footprint reduction for campus energy. The annual equivalent costs projected would be total cost needed to meet neutrality – in other words, that the remaining carbon footprint from grid-purchased power would be met through purchased offsets.

7) Earth Source Heat Combined with Biomass
This solution would replace the Central Energy Plant with a set of deep geothermal wells and a biomass boiler plant to manage 3-9 percent of the peak load. Similar to Earth Source Heat + biomass + wind, water and solar, with no renewable energy development for purchased electricity. Instead, grid electricity would be purchased with a small amount generated on site.

8) Earth Source Heat (Only)
Similar to previous two Earth Source Heat solutions, with stand-alone ESH system design to carry full heating load (no supplemental technologies for peaking).

9) and 10) Air Source Heat Pumps (only) and Ground Source Heat Pumps (only)
Since both technologies provide both heating and cooling benefits, this solution is less effective for the Cornell campus where cooling needs are already met by Lake Source Cooling. If electricity were generated on-site with gas turbines, this solution would increase Cornell's carbon footprint; if sourced from the current grid, the carbon reduction effect is small; if sourced from a future carbon-free grid (or campus power sources), it could reduce carbon impacts by up to 40-50 percent.

## Non-Feasible Solutions: Biomass Gasification and Combustion

Biomass gasification and combustion were explored as stand-alone heating and powering solutions but do not appear to be feasible. Cornell agricultural experts estimate the maximum sustainable yield on "local" Cornell lands (those potentially available for biomass within 25 miles of central campus) could only provide about 15 percent of the energy needed to heat the campus. If produced regionally, biomass production could put significant strain on the ecological carrying capacity of our region, without net benefit on the surrounding community. Biomass is considered potentially viable as part of a combined solution as proposed earlier in this report.

## Carbon Offsetting Solutions

Cornell can offset the impact of greenhouse gas emissions that we cannot eliminate by purchasing or investing in projects that reduce carbon elsewhere. Developing a portfolio of *local* offset projects can also help address economic disparities and have a positive impact on local resilience. These projects – referred to in the Cornell Climate Action Plan as "mission-linked offsets" can provide Cornell with the opportunity to invest in tangible actions with unique and important opportunities for multidisciplinary research, entwined with benefits to our immediate and global community.

1) Mission Linked
Mission-linked offsets provide Cornell with the opportunity to invest in projects in our community and region that reduce carbon and have a positive impact on the local economy. Projects for consideration might include: Continued and Expanded Active Forest Management (an estimated 3,000 acres of Cornell lands that currently are abandoned fields or marginal farmland could be used to plant native tree species), pursuing land-lease opportunities that support community solar, energy efficiency renovations in low-

income or rental properties, heating fuel switch from fossil fuels to low/no carbon alternatives for barns and homes, improving carbon storage in agricultural soil, or reducing methane in agricultural industries.

2) Purchased

Potential solutions here may include purchasing Renewable Energy Credits, or purchasing third-party certified carbon offsets at a national or international location with no direct involvement in projects. A 2009 survey of Tompkins County residents, conducted by Cornell Professor Katherine McComas, found that community support was relatively low for purchased carbon offsets compared with other solutions proposed for the Climate Action Plan.

# Conclusions and Recommendations

Cornell University, with its actively engaged community of students, faculty and staff, its deep and abiding tradition of collaboration across the campus, including the Facilities group - Infrastructure, Properties and Planning - that brings to life the campus as a "living laboratory," is uniquely positioned to achieve the goal of carbon neutrality by 2035, in the cold climate of Ithaca, New York. If in achieving this goal we are able to demonstrate new technology at an industrial scale, we will be providing important solutions that communities large and small can implement to make steady progress toward reducing their carbon footprints. Through this process, students will leave Cornell armed with the knowledge to lead change around the world.

For Cornell to achieve this lofty goal, it must begin making investments and changes now. The most immediate opportunities are on the *demand side*. Through programs underway and recommended, we recommend that over the next five years the university:

- Build on the success of the Think Big, Live Green campaign and continue to develop and deploy training tools to educate the campus on ways each and every member can contribute to reducing the energy consumption and the carbon footprint;
- Ensure all students graduate with a basic literacy of climate change – an understanding of their influence on climate and its influence on them and society. An educated student body will generate and help implement campus solutions, and carry the knowledge of climate-smart behaviors and solutions with them after graduation;
- Modify capital projects approval processes to explicitly account for long-term energy savings and the quadruple bottom line so as to incentivize higher energy performance in deferred maintenance projects, renovations and new construction;
- Expand the successful Energy Conservation Initiative and continuous recommissioning program to further drive down the energy use of existing buildings through increased investment in both, and extending the payback period required for energy conservation projects; and
- Prioritize development of infrastructure to support a campus fleet of clean-fuel vehicles and replace the existing fleet accordingly.

To address the need for renewable, non-carbon-based energy sources, a gated process is recommended, whereby technologies are tested and, depending on the outcome, decisions are made to continue or move to another option.

- Cost-effective wind, water, and solar projects should be pursued to strive to meet or offset 100 percent of the expected annual campus electricity demand. New York state's new Clean Energy Standard mandates that 50 percent of grid power will be supplied from renewable sources by 2030; the University should continue to be an invested partner in this grid transformation as well. Wind, water, and solar projects should engage Cornell's academic expertise on questions of appropriate siting, community acceptance, and environmental and wildlife impacts.
- Earth Source Heat is the most promising technology for heating the campus in our climate. If successful, it would provide a new source of heat that could be more widely deployed and potentially give birth to a new industry right here in upstate New York. Earth Source Heat has the highest likelihood of attracting partners that would defray the cost of its implementation. The possibility of creating an entirely new energy source has already attracted the attention of private corporations and the state. However, this is unproven technology, and as such there must be well-defined tests to determine its feasibility. Over the next five years, Cornell should pursue proposals for funding leading to a test well, and then reassess the viability of Earth Source Heat. If the test well is viable, a second well should be drilled to create a well pair to heat a portion of the campus that has been retrofitted with a hot water district heating system. We estimate the time required to complete the first well pair is 10 years. If at that time Earth Source Heat continues to look viable, Cornell should implement it as a campus-wide utility.

- If in the first 5-10 years of testing Earth Source Heat is found not to be viable, the next most cost-effective technology is ground source heat pumps. Ground source heat pumps are a proven technology, and so its deployment would require less testing, and could be completed by 2035, however this approach uses standard technology, is unlikely to attract offsetting external funding, and would involve costs that cannot presently be undertaken without major negative impacts on other university missions. The precise approach (for example, building-by-building or using a hot water district heating system) should be evaluated if this solution is pursued. Ground source heat pumps create a significantly greater demand for electric power, and the deployment of wind and solar farms would have to be adjusted accordingly. Although air source heat pumps alone are a lower cost alternative, the higher demand for electricity relative to ground source heat pumps makes it prohibitive for a research campus. Cornell should evaluate the use of ground source heat pumps, and the optimizations to the campus heat distribution system required to support both ground source heat pumps and Earth Source Heat during the Earth Source Heat evaluation period.
- Considering only technological feasibility, the technical challenges associated with small modular nuclear reactors may be overcome in a decade, and nuclear could be revisited if Earth Source Heat is not successful. This must be balanced with community concerns.
- The use of biomass to accommodate peak loads should be evaluated. However, the scale of biomass required for a complete solution is too large to be practical.

The capital costs for all of the solutions are very high. External sources of funding for these efforts offer the only apparent way to pay for them without major disruptions to the teaching mission. Consequently, Cornell should seek partnerships with local, state and federal government, private corporations and non-profit foundations that support the energy sector. The building of a consortium of engaged partners should begin immediately and be sustained over the lifetime of the project. Indeed, the committee believes this to be a great benefit of the Cornell commitment to carbon neutrality, as it could enhance the local economy and magnify the impact through this demonstration of a small community achieving carbon neutrality.

There are economic risks associated with “business as usual” including a vulnerability to volatility in fossil-fuel based energy prices and potential federal carbon charges or cap-and-trade regulations. Cornell should adopt a decision-making framework that considers the socialized costs associated with greenhouse gases emitted by the University and the avoided risk of pursuing mitigation solutions in addition to project costs.

Where Cornell cannot reduce all net emissions to zero, there exist opportunities to pursue mission-linked carbon offsets that have a positive impact on local resilience and are economically practical. Rather than viewing these offsets as additional burdens, they can instead be shown to offer unique and important opportunities for multidisciplinary research and community partnership.

# Appendix A
## Suggested Economic Parameters for the Carbon Neutral Campus Alternatives Report

William Schulze, Dyson School

Three questions have been raised concerning the analysis of alternatives for a carbon-neutral Cornell campus that are in the domain of applied economics. They are 1) what discount rate should be used for evaluating alternatives, 2) what social cost should be used for valuing the benefits of reduced CO2 emissions, and 3) what is the future price of natural gas likely to be.

Figure 3: Dilbert Comic


### Choice of Discount Rate

As suggested in the cartoon, uncertainty regarding choice of discount rate, as well as other assumptions used in any analysis of future revenues and costs will be uncertain and controversial. Cornell theoretically should use its own opportunity cost of capital as the discount rate for analyzing the alternative costs and revenues associated with attaining carbon neutrality. In other words, if Cornell were to issue bonds to invest in and pay for a carbon neutral campus, it would have to pay a competitive interest rate.

As an example, Columbia University recently sold $50 million in tax-exempt bonds with a yield of 1.67 percent. If the money were used to construct a dormitory, it would be appropriate to use the same rate as the discount rate to see if the discounted present value of future revenues net of operating costs would be at least equal to the $50 million construction cost. Another way to do the analysis would be to annualize the capital cost at the same rate to see if annual revenues minus operating costs exceed the annualized capital cost. For many, this is a more intuitive way to understand the analysis.

However, it should be noted that using this low a discount rate could be very risky unless Cornell would actually borrow the money at today's extraordinarily low rates. Current interest rates are a product of Federal Reserve policies to stimulate the economy and are unlikely to persist much longer. Cornell's treasurer has suggested that, in nominal terms, an appropriate rate would be a little under 6 percent. This is in line with the historic average of long-term interest rates. However, for long-term analysis, a real rate of discount is generally employed where the inflation rate is subtracted from the discount rate, and revenue and cost estimates are made in constant dollars. This eliminates the need to guess future inflation rates. The current (2016) inflation rate is 1 percent. Thus, I suggest that, unless Cornell is prepared to fully fund a carbon neutral campus by borrowing now, a real rate of discount of 5 percent (6 percent - 1 percent) be used for the analysis.

## Appendix A: Suggested Economic Parameters for the Carbon Neutral Campus

### The Social Cost of Carbon

If Cornell wishes to perform a benefit-cost analysis from the point of view of global society, an estimate of the social cost of carbon emissions is required. The social costs of CO2 presented in the table below (for alternative discount rates) have been estimated by an interagency group of the U.S. government that examined a wide variety of studies. These studies estimated the costs based on the economic impacts over time on agriculture, heating and cooling, land lost to a rise in sea level, etc.

Obviously, as indicated by the last column, there exists considerable uncertainty in the future of both the magnitude of climate change and the economic impacts of climate change. Another major source of uncertainty is choice of discount rate. Note that the first column uses a 5 percent discount rate identical to the one suggested above based on long-term costs of borrowing.

Figure 4: Social Cost of Carbon

**Social Cost of $CO_2$, 2015-2050 [a] (in 2007 Dollars per metric ton $CO_2$)**
Source: Technical Support Document: Technical Update of the Social Cost of Carbon for Regulatory Impact Analysis Under Executive Order 12866 (May 2013, Revised July 2015)

| | Discount Rate and Statistic | | | |
|---|---|---|---|---|
| Year | 5% Average | 3% Average | 2.5% Average | 3% 95$^{th}$ percentile |
| 2015 | \$11 | \$36 | \$56 | \$105 |
| 2020 | \$12 | \$42 | \$62 | \$123 |
| 2025 | \$14 | \$46 | \$68 | \$138 |
| 2030 | \$16 | \$50 | \$73 | \$152 |
| 2035 | \$18 | \$55 | \$78 | \$168 |
| 2040 | \$21 | \$60 | \$84 | \$183 |
| 2045 | \$23 | \$64 | \$89 | \$197 |
| 2050 | \$26 | \$69 | \$95 | \$212 |

[a] The SC-$CO_2$ values are dollar-year and emissions-year specific.

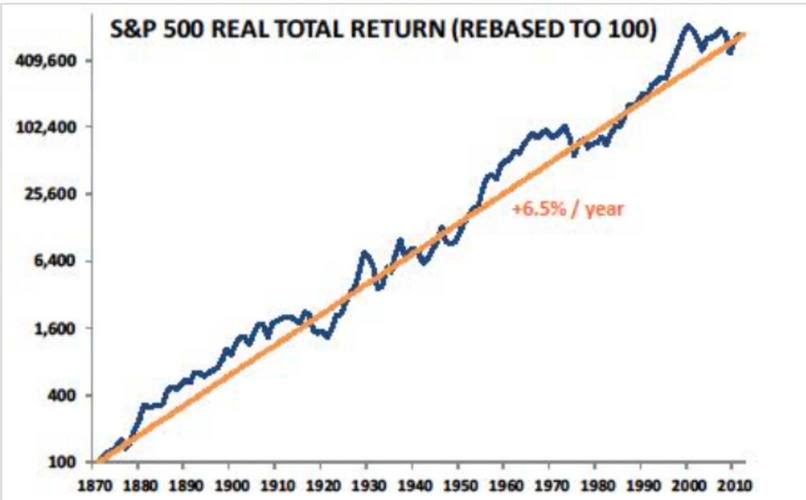
However, there is a major difference between calculating the costs to Cornell of achieving carbon neutrality and discounting the damages to future generations of climate change. Ethical questions must be raised on the rights of individuals and generations in the future. In other words, is it ethically acceptable for the current generation to damage future generations without actual compensation? As an example, take the libertarian ethical point of view that would argue that we, as the current generation, are free to do whatever we want to do, as long as we do not hurt future generations. This requires us to compensate future damages for any remaining damages even after we partially control CO2 emissions.

One way to do that would be to calculate any remaining damages and put money into an investment fund that would reinvest earnings until the date where they would be paid out to a particular damaged generation in a particular future year. The figure below shows that the long run return (with reinvestment) from the S&P 500 that has averaged a remarkably consistent 6.5 percent. But, to determine how much we would need to put in the fund, we would need to discount future remaining damages at 6.5 percent rate, assuming that the stock market would continue to grow as it has in the past, so the correct amount would be available in the future.

Note that efficiency requires that we trade off existing control costs for CO2 against the cost of putting money into this fund so the discounted present value of damages per ton of CO2 emitted should be used to value the benefits of current control cost measures.

Of course, the political odds of such a fund being established can be precisely determined with great accuracy to be exactly zero.  If this is the case, what should be done? One solution that many economists advocate is to use a discount rate lower than 6.5 percent. Hence a range of discount rates is presented in the table giving alternative measures of the social cost of CO2. The most commonly used value for the social cost of carbon is based on a discount rate of 3 percent. Other rates are used for sensitivity analysis.

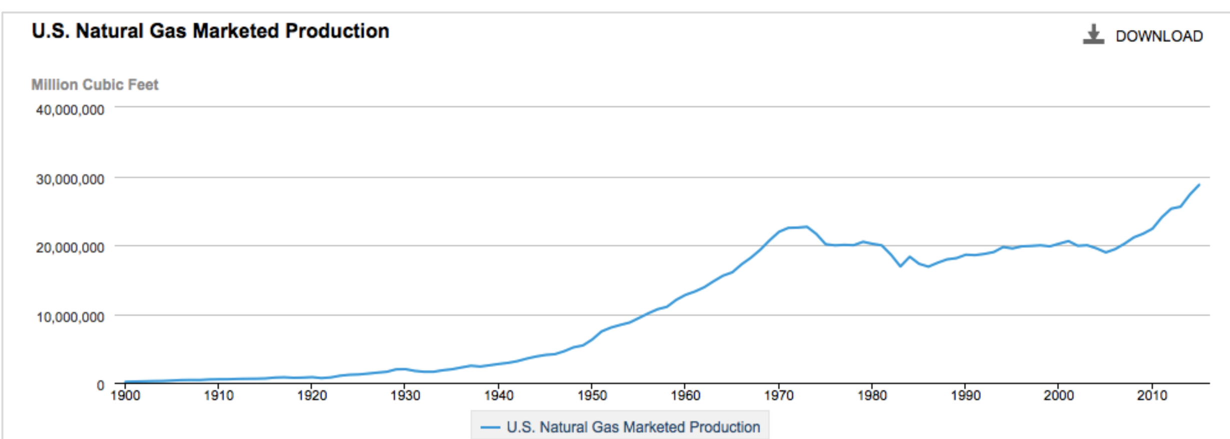
Figure 5: S&P 500 Return Rates




### Predicting Natural Gas Prices

The long run history of natural gas production for the U.S. is shown in the figure below. Prices were regulated beginning in 1938 by the Natural Gas Act until 1978 when Congress began a deregulation process that was completed in 1989, effectively reversing a decline in production. The rapid increase in production beginning around 2005 is associated with the widespread use of fracking to obtain shale gas.

Figure 6: US Natural Gas Marketed Production



Appendix A: Suggested Economic Parameters for the Carbon Neutral Campus

The next figure demonstrates the past and likely future production of shale gas in comparison to other sources of gas. Henry hub spot prices for natural gas are shown in the next figure that covers the more recent past since the 1990s. The price spikes in the time trend can be explained by increases in demand associated with weather and the downward trend since 2005 (ignoring price spikes) by the increased availability of gas from fracking. Recently, the very low prices have caused a switch to drilling for wet gas in Pennsylvania, which produces byproducts such as propane and ethane that are valuable and effectively subsidize the continued increase in production of methane which is the major constituent in natural gas. Shell is building a $6 billion facility in western Pennsylvania to crack ethane into ethylene used in the manufacturing of plastics.

Figure 7: Shale Gas Production, U.S.

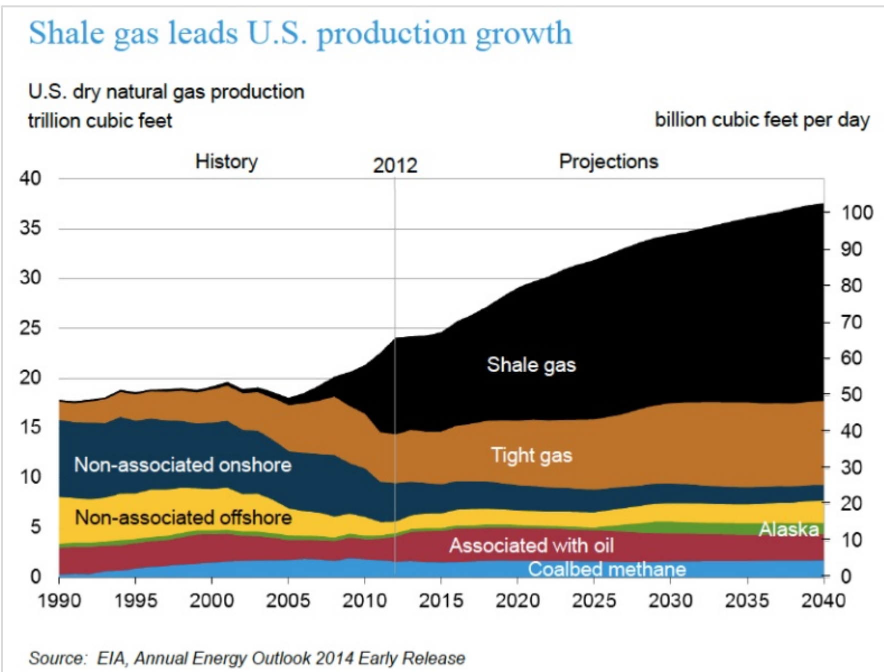
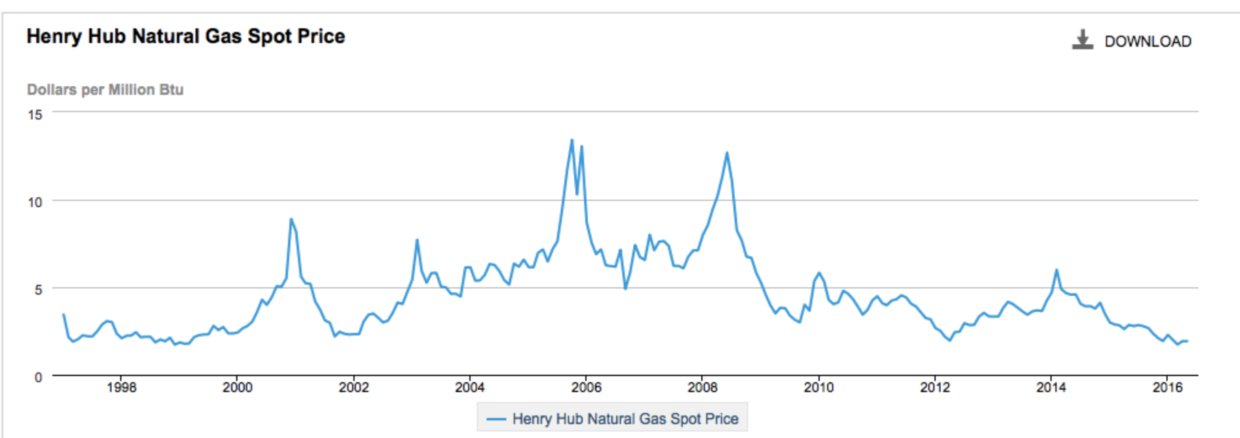
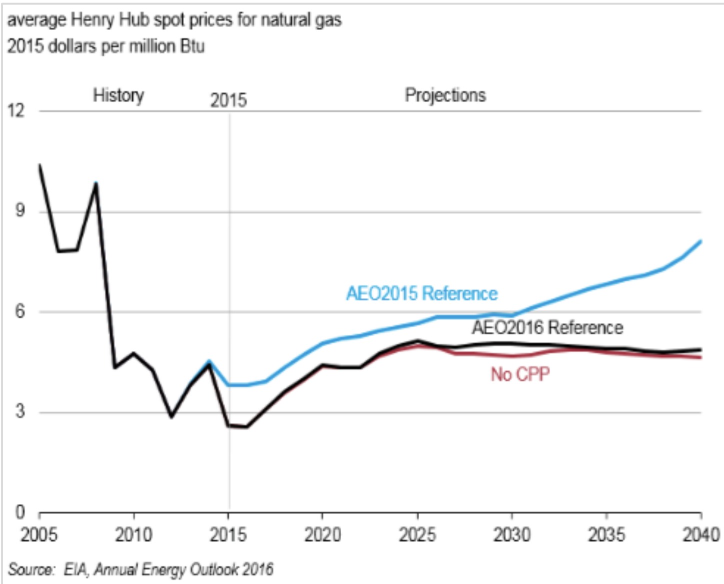



Figure 8: Henry Hub Natural Gas Spot Price



The consensus is that natural gas will remain readily available and relatively inexpensive, but that the lowest price of \$1.92/mcf shown in the figure above will not persist and eventually rise to the \$4 to \$5 range as shown in the latest estimates from the Energy Information Agency. Simply put, demand for natural gas will catch up with supply as new pipelines, many in the planning stage or under construction, are put in place to deliver gas to high-value markets and exports of liquefied natural gas also increase.

Figure 9: Average Henry Hub Prices for Natural Gas, 2016




Finally, Cornell University is unlikely to be taxed for carbon emissions from on-site power generation under the Regional Greenhouse Gas Initiative (RGGI) – the legally mandated cap-and-trade market for Northeastern and Mid-Atlantic States including New York. Anticipated RGGI costs for purchased electricity are, however, embedded in those future energy forecasts.

# Appendix B

## Assumptions for All Campus Energy Supply Solutions

For campus operations, Cornell will continue to:

- Operate Lake Source Cooling to meet the majority of campus cooling needs
- Operate existing campus hydroplant and solar facilities
- Continue development of the 34MW of wind, water, and solar projects currently underway
- Ensure 0 percent growth in campus energy use through green building and construction standards
- Invest in and support aggressive energy conservation efforts in facilities and through engagement
- Pursue solutions that meet both campus and regional carbon reduction goals, where possible
- Support other ongoing and active carbon-reduction activities in the Climate Action Plan
- Convert steam to hot water for the campus energy distribution system

For considering external influences on energy:

- Purchased energy will have fossil fuels as part of the grid mix
- Purchased energy will also have more renewable energy as a result of New York's 2016 Clean Energy Standard which sets a goal of 50 percent renewables by 2030

For finances, this report assumes:

- Energy forecasting using standard U.S. Energy Information Administration (EIA) pricing
- Cornell's current natural gas costs will rise to meet national energy cost standard over the next 10 years
- All costs are in "real" values, i.e., no general inflation was included in the analysis
- All figures include a real discount rate of 5 percent, which represents the opportunity cost of capital through borrowing above and beyond the level of inflation
- Capital expenditures (capex) and annual operating expenses (opex) are combined to calculate the annual equivalent cost

For considering external influences on carbon:

- Cornell is unlikely to be taxed for on-campus energy production through the New York State Regional Greenhouse Gas Initiative, but purchased energy will include a tax
- Cornell may see a carbon tax or cap-and-trade system implemented at the federal level that incurs a price on climate change impacts

# Appendix C
## Assumptions Wind, Water, and Solar

Using renewable energy (wind, water, and solar technologies) to provide the power needs of the campus involves developing sufficient new facilities on and off campus to supply an amount of electricity equivalent to the net electric need on an annual basis[2]. Wind, water, and solar (WWS) solutions meet only electricity needs for the campus, not heat. However, integration of new solar photovoltaic and wind energy into the campus energy portfolio and continued efforts to optimize the existing hydroelectric plant in Fall Creek are key components for achieving a carbon-neutral campus. It is also important for Cornell to continue to support and participate in New York state's efforts to reduce the carbon footprint of the grid through providing academic and practical expertise and demonstration partnerships.

WWS are proven technologies with readily available implementation and, sited properly, relatively benign environmental and community impact. Community concerns about siting facilities, particularly wind turbines, and storage capacity to mitigate the intermittency of these resources are key remaining challenges.

The feasibility of this solution (that is, finding a combination of renewable energy technologies to fit the projected electricity load for the campus) was financially evaluated using a hypothetical case whereby all of the electricity needed to serve current campus load was developed from WWS resources (50 percent solar and 50 percent wind). Again, this analysis assumes no external funds or use of power purchase agreements. It is important to note that through public/private partnerships and leveraging existing federal and state government grants and rebate programs WWS projects to date have not only been cost effective, but have generated savings.

Table 9: Campus Power Supply Solution Scenario ($ Millions / Year)

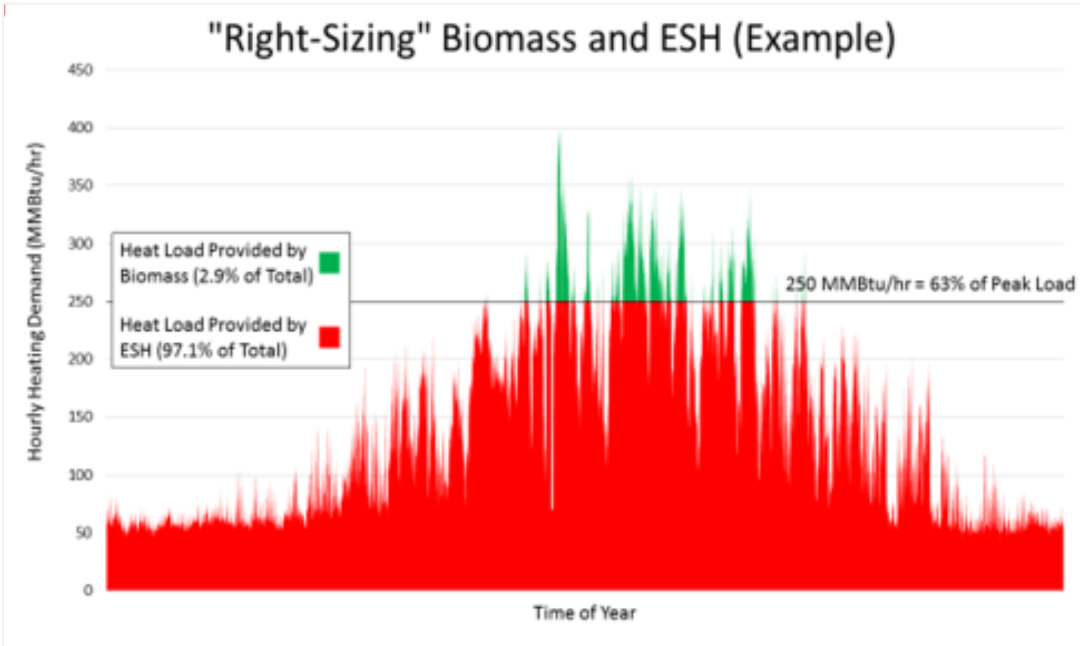
| Renewable Energy Type | Up-Front Capital Cost (excluding external funds) | Annual Operating Cost | Annual Equivalent Cost (over 30 years) |
|---|---|---|---|
| 50% PV and 50% Wind to meet total current campus electric load | $270M | ($13) (Benefit to Cornell, relative to BAU plus offsets) | $3 |

[2] The annual electric needs of the campus will be highly dependent on the heating solution – e.g., preliminary estimates for GSHP are that average campus electric usage would increase ~43%, and peak usage during the coldest winter weather would approximately double. The New York State Clean Energy Standard mandates that 50% of grid power will be supplied from renewable sources by 2030.

# Appendix D

## Biomass Peaking with Earth Source Heat Solutions

Figure 10: Designing Earth Source Heat with Biomass Peaking




The capital costs for the ESH stand-alone option include $210M for the development of ESH well sets (7 sets), based on analysis of industry costs documented in a recently prepared *ESH Preparatory Phase Work Plan*. Additional costs include $20M for a pump/heat exchange facility (based also from Work Plan estimates, and compared to the Lake Source Cooling pump and heat exchanger facility, which cost about $15M and has a very similar thermal capacity). A figure of $236M was added for distribution conversion based on an industry-verified estimate by E&S.

The pairing of biomass with ESH would be similar, except that fewer wells are used for ESH. Instead, a biomass storage and processing facility and biomass boiler system would also be needed, sized as appropriate for the peak heating needs of campus (final sizing will be coordinated with the results of the ESH test program), as shown in the image above in green and above the gray line. At 5 wells pairs (sufficient to capture about 97 percent of the annual heat load), the first cost becomes $150M. Additional costs include $20M for a peaking biomass plant and $6M for a biomass storage and processing center. The latter figures were calculated with consideration of the previously noted biomass plant costs, with higher unit costs included to account for the smaller scale needed for B/ESH. In both cases, it is assumed that the system is sized for the entire heat load and Cornell fully finances all costs.

Table 10: Financial Results of ESH Options

| | ESH Technology Cost | Total Capital Expense | Annual Equivalent Cost |
|---|---|---|---|
| Earth Source Heat, WWS, Biomass | $150 | $700M | $71M |
| Earth Source Heat, WWS | $210 | $730M | $72M |

# References

This report builds and references prior reports, memos, and ongoing updates on carbon neutrality. These should be considered essential appendices to this report and can be found on the Cornell University Sustainable Campus website. Financial assumptions, figures, and modeling are drawn from the supplemental guidance documents listed here.

## *Climate Action Plan*


- (Report) 2009 Climate Action Plan
- (Report) 2013 Climate Action Plan Update & Roadmap
- (Report) 2014 Climate Action Plan Acceleration Working Group Report - *Companion document to the 2013 CAP Update & Roadmap*
- (Website) Sustainable Campus, Climate Action
- (Website) Sustainable Campus, Greenhouse Gas Emissions Inventory


## *Supplemental Guidance*


- (Report) 2016 Cornell University Climate Neutral Campus Energy Alternatives Report (CNCEAR)
- (Memo) 2016, A Comprehensive Climate Change Engagement and Education Campaign at Cornell University (Draft), Hoffman et al.
- (Memo) 2016 Methane Leakage and the Greenhouse Gas Inventory for Cornell University, Bob Howarth