2016 Climate Neutral Campus Energy Alternatives Report (CNCEAR)

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Table of Contents

Appendices:

A. Quadruple Bottom Line Rating Session Notes
B. Additional Technical Information for Reviewed Options
C. Calculation Spreadsheets
D. Campus District Hot Water Heating System
E. Cornell Energy Conservation Initiative (ECI) 2015 Summary Report
F. Water, Wind, and Solar (WWS) Activities at Cornell
G. Carbon Offset White paper

Executive Summary

This report provides an analysis of options that Cornell University may choose to pursue climate neutrality for the Ithaca Campus. The intent of this report it to provide critical information for consideration by the Senior Leader Climate Action Group (SLCAG) in recommending continuing and future initiatives toward this carbon neutrality goal.

Background

Cornell already employs many strategies and systems to reduce our Greenhouse Gas Emissions (GHGs). These strategies and systems, discussed in detail in the "Base Case Analysis" (Section 3) include, but are not limited to:

- Intensive campus-wide energy conservation and conservation behavior programs
- Integration of currently-available renewable energy (hydropower and solar energy) within campus
- Advancement of various forms of financial contracts for additional solar PV (and proposed wind) facilities on other Cornell lands or within our region to encourage non-fossil energy production, after case-by-case financial analysis
- Deployment of a significant number of all-electric, hybrid, and energy-efficient vehicles in the Cornell campus fleet and strategic placement of vehicular charging stations
- Transportation demand management programs to reduce commuting and travel impacts
- Continued maintenance and operation of highly-efficient district energy systems such as Lake Source Cooling and the Central Energy Plant (CEP), which provides energy through a combined heat and power process using natural gas turbines and steam boilers
- Specified energy standards for new buildings and significant renovations
- Continuous commissioning of campus buildings to maintain energy-efficient operations

Cornell also includes robust academic programs related to GHG reduction and general environmental protection, including academic centers and programs devoted to these areas.

Despite these efforts, a carbon-neutral future remains a significant challenge. Specifically, Cornell has reduced our GHG emissions about 33% since 2008, but continues to emit almost 170,000 tons of GHGs (CO_2 equivalent) annually from our central energy operations on campus. An additional total of nearly 60,000 tons of GHGs (CO_2 equivalent) are associated with our commuting and business travel and are included in our annual emissions reporting.

The central plant figures do not include methane emissions associated with upstream gas development and transmission, which could substantially increase those GHG impacts, if included. Even if we continue our current efforts, we cannot expect substantial further reductions without significant changes in the ways that we generate, distribute, and utilize energy on campus.

Analysis

This report summarizes some prior work and presents a refreshed analysis of a multitude of GHG-reduction options compared to a Base Case "Business as Usual" (BAU), which assumed continued use of the CEP using Natural Gas. Section 4 details the assumptions used in the analysis. The reviewed options include the following:

- Base Case "Business as Usual" (BAU) with the CEP using Natural Gas, with the additional cost associated with the purchase of carbon offsets to offset GHG emissions
- Green Development and Energy Conservation programs are incorporated into all scenarios, inclusive of the BAU option, to maintain energy requirements at current levels; some additional conservation program scenarios are also analyzed as a stand-along option
- Bioenergy via biomass combustion (BC) or biomass gasification (BG): BC would be used to replace campus heating needs, while BG could allow use of this bio-gas via the CEP and therefore could supply both heat and power
- Earth Source Heat (ESH), Cornell's version of Enhanced Geothermal Energy (EGS)
- Ground-source heat pumps (GSHP)
- Air-source heat pumps (ASHP)
- Small modular nuclear reactor (SMR)
- Renewable Electricity Generation with Wind, Water, and Solar (WWS)
- Transportation-Related Initiatives, including:
  - Replacement of Fleet (and some commuting) vehicles with electric vehicles over time
  - Purchase of Carbon Offsets for commuting and air travel scenarios
  - Electric Vehicle Charging Stations

Some specific "combination" options were also investigated, including:

- ESH with biomass combustion used for peak heat needs on cold days ("B/ESH")
- ESH with WWS use to provide all of the campus energy (heat plus electricity)
- B/ESH with WWS used to provide all of the campus energy needs (heat plus electricity)
- ASHP with WWS used to provide all of the campus energy needs (heat plus electricity)
- GSHP with WWS used to provide all of the campus energy needs (heat plus electricity)

Summary Findings

Table Exec-1 provides a quick summary of some of the major results of the analysis described in this report. A similar table with additional information is included in Section 9.

Table Exec-1: Key Summary of Investigated Options

Technology	**CAPEX ($2016)**	**OPEX (Year One:2028) ($2016))**	**GHGs reduced (MT/yr)**	**Land Area Required (acres)**
BAU+ (Business as Usual+ Offsets) (*for comparison*)	$0M	$50M(7)	None	N/A
ESH (Earth Source Heat)	$466M	$36M (7)	97,000	5[1]
B/ESH (Biomass + ESH)	$427M	$38M(7)	97,000	5[1] + 430[2}
BC (Biomass Combustion)	$336M	$43M(7)	103,000	14,000 [2]
BG (Biomass Gasification)	$416M	$32M	All Central Energy Plant (CEP) GHGs	26,000 [2]
GSHP (Ground Source Heat Pumps)	$596M	$43M(7)	73,000	150 [3]
ASHP (Air Source HPs)	$486M	$50M(7)	65,000	5 [4]
SMR (Small Modular Nuclear Reactor)	$701M	$34M	All CEP GHGs	10 [5]
GSHP + WWS (GSHP plus Wind, Water, & Solar Elect)	$929M	$26M	All CEP GHGs	150 [3] 940 [6]
ASHP + WWS	$915M	$28M	All CEP GHGs	5 [4] 1090 [6]
ESH + WWS	$734M	$22M	All CEP GHGs	5 [1] + 430[2] +725 [6]
B/ESH + WWS	$695M	$24M	All CEP GHGs	5 [1] + 725 [6]

Table Notes:

[1] Wellhead infrastructure & heat exchange facility
[2] Biomass crop production (assumed to be all shrub willow for comparison purposes)
[3] Geothermal wells
[4] Heat exchange facilities
[5] Reactor/cooling facility
[6] WWS PV and Wind land areas; some off-campus
(7) these costs include purchased grid electricity and costs of offsets (not including leakage)

Table Exec-2, discussed in Chapter 8, presents this cost analysis using the concept of "annual equivalent costs". This metric allows a comparison of the theoretical annual expense (the total of annual operating cost and capital debt cost) that would result from implementation of each case using the financial assumptions detailed in this report.

Table Exec-2 also introduces an important consideration relating to GHG emissions described in more detail in Chapter 8. Specifically, the baseline financial analysis of this report for all alternatives (other than BAU) includes “offsets” which are applied to the direct emissions at Cornell (“Scope 1 emissions”) or at the power plants in the grid supplying electricity to Cornell (“Scope 2 emissions”), as is the common convention. However, this convention does not account for the “upstream” methane emissions that are incidental to natural gas use in our area, as discussed in Section 8. For Cornell to take full responsibility for the greenhouse gas emissions associated with the shale gas development and utilization by the University, members of SLCAG have advocated for an accounting to also include these “Scope 3” emissions. Table Exec-2 shows the comparison of annual costs and the dramatic effect that the inclusion of “upstream emissions” would have on the Annual Equivalent Costs for various options.

Table Exec-2: Annual Equivalent Total Costs, with and without Upstream Methane Emissions

	Annual Equivalent Costs (Capital + Operating)	
Scenario	**Current Scope 1 & 2** ($M 2016)	**Scope 1, 2, & 3 (Upstream CH_4)** ($M 2016)
BAU + Offsets (Comparison)	52	85
Alternative		
BC (Biomass Combustion)	63	71
BG (Biomass Gasification)	56	56
ESH (Earth Source Heat)	72	80
B/ESH (Biomass/ESH)	69	78
ASHP (Air Source Heat Pump)	79	92
GSHP (Ground Source HP)	77	87
SMR (Small Modular Reactor)	76	76
ESH + Wind, Water, Solar	72	72
B/ESH + WWS	71	71
GSHP + WWS	81	81
ASHP + WWS	90	90

As Table Exec-2 shows, the Annual Equivalent Costs for BAU (with offset costs) under current “carbon accounting rules” is the lowest cost option, but with “upstream” methane leakage added as detailed in Chapter 8, those leveled annual costs becomes higher than many other options.

Summary Conclusions

Chapter 9 of this report presents conclusions of this study. A more succinct summary of those conclusions is presented here; Chapter 9 provides additional detail and context.

A primary conclusion of this analysis is that, to achieve carbon neutrality “within our campus limits”, Cornell will need to incorporate major unconventional energy sources such as ESH with substantial WWS, an SMR, a very large bioenergy system, extensive heat pumps with substantial

WWS, or a combination of these actions. Each of these alternatives presents serious technical, social, and fiscal challenges. The particular benefits and challenges of each action are detailed in the Analysis section (Section 7).

The analysis completed as part of this report also suggests that a combination of actions is likely to optimize overall economy and effectiveness in reducing GHG impacts. This is both due both the need to replace a variety of fossil fuels involved in our GHG footprint (i.e., gas, purchased electricity, and liquid fuels) and the inherent challenges of single solutions in meeting our goals (i.e., reliability, meeting peak loads, preserving campus lands for a wide variety of uses, multiple research interests, funding opportunities, etc.)

As an alternative to large-scale structural changes, Cornell could also achieve neutrality in an “accounting” sense by the purchase of **offsets** or **renewable energy credits** in amounts representing all of the energy used on campus. Chapter 6 explores these “offsetting” options and presents some information related to offset costs and practical impacts to the University.

Quadruple-Bottom Line (QBL) Rankings of Options Considered

Ratings were developed through a core group of SLCAG members with diverse interests in a workshop setting (see section 3 for details). Tables Exec-3 and Exec-4 summarizes the QBL Rankings for each of the Options considered, as detailed in the Analysis Section. Color is used to provide a more visual “snapshot” of these analyses, with “Green” indicating areas of “high” ranking (3.5 or greater, on a scale of 1 to 5), “Yellow” areas of “low” ranking (2.5 or less), and no color for essentially neutral or balanced rankings (greater than 2.5 or less than 3.5). The assumptions leading to the financial costs included in these tables are explained in detail in this report and a working (Excel) spreadsheet made available to check assumptions and calculations and check scenarios.

The QBL rankings of actions are presented in two separate groups, as follows:

- Table Exec-3 includes alternatives scaled to represent both “complete GHG solutions” (i.e., options to get to carbon neutrality) and options which provide only campus-wide heat, and therefore must be coupled with renewable electricity (WWS) in order to be considered a whole-campus carbon-neutral solution.

- Table Exec-4 includes alternatives which will not themselves result in carbon neutrality, but are important in supporting a carbon-reduction goal (Green Development, Energy Conservation, and Transportation actions)

For both tables, a more detailed discussion of the factors that resulted in these rankings is provided in the Section 7 – Analysis.

Table Exec-3: SLCAG QBL Rankings for Campus GHG-Reduction Options

		Rating (1-5) (1= Lowest; 5=Most Favorable)			
Alternative	Annual Equivalent Cost[1] ($M 2016)	*Supports Cornell Mission (Purpose)*	*Supports Cornell Finances (Prosperity)*	*Supports Community Goals (People)*	*Supports Environmental Needs (Planet)*
Baseline Comparison					
BAU (no offsets)	45	2.0	3.5	1.7	1.5
Complete GHG Solutions					
BAU+ Offsets	52/85	3.0	1.5	2.0	2.0
BG	56/56	4.1	3.3	2.2	2.6
SMR	76/76	1.7	2.2	1.8	2.9
ESH + WWS	72/72	4.4	2.7	3.1	4.8
ESH + BC + WWS	71/71	4.7	2.8	3.2	4.6
ASHP + WWS	90/90	3.1	1.4	3.3	3.9
GSHP + WWS	81/81	3.7	2.3	3.6	4.2
Partial GHG Solutions					
Wind Power	*Note 2*	3.9	3.1	3.1	5.0
PV Power	*Note 2*	3.1	3.4	4.0	5.0
Hydroelectric Power	*Note 2*	2.8	1.9	3.0	4.6
WWS – Electric for Campus	*+ $20M* [2]	3.7	2.6	3.9	5.0
ASHP	79/92	2.6	2.3	3.1	2.8
GSHP	77/87	2.9	2.3	3.2	3.7
BC	63/71	3.4	3.1	2.1	2.4
ESH	72/80	4.4	3.0	3.5	4.3
B/ESH	69/77	4.8	2.3	3.3	4.3

Note 1: First figure represents the annual equivalent costs including offset costs based on "traditional" Scope 1 and 2 GHG emissions accounting; the second figure represents these costs based on inclusion of assumed Scope 3 upstream methane emissions as detailed in Section 8. "Total solution" options which result in essentially no GHG emissions have the same annual cost since no offsets are needed.

Note 2: Not total campus solutions; see Analysis section for more info on cost impacts.

Table Exec-4: SLCAG QBL Rankings for GHG-Reduction Supporting Actions

	Rating (1-5) (1= Lowest; 5=Most Favorable)			
Supporting Technology	*Supports Cornell Mission (Purpose)*	*Supports Cornell Finances (Prosperity)*	*Supports Community Goals (People)*	*Supports Environmental Needs (Planet)*
Electric Charging Stations	**1.6**	**2.3**	**3.9**	**4.1**
Green Development	**3.6**	**3.1**	**3.6**	**4.4**
More Recommissioning	**3.1**	**4.2**	**3.4**	**4.3**
Energy Conservation	**3.6**	**4.2**	**4.2**	**4.3**

This data suggests the following additional findings and conclusions:

- The **Business-As-Usual (BAU)** case is the most cost-effective and has the lowest physical impact on the campus. However, it does not advance Cornell towards climate neutrality nor provide additional support for its academic or research mission.

- The **Business-As-Usual (BAU) case with the additional purchase of Carbon Offsets** at the assumed "Social Cost of Carbon" rate is likely the most cost-effective solution to a claim of carbon neutrality. However, this action does little in support of Cornell's academic mission and costs substantially more (about $7M per year more) than BAU.

- When the **Social Cost of Carbon** is embedded in all costs and Cornell models our impacts to include **methane losses associated with shale gas development** as proposed by Cornell researchers (Howarth et al), most of the options reviewed are financially comparable to the BAU+ Offsets case. This figure (~$85M) represents an approximate doubling of the BAU (without offsets) base case annual expense (~$42M).

- **Biomass Gasification (BG)** is the lowest cost option for modifying the total campus energy systems. However, this option does not appear feasible as a campus-wide solution due to the huge amount of biomass needed, which could not be sustainably harvested from available Cornell lands. Cornell academic experts calculate that the maximum sustainable yield on "local" Cornell lands (those potentially available for biomass within 25 miles of central campus) could provide about **15%** of the energy needed for heating campus. As a more limited partial solution, BG rates relatively high in its potential support of the academic and research mission of Cornell and particularly in its role as a land-grant institution. Greater academic work into the concept of "renewable biomass" is needed for this concept to be proven as a "net zero" option.

- A **Small Modular Reactor (SMR)** is the only "stand-alone" option studied that would be predicted to provide all the heat and electricity needed for campus. This solution is also technically-advanced to a point that there is little concern about meeting the campus capacity, albeit with radioactive fuel that would be imported. Significant concerns regarding this choice include unclear capital costs and operating costs, timing of technology (suitable for institution application), likely permitting challenges, and predicted local approvals and environmental assessment challenges. Cornell does not currently have a nuclear engineering academic discipline, reducing the value of this choice to the academic mission.

- Other alternatives will likely require **combinations of actions**, barring complete transformation of the external electric grid (so that is it fed entirely by carbon-free sources). For example, the current **Earth Source Heat** (**ESH)** conceptual plan does not anticipate the production of fluid at temperatures suitable for substantial electric production, so other renewable electricity would be needed. It is slightly more cost-effective to use biomass (and/or hot water storage and/or strategically-placed heat pumps) to provide peaking on extreme cold days than to oversize ESH for peak loads. Therefore, the "total energy" concepts analyzed for ESH includes both a full-load sized **ESH and an option with "peaking" biomass boilers (B/ESH); both use Wind, Water, and Solar (WWS)** for electrical production. A test well would be necessary to better confirm ESH potential and update probable costs.

- **Air-Source or Ground-Source Heat Pumps (ASHPs and GSHPs)** are technically proven and immediately available, but estimated total costs for heat pumps as a campus-wide solution are high. Heat pumps are not well-matched to our current campus needs, as Cornell has super-efficient Lake Source Cooling and requires only heating and electricity. As our buildings are currently designed for, and need, substantially higher temperature heat than is available from standard heat pumps, significant capital investment is needed for integration of this heat as well. Completely converting campus to heat pumps for heating would also require significant additional electricity. If this electricity was generated on-site with gas turbines, this might increase our carbon footprint; if sourced from the current grid, the positive effect is small; but if sourced from a future carbon-free grid (or campus power sources), it could represent a carbon-neutral solution. Thus, the net GHG impact of this solution is heavily dependent on the source of electricity needed to power the heat pumps. If coupled with WWS, this becomes a full-campus solution, but, as noted in the next bullet, obtaining sufficient WWS renewable electricity is a substantial challenge. Nonetheless, strategic use of heat pumps for limited "peaking" use may be very economical when combined with other solutions for heat provision and could reduce both capital and operating costs while assisting in GHG reductions if strategically applied.

- **Wind, Water, and Solar (WWS)** are all proven technologies for the generation of renewable electricity, but strongly dependent on the availability of local resources. Significant increases in renewable WWS are necessary for most carbon-neutral solution or low-carbon solutions, barring complete external transformation of the electric grid. Due to the relatively dense and energy-dependent nature of the campus, obtaining all of the electricity we need from renewable resources would require a significant commitment of campus land and resources, including off-campus resources. Options which *increase* electrical loads (e.g., extensive heat pumps) create additional WWS needs and thus further challenges to identifying sufficient renewable resources to reach climate neutrality.

- Transportation Options (**electric vehicles and charging stations**) are promising technologies that “score” well with no significant weaknesses other than incurring additional financial costs to the University. If implemented fully, these technologies could reduce campus carbon emissions about 13% if the additional electricity required could be sourced from renewable sources. Carbon emissions reduction is still about 11% if the electricity is grid-sourced, assuming current grid emission factors.

- **Continued energy conservation, commissioning, and green building standards reduce energy demands and are essential** to minimizing capital costs for non-BAU options and also necessary to improve the potential for GHG reductions for all options except SMR. Reducing energy needs is least critical for SMRs because many current reactors under development are already oversized for the needs of the Ithaca Campus. However, if this extra “conserved” power could be locally supplied to the community or to the grid, continued conservation measures would extend the carbon-reducing impact of the SMR further beyond campus boundaries.

Summary Recommendations

Recommendations resulting from the analysis described in this report include the following:

- **Expand support for electric and hybrid vehicles on campus.** Encouraging and supporting electric vehicle use can reduce that portion of our GHG impact related to commuting (about 13%) while improving both global GHG emissions and local air quality. Electric vehicle use is a practical and effective way for Cornell to deal with these types of emissions, although this option also relies on outside market forces (availability of economic electric vehicles) and social forces (high level participation by our commuters, who represent a substantial share of the emissions included in this analysis).

- **Adopt aggressive building energy standards and continue energy conservation programs.** Better energy standards and energy conservation at both the building and system level saves energy, avoids unnecessary capital expenses for supply and distribution systems, reduces costs for future system replacements, and reduces potential GHG emissions. Cornell’s energy conservation programs have been documented to significantly reduced both energy peaks and average loads.

- **Establish and enforce formal heating system design standards that prescribe building system temperatures immediately.** Future buildings and current building heating system upgrades should be designed to allow for both a lower supply temperature and a significantly reduced return temperature limit. This would significantly reduce costs of future system infrastructure and enable integration of cost-effective renewable and waste heat recovery as these technologies are developed and implemented.

- **Convert the current "primarily steam" system to a "steam-driven cascading heat system".** Currently, nearly 20% of heat energy sent to campus as steam is "wasted" due to thermal losses and cumulative steam leaks. In this improved system, the majority (or all) of the campus heat is distributed as hot water, reducing losses (and associated GHGs) to about 2%. The cost of a phased system conversion to hot water distribution is incorporated into each of the options (except BAU). Section 7 provides further information on the rationale for conversion to hot water distribution for various options. Once the system is converted, heat supply systems (i.e., Earth Source Heat, Heat Pumps, Nuclear Energy waste heat, Biomass Boilers, etc.) can be integrated.

- **Seek funding for an ESH Test Well.** An ESH test well program is needed to verify if ESH is a viable alternative to be part of a future climate-neutral campus. ESH holds great promise as a multi-disciplinary research focus and could have regional and national energy implications. Such research is appropriate for a premier research institution like Cornell. Future support for ESH *beyond* a test well should be contingent on test well results, research value, and funding availability.

- **Initiate a research program to explore the integration of appropriate levels of biomass into the campus energy system.** The development of a sustainable bioenergy system at Cornell is a long-standing goal for many researchers since the concept of the Cornell University Renewable Bioenergy Initiative ("CURBI") was launched almost a decade ago. A functional research platform (i.e., location for the storage, management, and processing of biomass) for bioenergy research will allow multi-disciplinary teams to explore the costs, benefits, and environmental trade-offs implicit in bioenergy production and will create a national model for sustainable harvesting practices. Actual field tests on various Cornell lands will provide robust multi-disciplinary research opportunities. The selection of an appropriate conversion technology (biogas generator, boiler, or similar system) will be enhanced by site-specific testing and practical experimentation with wood/crop storage and handling methods to develop best practices for mitigating unintended negative consequences. A key goal will be to establish an appropriate scale and practices for future bioenergy integration and to identify campus leaders willing to champion CURBI.

- **Continue to explore conventional renewable electric (WWS)** opportunities. Integration of PV and wind energy into the local campus grid and continued recent efforts to optimize the existing hydroelectric plant in Fall Creek are key components for a carbon-neutral campus. Additional WWS resources on Cornell lands located beyond CU's distributed electric grid and support for WWS within the broader community will be also be needed to further reduce carbon impacts.

- **Continue to follow progress in other innovative technologies,** such as small modular nuclear reactors. Because Cornell does not have special expertise in this field and progress is likely to originate with private corporations, Cornell may not be able to impact development substantially but should be poised to revisit this option as external development occurs.

- **Continue to explore Community “Offsetting Actions”**. Initial research shows that financial-only offsetting acts have limited (or even potentially-negative) social value. However, providing more direct support to the local community is likely to be more favorably viewed and could provide practical community economic benefits as well as environmental gains.
- If considering the purchase of Offsets from outside the community, **investigate unique or mission-linked opportunities** that highlight Cornell’s commitment to sustainability. This approach may offset concerns that Cornell is merely “buying their way” out of the issue of climate change impacts.
- **Communicate the challenge.** There is no simple or obvious cost-effective path to climate neutrality. However, Cornell is more likely to obtain grant support for innovative or significant research or application improvements which fulfill core University mission goals if the University targets dramatic reductions in carbon emissions and demonstrates an institutional commitment to those goals. While achieving zero emissions may appear unrealistic at this time, the University is better positioned for leadership in this area than most institutions. While aiming for a high standard, the challenge of that goal and recognition of the important role of research and innovation should be readily acknowledged.

Section 1: Purpose and Background

Cornell's current Climate Action Plan (CAP), first published in 2009, calls for reaching climate neutrality at its Ithaca campus by 2050. In 2015, the Faculty Senate passed a resolution, supported by student environmental organizations, that the University seek to accelerate its efforts, and target the achievement of this goal by 2035.

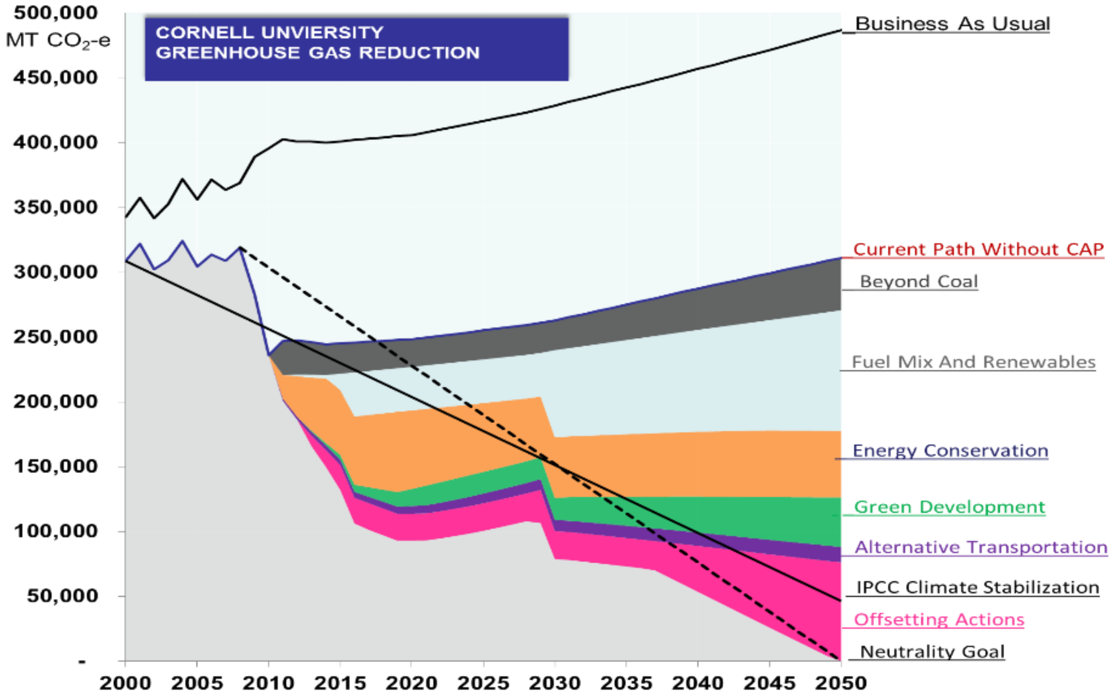


FIGURE 1.1 "WEDGE CHART" FROM THE ORIGINAL 2009 CAP, SHOWING ESTIMATED CONTRIBUTIONS OF VARIOUS COMPONENTS TO THE ORIGINAL OVERALL GHG REDUCTION GOAL ("CARBON NEUTRALITY BY 2050")

Obtaining Climate Neutrality requires progress across several broad areas (Fig. 1.1). The 2009 Climate Action Plan *Fuel Mix and Renewables* "wedge" was targeted to reduce campus GHG emissions by 42% by replacing the use of fossil fuels with clean, renewable energy. Progress to date has taken shape in several forms including aggressive and extensive conservation, a new combined heat and power facility, complete elimination of coal, and direct ownership and installation and power-purchase agreements with third party developers.

Since the publication of the original "wedge chart", Cornell has continued programs for GHG reductions and made significant progress towards that goal, as shown in Figure 1.2. The most recent CAP (2016) update no longer uses the "wedges" description but continues to highlight the importance of renewable energy integration, as documented at http://climateaction.cornell.edu .

To continue progress with specific commitments, the University needs a definitive path forward. This report summarizes analysis of various options aimed at producing this “Carbon Neutral” campus for the Ithaca, NY campus of Cornell.

Past efforts documented in the CAP identified a direct geothermal heating solution, Earth Source Heat, as a primary technology that, together with energy conservation, green construction practices, renewable electric energy, and other campus-wide initiatives could help Cornell achieve climate neutrality. However, Earth Source Heat, a technology not currently deployed in our geological region, may be not technically, socially, or financially feasible, so this report aims to identify other potential paths forward in the event that Earth Source Heat cannot be funded, isn’t successful in securing local approval, or cannot meet campus demands. As shown in Figure 1.2, Earth Source Heat (shown as “Hybrid ESH”, implemented in two stages) is currently a very significant and necessary part of our future carbon-reduction projections.

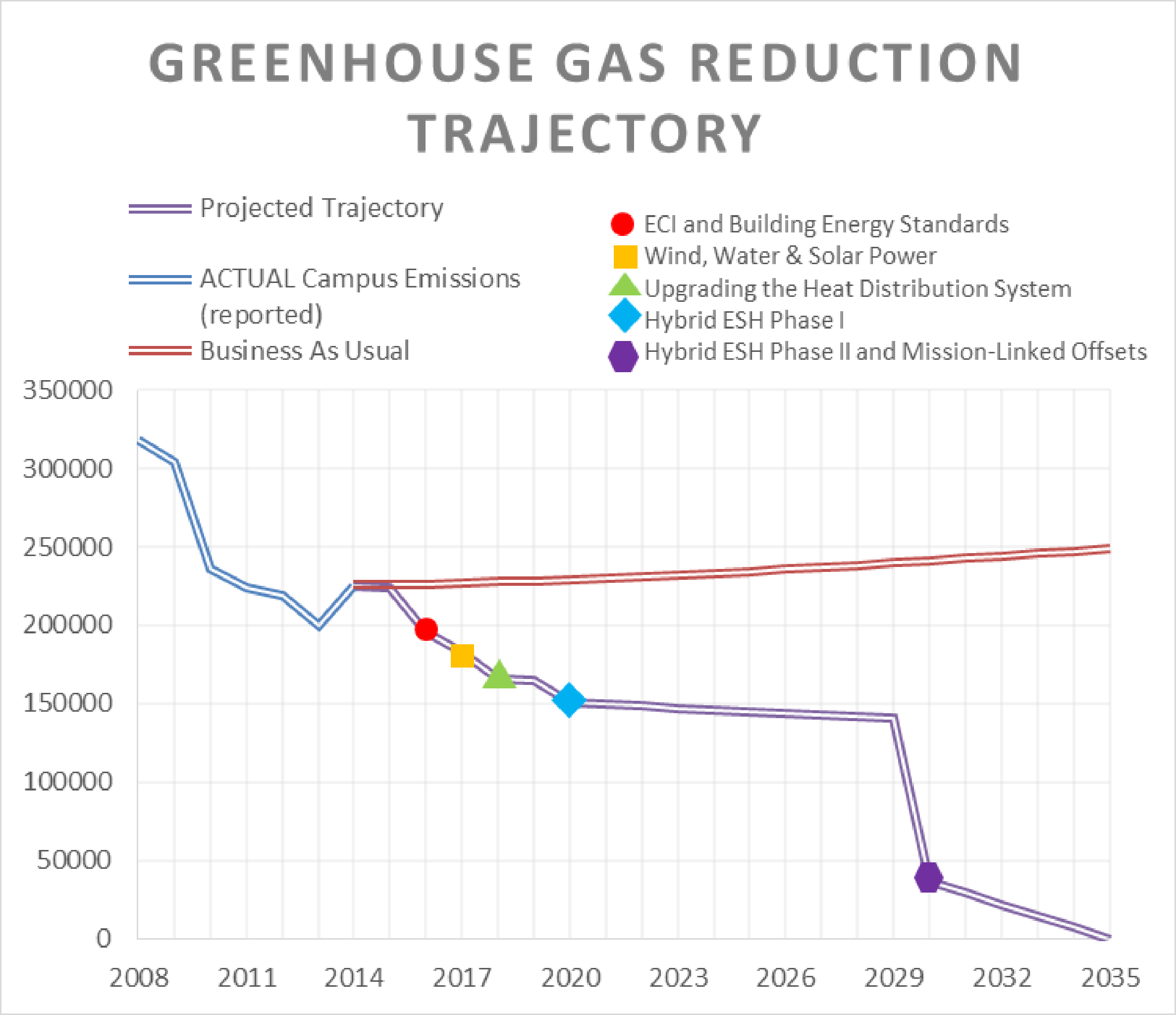


FIGURE 2.2: GHG REDUCTION PROGRESS, WITH PROPOSED FUTURE REDUCTION GOALS (CORNELL ENERGY & SUSTAINABILITY)

Section 2: Scope of this Report

This report builds upon past work to provide information needed by decision-makers to understand options for achieving carbon neutrality by 2035.

Past work and data incorporated into this report include the following:

- Cornell's "2009 Climate Action Plan" (CAP), including updates. See: http://www.sustainablecampus.cornell.edu/initiatives/climate-action-plan
- 2015 Thermal Resources Study Report, an in-house study
- June 2015 Campus Distributed Heating System Long Term Plan, another in-house study
- Data from Energy & Sustainability (E&S) related to Cornell's achievements in, and plans for, purchasing renewable energy via Power Purchase Agreements and similar actions
- Energy Conservation Initiative (ECI) data, analysis, and planning work by E&S
- Deferred Maintenance Plan (specifically to consider the impact of "gut renovations" on energy use and the cost to minimize use to "best in class" standards)
- Carbon Offset White paper

The report reviews these past works and develops alternative strategies for Carbon Neutrality. Past efforts, will be summarized and updated as appropriate to incorporate newer technologies and new knowledge. In addition, this report reviews the strategy of using carbon offsets as an alternative to eliminating fossil fuel and eliminating commuting and air travel emissions.

Our current "carbon footprint" also includes two types of GHG emissions associated with Cornell, namely "commuting" emissions (those associated with individuals commuting daily to work at Cornell) and "business travel", which includes fleet vehicles but is substantially related to distance travel and especially to airline travel. The original CAP and CAP updates provide a broad host of actions to reduce these types of emissions including programs encouraging alternatives to single-occupancy commuting ("transportation demand management"), distance conferencing, and fleet purchase of highly-efficient or electric fleet vehicles. In this report, we look specifically at increased support for electric vehicle charging stations as an enhancement to those programs, especially as technology has advanced to the point that electrically-charged vehicles are more common. Otherwise, this report is primarily focused on emissions related to energy (heat, cooling, and electrical power use) for campus, which accounts for the lion's share of our emissions are represent the emissions areas where Cornell has the most control.

For electricity, the concept of "net zero on an annual basis" will be considered achievement of the goal; specifically, the goal will be the generation of sufficient non-fossil-based electricity annually to offset all of the electricity use on campus on an annual basis, while not requiring disconnection from the utility grid or generation of all peak energy use at all times. Should an option be suitable for complete “energy independence from the grid”, this is acknowledged in the report as a potential achievement “above and beyond” the net zero goal. This strategy will also be compared and contrasted with the alternative strategy of purchasing offsets in lieu of changing our fuel mix or generation practices.

A focus of this report will be to establish approaches to Climate Neutrality using “proven technology.” This focus carries the implicit assumption that Earth Source Heat (ESH) remains unproven in this region (i.e., given the current knowledge of our local geology and local energy pricing and policy, it may not be able to economically provide the energy needed), or may not be successful in getting required local approvals. ESH will be included in the analysis to provide comparison and contrast with other options studied, but other alternatives are still desired to mitigate the risk should ESH be found unsuitable for Cornell.

Cornell’s current Climate Action Plan (CAP) calls for reaching climate neutrality at its Ithaca campus. The Ithaca campus already utilizes Lake Source Cooling (LSC) to provide essentially all central campus cooling at extraordinarily low energy input rates and without the extensive use of chemical refrigerant and all options assume the continued use of LSC. Alternative studies are therefore focused on electrical supply and campus heating alternatives, which are both substantially provided today by a gas-fired Central Energy Plant (CEP).

A range of potential energy options were considered. These include several options analyzed in detail as part of the 2008 CAP, additional alternatives representing technologies employed successfully by other U.S. universities in recent years, and reconsideration of a modular nuclear power reactor, an idea considered briefly in the 2008 CAP effort. This study was requested due to several factors; namely, an acknowledgement of the continuous advances in technology and development of solutions since the original CAP; the failure of the initial CAP solutions to receive sufficient funding necessary for rapid advancement; an expression of interest by the Faculty Senate and supported by former President Skorton for acceleration of the CAP goals; and significant financial challenges based on changes in the energy marketplace: specifically, much lower natural gas prices in 2015 and early 2016 compared to 2008. This latter factor significantly impacts the financial evaluation of alternative energy resources.

In reviewing potential alternatives, a “Business-As-Usual” (BAU) case was developed, along with the following technologies and strategies:

- BAU (with natural gas used at the CEP), plus carbon offsets
- Green Development and Energy Conservation (incorporated into all scenarios)
- Bioenergy via biomass combustion (BC)
- Bioenergy via biomass gasification (BG)
- Earth Source Heat (ESH), Cornell’s version of Enhanced Geothermal Energy (EGS)
- Ground-source heat pumps (GSHP)

- Air-source heat pumps (ASHP)
- Small modular nuclear reactor (SMR)
- Wind Energy
- Solar Energy
- Hydroelectric Energy
- Replacement of fleet (and some commuting) vehicles with electric vehicles (EVs) over time combined with greater deployment of EV Charging Stations
- Purchase of Carbon Offsets (both for commuting and air travel scenarios and to cover any GHG emissions that remain as part of a broader alternative)

Building upon the results of this analysis and acknowledging that combined technologies might offer significant benefits, we also reviewed combinations of strategies. Primary combination strategies reviewed include the following:

- ESH to provide heat and renewable electricity (WWS) to provide the electricity needed for campus.
- ESH with biomass (BG) for "peaking loads" to provide heat (shortened to "B/ESH"), and renewable electricity (WWS)
- Heat pumps (ASHPs or GSHPs) with renewable electricity (WWS)

Each alternative was researched and given a qualitative score in each of categories covering Cornell's "quadruple bottom line" considerations (Planet, People, Prosperity, and "Purpose" – i.e. alignment with Cornell's mission). A summary of those "rankings" are included in the analysis sections and a table with all rankings included in the Conclusions and Executive Summary sections.

Other combined options alternatives and strategies could also be assessed at smaller scale. For example, the ESH or B/ESH option may also be supported by integration of hot water storage or by a limited heat pump application that utilizes a select waste heat source (for example, waste heat from the Wilson Synchrotron or energy transfer with the chilled water return line). Such targeted applications can more easily be evaluated once primary technologies are selected for campus-wide application. In most cases, the smaller-scale solution would be implemented over only one portion of the energy system of campus and then expanded over time if warranted based on costs and measured impacts.

Section 3: Quadruple Bottom Line Rating Systems

All technologies reviewed in this report were evaluated according to “quadruple bottom line” considerations: Planet (environmental), People (social), Prosperity (economic), and Purpose (institutional mission), using the following 12 criteria:

Environmental (Planet).
The following criteria pertain to the ability of the technology to meet our GHG reduction goals without causing other significant negative impacts:

- Thermal resource:
    - How much energy is potentially available?
    - How well suited is it to provide the quantities/rates of energy we need?
    - What temperatures can be generated? Suitable for steam or electricity?
- GHG offset potential:
    - To what extent will this technology simply shift campus energy demand to offsite sources, such as the electric grid?
    - What is the net GHG reduction potential?
- Technical unknowns:
    - What needs to be learned or resolved to ensure the technology will work?
- Implementation time:
    - Testing, demonstration, installation
    - What is the risk that the technology will not meet our climate neutrality goal?
- Non-GHG environmental impacts:
    - Land use, open space, biodiversity
    - Water use, potential for contamination
    - Non-GHG air emissions
    - Waste generation
    - Natural radiation from underground materials
    - Seismic risk

Economic (Profit):

- Cost:
    - Capital (short term) and operating (long term) cost estimates
- Uncertainty:
    - What is the risk that technical, social, or permitting challenges will slow the project or increase costs?

Social (People):

- Social benefit:
    - Is technology potentially transferable to other users?
    - Scalable to help with regional or global GHG reduction efforts?
    - Local/regional job creation and retention
- Community impacts:
    - Character of the community
    - Impacts on critical community resources
    - Traffic
    - Infrastructure
    - Visual impacts
    - Human health and safety
- Community acceptance:
    - Alignment with community values
    - Socioeconomics and Environmental Justice
- Regulatory Approval:
    - Are any significant issues anticipated related to regulatory approvals?

Institutional (Purpose):

- Alignment with Cornell mission:
    - Education, research, outreach opportunities
    - Breadth and scope of opportunities in alignment with existing Cornell programs
    - Impact on real or perceived institutional leadership and reputation

Methodology

Ratings were developed through a core group of SLCAG members with diverse interests in a workshop setting. The rating process was facilitated by Steve Beyers and Matt Kozlowski, representatives of Cornell's Infrastructure, Properties, and Planning organization. Steve and Matt had prior involvement in leading project workshops in support of the campus-wide Green Building program and also participated in the ranking workshops that were part of the generation of the original Climate Action Plan.

To facilitate their QBL assessments, SLCAG members were provided with summary information on each technology as included in this report and briefed on the rating system described in this Section. The workshop included a general discussion of the potential benefits and impacts of the action. Following this discussion, each member of the rating team provided a "blind" rating. The blind ratings were revealed and an "average rating" calculated.

After discussions of all options were complete, the results of the discussion were summarized and the entire portfolio of options compared for consistency with adjustments made as necessary to reach group consensus and ensure concerns or options were expressed. Each alternative (and evaluated combination of alternatives) reveals different benefits and impacts. Ratings were selected from a scale of 1 to 5, with 1 being “low” and 5 being “high”.

Section 7 describes some general notes regarding QBL impacts for each option. Appendix A provides a summary of the SLCAG rating results, including both the actual ratings and the Standard Deviation of the sample, to provide some additional insights into the conformity of viewpoints related to these ratings.

SLCAG previously received a report from a group of graduate students in the Sustainable Business Development program at Cornell. This paper recommended similar rating methodology and sought methods to help quantify disparate rating areas (i.e., to provide a comparison value for “impacts to people” and “financial impacts”). However, the student group did not succeed in resolving a specific quantitative comparison, since there was no clear consensus on how these areas should or could be compared. Therefore, in this report we have not tried to “total” disparate QBL rankings or compare them on a strict quantitative basis. Rather, the results are merely presented in parallel so that non-financial attributes of each area can be identified and appropriately considered by campus leadership (SLCAG).

Section 4: Financial Analysis Assumptions

For the purposes of this study, assumptions were made about energy costs, discount rates, net present value term (“project life”), offset values, and similar factors. These assumptions are reviewed in this Section.

4a Current and Future Energy Cost Assumptions

In evaluating options, future energy cost estimates are required. The art of predicting future energy costs is inexact and relies on numerous factors outside the control of the University, so some simplifying assumptions were desired. Figure 4.1 shows an example of historical rates (in this example, for the wholesale cost of gas at the “Henry Hub” regional terminal, a common cost marker). As the figure demonstrates, the cost of natural gas has been neither consistent nor easily characterized over time.

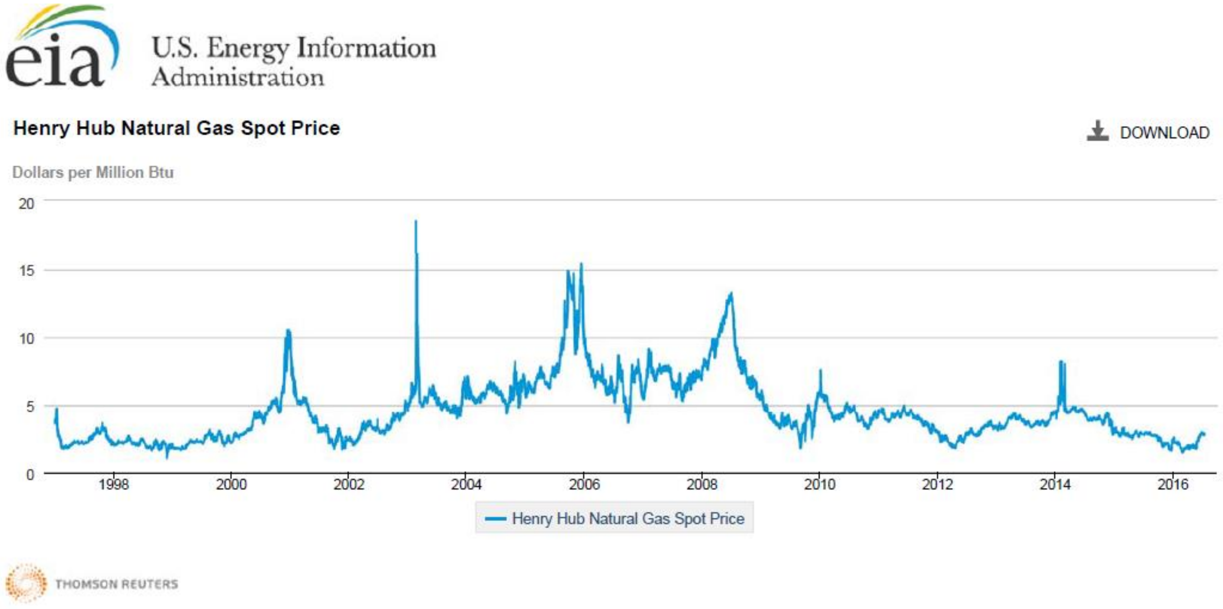
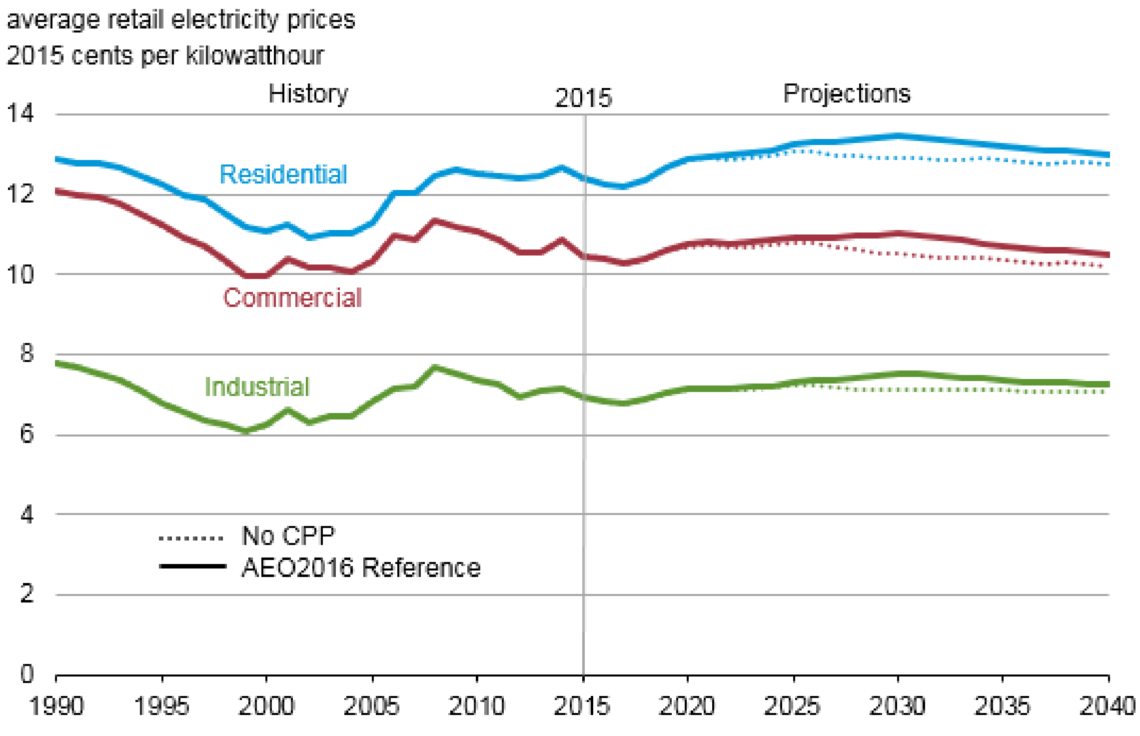


Figure 4.1; Historical “Henry Hub” Natural Gas Prices

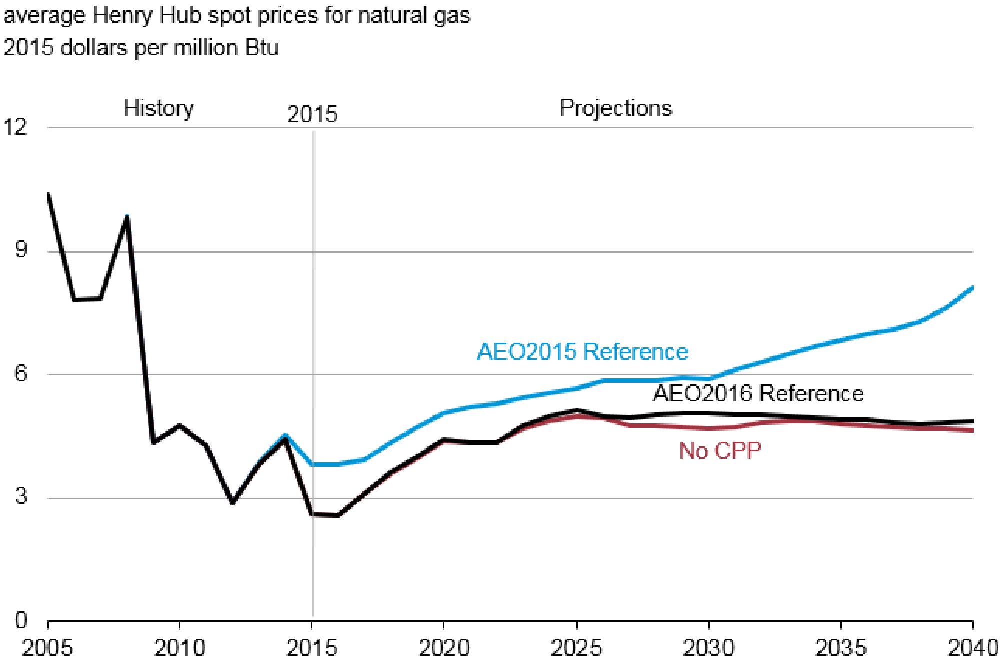
Future energy costs are also unpredictable. Figures 4.2 and 4.3 shows future cost predictions by the federal government’s Energy Information Agency (EIA) for both gas and electric, respectively. Some patterns are noted by the EIA and revealed by the figures:

- Current prices are depressed due to recent development below the point of long-term “supply and demand” price stability, and that prices will recover in the next several years.
- Once recovery is complete, prices will remain relatively “flat” for the foreseeable future, in constant (2016) dollars
- Predictions are not highly accurate, as suggested by the relatively wide change in the 2015 prediction versus the 2016 predictions are shown on in Figure 4.3



Source: EIA, Annual Energy Outlook 2016

<u>Figure 4.2: U.S. Energy Information Agency (EIA) Long-Range Future U.S. Electrical Costs Projections</u>



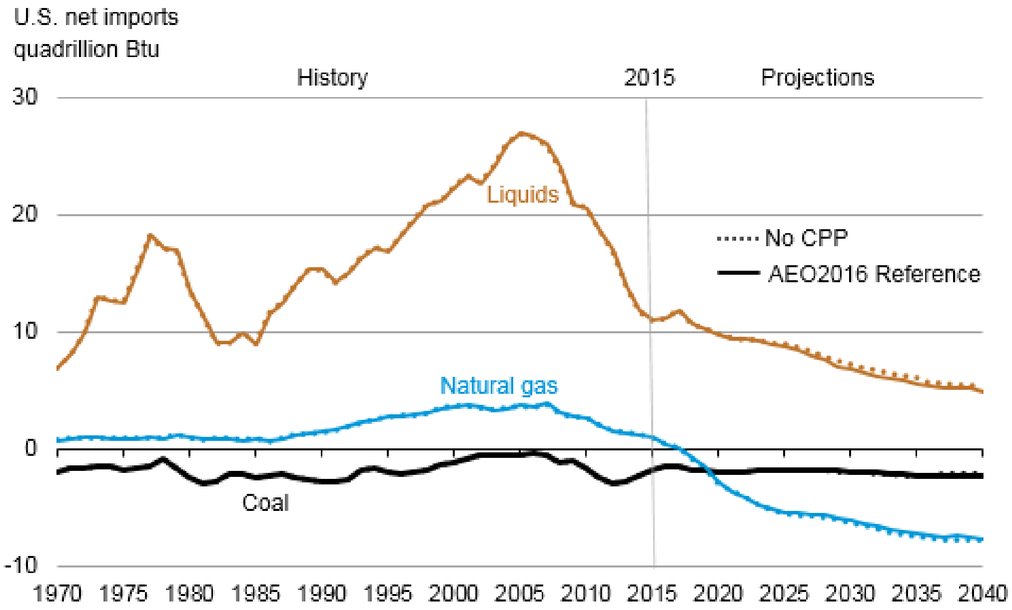
Source: EIA, Annual Energy Outlook 2016

<u>Figure 4.3: EIA Long-Range Estimates of Future U.S. Natural Gas Costs</u>

Based on past history, prices are unlikely to be as “flat” as projected; these expert estimates are at best a consensus option of average future prices over longer time periods rather than a prediction of short-term volatility.

Cornell currently enjoys below-national-market-costs for both natural gas and for electricity, due to our proximity to a “constrained” interstate pipeline containing a large amount of natural gas produced by the Marcellus Shale formation. This fact impacts both natural gas pricing and local electrical rates, since a significant portion of the electrical generation (and an even higher proportion of the “non-baseline” generation, from which real-time-price is set) is produced using natural gas turbines in our area.

Due to insufficient pipeline capacity and limited current natural gas export, these local prices are significantly below the “Henry Hub” prices commonly referenced nationally (Henry Hub is a large natural gas terminal station in Louisiana). However, based on consultation with energy experts including our own Professor Schulze, the impact of anticipated new large pipeline construction and new liquefied natural gas facilities to allow for export to the international market, Cornell should expect prices to rise to rates similar to national averages in the next 6-10 years. Our financial modeling therefore reflects this expectation by starting with low pricing (similar to our experience over the past 1-2 years) and ramping up to “national” pricing levels within 10 years. Similarly, EIA also models natural gas and electric costs as “recovering” to somewhat higher prices in the shorter term (within about 10 years), in part due to the expectation of higher energy exports, as shown in Figure 4.4. Because natural gas costs are much higher in many countries than it is in the U.S., a growth in export capacity is anticipated by EIA to result in higher future energy costs for domestic users.



Source: EIA, Annual Energy Outlook 2016

Figure 4.4: EIA Projections: The U.S. will be a net exporter of natural gas in the near future and continue to be a growing exporter into the more distant future

Since our actions are all modeled as starting in FY 2027 and all of our NPV calculations are based on 2027-2056, this "ramping up" does not impact the financial analysis reported in this document. Specifically, this analysis assumes a "leveled" future cost for both electric and natural gas supply ($0.07/KW-hr and $5/MMBtu, respectively) based on the EIA's costs.

4b Marginal Energy Costs versus Full Energy Value

All scenarios within this analysis look at actual marginal energy costs (just the actual cost to Cornell for the additional energy) with the exception of the "demand management" analyses in this report (energy conservation, re-commissioning, and green building standards). The full billed energy rate is used in those demand management cases, based on current billed rates (future rates may vary, increasing somewhat with energy cost increases but decreasing when debt is retired). This is accomplished by adding a multiplier in the spreadsheet to account for this difference.

For small actions that will only impact a single facility or a small part of campus, the actual financial impact to the University may be much closer to the marginal energy cost, but for larger projects and over time, the full billed cost is more representative of the true value of the demand management action, since cumulative impacts impact the overall capital and operating systems used to provide energy. Since this report is generally concerned with broad, long-term options, the full (billed) value was used for analysis purposes.

4c Discount Rate and Present Value Term

Based on discussions with SLCAG and others, this report utilizes a Real Discount Rate of 5%. This assumes a return on investment of 5% beyond the level of inflation, representing the anticipated return over time of Cornell's investments (i.e., other options for our funds). This rate is used for all analyses except where specifically noted otherwise. Similarly, when annualizing costs, this same figure (5%) is used to calculate the cost of money associated with capital expenditures.

The analysis associated with this report used a 30-year term (2027-2056) to evaluate average annual costs. This term length reflects a compromise in the average expected life of most of the capital improvements compared.

For certain options, additional capital outlays are required and are included within that 30-year term. For example, ESH is modeled with the relatively conservative assumption that the heat reservoir will provide 10 years of heat at the calculated value before re-drilling into another hot reservoir will be needed (during which time the prior reservoir may begin to recover). Similarly, Small Nuclear Reactors are expected to require refueling each ten years. Costs for each of these design expectations are included in the analysis in the appropriate years. Finally, some capital expenditures will still have value after 30 years; for each option, an estimate of this “residual value” is added back into the last year of analysis to allow this value to be considered in the overall analysis.

4d Treatment of Escalation

This analysis assumes that future capital costs, energy costs, and most other costs rise at the same rate of inflation. All costs are reported in constant “2016 U.S. Dollars”. Since a real discount rate is used and all costs are reported in current dollars, energy costs and operating costs appear “flat” in future years in this report. Using the spreadsheet of capital and operating costs, adjustments to escalation could be added. However, since the EIA has predicted that energy costs will remain relatively steady (and even decrease in some years) in current-dollar terms, and we have generally assumed that the analysis starts at the time of capital investment (which in our case were determined to be 2027), we have not included differential escalation for the purpose of this report.

The exception is in our calculation of “social offset costs”, which is described in the next paragraphs and does include an escalating value over time.

4e Valuing External Costs

While we have performed a “quadruple bottom line” analysis, we have not attempted to convert non-financial values (social, environmental, or institutional) into equivalent dollars. However, the analysis (in other than the primary BAU case) does include a consideration of how the valuation of “external costs” (those that may impact others, but not Cornell directly) might impact decision-making.

Specifically, the analyses include the environmental or social value of reduced greenhouse gas emissions by including a cost of “offsets” for GHG emissions in each “campus solution” case other than the first “Business as Usual (BAU)” case. In scenarios where there are no fossil fuels to offset (such as the case with the Small Nuclear Reactor, which would provide all electricity and heat), this cost is zero. For partial-solution scenarios that, for example, require more electricity (such as heat pumps), offset costs are included to account for the additional electricity, which is assumed to originate from the local electrical grid. For this analysis, GHGs associated with this “purchased electricity” is calculated at current grid “embedded carbon” rates in this region, which are relatively low compared to national rates.

Options which include WWS renewable electricity at a scale to match the net usage of campus are not assessed these “offset” costs. Despite this accounting treatment, Cornell would actually utilize grid electricity for these options, due to the asymmetry between loads and generation common to wind and solar renewable resources and also due to the fact that renewable energy of this scale would likely be generated off-campus and not physically within Cornell's internal electrical distribution system.

There is also a separate analysis that incorporates the same logic but increases the calculation of emissions based on "upstream methane emissions" (per calculations by Professor Howarth et al) under the assumption that such methane is associated with natural gas originating from shale formations by virtue of industry practices and technical difficulties in controlling this "leakage". Since methane has a much higher GHG potential than carbon dioxide, this impact is substantial.

The financial value used for all "offset" calculations (Figure 4.5), as published by the U.S. Environmental Protection Agency (https://www3.epa.gov/climatechange/EPAactivities/economics/scc.html), was recommended for use in this analysis by Dr. Schulze based on his decades-long involvement in carbon pricing and valuation. The values chosen (see circled values in Figure 4.5) represent a "compromise" between a higher social cost calculated with a higher Discount Rate (which generally treats social and health costs the same as any capital or operating asset) and a lower social costs calculated by assuming a lower Discount Rate (or, equivalently, more conservative assumptions regarding potential health and social impacts of climate change and how these might impact finances).

Social Cost of CO_2, 2015-2050 [a] (Dollars per metric ton CO_2)

Source: Technical Support Document (PDF, 21 pp, 1 MB): 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% 95th 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.

<u>Figure 4.5: Offset Costs.</u>

This report used prices from the "3% Average" Column

Section 5: Action Categories Considered

For the purpose of the analysis of this report, potential actions have been separated into three action categories:

- Green Development and Energy Conservation
- Integration of Carbon-Free Energy
- Offsets and Offsetting Actions

5a Green Development and Energy Conservation

The foundation for the Cornell CAP, and indeed for nearly all climate action plans in existence, are the twin strategies of “green development” (i.e., designing and building systems to use only the minimum energy needed) and “energy conservation” (i.e., updating and adjusting building systems to use less energy while accomplishing academic goals). In each of these areas, Cornell has robust programs with large impact.

In the area of Green Development, institutional changes which occurred at about the same time as the 2009 CAP (and in part influenced by that commitment) included a broad commitment to reducing the physical growth rate of campus. The focus of this program was to make more efficient use of existing space, rather than to add new space, unless new space was absolutely necessary in accomplishing our academic mission. Sometimes termed “Smart Growth”, this broad concept was a key action item in the 2009 CAP. To implement this Smart Growth idea, a specific review process became part of all Project Authorization Request (PAR) reviews to first review space needs and availability, and to acknowledge future O&M costs and impacts. The result of this review process (coinciding with a University commitment to reduce debt) was a significant reduction in planned new facilities. In addition to the many millions in capital costs saved by avoiding new construction, another important benefit has been the accompanying lower O&M costs (which includes energy use and costs, and thus energy-related climate impacts) by millions of dollars annually. Nonetheless, Cornell is a dynamic institution and some areas of growth are still expected; “Smart Growth” does not equate to no growth.

In addition to Smart Growth, Green Development also included a commitment to low-energy buildings, with a design standard that targets energy use of no more than 67% of the energy mandated by the Energy Conservation Code (i.e., a 33% reduction from that standard) and that provides specific, metered energy use per unit area (BTU/gsf-year) for every project. Together, these two actions have significantly impacted the current energy needs of campus by reducing building energy needs, just as predicted in the 2009 CAP.

Broad-based Energy Conservation actions have also been implemented. Although these programs have been in place for decades and were already robust at the time the 2009 CAP was created, significant supply-side projects (which reduce the input energy needed to supply campus heat and electricity) and demand-side projects (which reduce demand at buildings and facilities) have continued. Full-time staff including two experienced Certified Energy Managers help oversee the University's energy management program for the central plants (supply side) and the buildings (demand side). With decades of staff experience, energy conservation at Cornell is showing extremely positive results rivaling any institution in the nation.

Supply-side projects in the last several decades have included:

- Boiler steam pressure was doubled to 400 psig in 1986 so that cost-effective steam turbine electric generators could be installed. These steam generators now generate 30 million kWh per year in electricity (approximately 12-15% of total campus use) at about twice the thermal efficiency of conventional power plants. The steam pressure is reduced to distribution pressures (less than 100 psig) upon leaving the plant.

- The Combined Heat and Power Project (2009) added twin 15-MW combustion turbines with heat recovery steam generators to allow for primary (gas-driven) co-generation. Since this addition, the CEP has two stages of electrical generation (utilizing the combustion turbines first, then the steam turbines), allowing Cornell to cost-effectively produce most (85%+) of the electricity required to operate the campus annually.

- Other supply side energy conservation projects include variable speed drive draft fans, pump and fan variable speed drives, lower plant distribution pressures, installation of various technologies for improvements on combustion efficiency, replacement of Boilers #6 and 7 (and current replacement of former boilers 1 and 2 with new boilers 3 and 4), and distribution system leak repair and insulation upgrades.

- Significant upgrades and improvements to the steam supply system have been occurring since the 1980s. In the 1980's, large portions of the central steam supply system could be identified from the ground surface in early winter by lines of melted snow between manholes with visible steam emissions. Since that time, more than half of the steam system has been replaced with newer insulated lines and upgraded manholes, significantly reducing steam leaks and thermal losses of the system and improving safety and reliability. Upgrades continue annually based on maintenance inspections and analysis of annual infrared-guided "flyovers". Nonetheless, steam distribution losses, while significantly reduced, are still substantial; on an annual basis only about 83% of the energy in the steam leaving the CEP is received at buildings on campus; the other 17% is lost to thermal losses to the ground and air in tunnels and manholes and cumulative small steam leaks within steam traps and other equipment.

Demand-side programs have been just as, or perhaps even more, robust. Currently, most of the supply-side work is focused within two programs, specifically, the Energy Conservation Initiative (ECI) and the annual work of the Energy Conservation Control Team (ECCTs). ECI focuses on campus-wide analysis of buildings and systems to identify cost-effective ECI measures while the ECCT team provides campus-wide support in maintaining critical controls settings in buildings and replacing faulty controls so that low-energy controls function properly.

Some highlights of these programs include the following:

- Recent ECI results have shown a campus-wide reduction in both total demand and peak demand. The overall steam savings are forecasted at 70,000 klbs/year by FY 2015, ~7% of the typical ~1,000,000 klbs in annual steam sales. The percentage reduction in the peak is assumed to be half of the sales reduction, or ~3.5% of the peak (about 14 MMBTU/hour of ~400 MMBTU/hour). Appendix E summarizes recent performance of the ECI programs in reducing annual energy use.

- Based on a comprehensive internal study, ECI efforts have completely negated the impacts associated with construction projects over the past 15 years, reducing the peak to 404 klbs/hr for 2015 and keeping the peak curve for 2020 comparable with the pre-ECI (2012) peak curve. By 2030, barring future similar successes and allowing for modest growth, the 1-hr peak steam demand is projected to be 429 klbs/hr, an increase of approximately 4% over the calculated current peak of 412 klbs/hr; however, with continued ECI (as assumed throughout this report) we are assuming that the peak and annual rates remain unchanged, since capital growth has further slowed and there is now several decades of successful ECI history to back up this expectation.

- The success of energy conservation was uniquely demonstrated by the performance of the system over the 2014-15 winter. During that winter, which included a record-setting cold February in Ithaca, New York (with a total of 14 days with temperatures reaching below 0^{o}F, two days with temperatures at -18^{o}F or below, and an average temperature over the entire month of 10.3^{o}F) steam demand peaked at only 378 kBtu/hour. Moreover, this peak was for only one hour, on a -22^{o}F morning, which was below the calculated-basis -20^{o}F minimum value. Peaks on other days were more than 10% below the peak predicted based on prior data based on exterior temperature, suggesting consistently lower steam use than predicted.

- Dramatic and lasting conservation results are achieved by continuously optimizing our building automation and control systems, heat recovery systems, and lighting systems. Conservation-focused preventive maintenance on these systems reduces usage and maintains performance – in other words, saved money while improving comfort, safety, and lighting levels. Conservation studies and capital improvement projects add the latest features that can be cost effectively retrofitted to existing systems. New construction and renovation on campus are guided by mandated features, energy usage intensity goals, and life cycle cost benefit analysis. Our design standards have shown a high level of success in most cases, although they depend on accurate energy models from our design teams and a few newer buildings have provided less positive results.

- Lighting retrofits. Aside from broad-based ECI programs, several generations of programs have been instituted. Earlier programs (started in the 80's and 90's) focused largely on replacing incandescent and other low-efficiency lighting systems with fluorescent lighting systems and installing electronic ballasts with higher efficiency lamps. More recently, many of the older fluorescent lighting fixtures are being replaced with newer Light Emitting Diode (LED) technology. LED fixtures and luminaires can provide superior light (a wide range of color temperatures) using only a fraction of the electricity (sometimes as low as 10-15%) as used by comparable incandescent fixtures in the past. Unlike fluorescent bulbs, LEDs also are mercury-free, making them safer for use and disposal, and many are better suited to varying temperatures and dimming applications, allowing even greater savings.

- Microprocessor-based control equipment replaced former mechanical/pneumatic controls, starting in about 1985, providing much higher reliability, accuracy and automation. Digital controls have been periodically enhanced and upgraded ever since this conversion. Additional electrical improvements include variable speed drives (the standard for much of the equipment used for heating and cooling today) and occupancy sensing for light, ventilation, and temperature setpoints.

Overall, recent performance, combined with detailed projections, suggests that reduction in system losses and continued energy conservation could eliminate additional steam project needs in future years for decades, preventing the need for supply system expansion. Nonetheless, maintenance and end-of-life replacement of steam-producing systems will still be needed, and some expansion is possible if growth outpaces projections, decisions are made to curtail aggressive energy conservation in the longer run, or climate change results in colder-than-predicted future winters.

In addition to reductions due to physical changes in buildings, Energy & Sustainability has also implemented a program to educate and motivate members of the campus community to reduce their energy use. This includes the employment of a full-time employee who works with staff and students to promote all forms of sustainability on campus.

While the impact of this effort is apparent to many on campus, the overall campus energy demand at Cornell is strongly dependent on the energy needed for high-level research facilities (such as the Synchrotron or any of our large research facilities) and not as highly influenced by behaviors at the student/staff level as would be the case in a residential or commercial setting, since most energy systems are automatically controlled (or controlled at a level beyond the average individual). Also, since students normally spend only about 4 years on campus (and many are not on campus year-round), these efforts mainly serve to maintain lower-energy behavior and cannot be assumed to continuously reduce energy use, as some more permanent actions can. Rather, continuing this program is essential to maintaining current energy use and keeping it from rising when the informed/educated students graduate.

Overall, Green Development and Energy Conservation practices have succeeded in preventing growth in the use of campus energy since 2000, and if fact have helped slightly reduce electric and heating needs. The assumption for the future is that energy needs will remain relatively constant, even as the University continues to change and a broad-based research continues. This primary assumption (no increase in energy needs over time) was used in this report for evaluating options.

5b Integration of Carbon-Free Energy

Over the past several decades, the University has made great strides towards reducing carbon output from both the purchase and generation of electrical and thermal energy required to operate the campus and support the mission academic activities. These transitions have included large scale investments such as lake-source cooling, the combined heat and power plant, and distributed solar photovoltaic installations at outlying facilities (and a few small rooftop applications). While these investments have already produced impressive carbon reductions, the production of electrical and thermal energy required to operate and support campus physical infrastructure and assets still remains the highest source of carbon emissions within the University inventory.

As low-carbon energy production technology continues to evolve, new options for carbon-free generation continue to mature. Some options, such as Earth Source Heat show great promise, yet are technically unproven at this time. While the University should continue to support and investigate feasibility potential technical solutions as both a carbon-free utility option for the campus and as a pursuit tied to our academic mission, a full suite of mature technologies must be evaluated and implemented to ensure that carbon neutrality can and will be achieved on an accelerated 2035 timeline.

5c Offsetting Actions

Despite efforts to reduce climate impacts through conservation and efficiency efforts as well as the generation of carbon-free energy, zero carbon emissions may prove impossible within the confines of the University footprint, especially if transportation (commuting and business travel) impacts are included in the inventory as they are currently. This may reflect limitations in current technology, available financial resources, or lack of control over external systems (such as transportation emissions). Alternately, more financially and physically efficient forms of carbon mitigation may exist outside of the University physical footprint.

The original 2009 CAP did not recommend the direct purchase of Renewable Energy Credits (RECs) or similar offset purchases. Rather, it recommended the University explore carbon-offsetting actions, opportunities, and ideas more broadly, with the goal of identifying those actions that would support the financial, environmental, and social needs of the University and community as a whole. Actions which represented University innovation were especially appealing.

In addition to transportation sources, there are two other primary energy needs that currently result in high GHG emissions for campus, namely our campus heating load and our campus electrical load. In addition to considering these independently, this report also acknowledges the interconnection between heat and electrical production that results from our current high-efficiency Combined Heat and Power Plant (CHPP). Renewable alternatives that allow for continued co-generation are more attractive, since they relieve pressure on other renewable alternatives for creating electricity. Conversely, options which increase our overall electrical needs significantly increase our challenge of replacing grid electricity with renewable electric sources, and this interrelationship is also considered. Therefore, for each alternative, we have estimated how much electricity could be co-produced with heat, and the net impact each strategy would have on electricity production and consumption on campus [see Highlight Box 2].

A large number of available options were considered initially, regardless of initial impressions regarding technical difficulty, cost, or community acceptance. For example, although solar thermal is used in limited hot water applications on campus (e.g. CCHPP offices and Plantations Welcome Center), first order estimates indicated it cannot provide building-scale heating during times of peak demand and therefore it was not carried forward for detailed analysis as a primary option. However, this report does not assume that technologies not analyzed in detail have no viability, only that it would not represent a long-term focus, since it had limited potential as an overall solution.

All analyses assume that Lake Source Cooling (currently meets Cornell’s cooling demands with an effective coefficient of performance [COP] of ~25) would continue to operate at its current capacity. This assumption impacts certain technologies in terms of the thermal balance between heating and cooling loads.

Appendix G provides additional information on Carbon Offsets.

Section 6: Business-As-Usual (BAU) "Base Case" and BAU+ Offsets

To evaluate the cost of various options, we first provided a simple analysis of the Business-as-Usual (BAU) "Base Case". The BAU case assumes the long-term continued us of the current utilities infrastructure, including the Central Energy Plant (operating on commercial natural gas), Lake Source Cooling, and the current electrical infrastructure.

The BAU case represents no initial investment (no capital expense or CAPEX above current annual values) and only current operating costs, which essentially equate to the complete operating budget for these central utilities (those related to heating and electric generation only; chilled water utilities and potable water were not included).

One adjustment to the BAU budget (above current annual budget) was employed. Since no CAPEX is included in the Base Case above current values and E&S managers believe the current annual capital budget is insufficient for sustained operation without new capital at some future point within this analysis period, we added $4M annually to the budget. This new "operating budget" represents a value which E&S managers believe represents the costs to "perpetually operate" the plant, at least over the term of the project. Other than this adjustment, the current annual budget for each energy utility (steam, cooling, and electric) was used to estimate ongoing costs. Future base case operating costs are unchanged in current dollars except to account for expected changes in purchased utility (gas and electric) costs over time, as discussed in the assumptions section of this report.

We also present a second BAU Base Case that includes the purchase of offsets ("BAU+ Offsets") to cover all of the GHG emissions of the current BAU scenario. This second case is used to compare the total capital and operating costs reflective of various "action" options to the option of continued current operations and "buying our way out" of carbon emissions obligations. It might be worth noting that, as explained in Section 4, the current "market" cost for offsets is actually substantially lower than the values used in the analysis, since purchase of offsets for most entities (including Cornell) is currently "voluntary". Use of this higher "Social Cost of Carbon" value is therefore not a strict financial treatment, barring changes in regulations.

Section 7: Financial and QBL Analysis of Alternatives

In this Section (and referenced Appendices), the various alternatives for achieving climate neutrality are described and evaluated. A financial analysis of each option is provided. Additionally, the Quadruple Bottom Line (QBL) analysis of each alternative, as described in Section 3 and detailed in Appendix A, is included for reference.

In this section and in other summaries of this information, the following codes and color are used to assist in quickly communicating the QBL evaluation results:

- A ranking of “3.5 or higher” (on a scale of 1-5) is indicated by a “green” colored box and represents an alternative that rated a positive (beneficial) ranking in this area
- A ranking of “2.5 or lower is indicated by a “yellow” colored box to indicate that the alternative received a lower ranking (low benefit or potentially negative benefit) in that rating area
- A mid-level ranking (“between 2.5 and 3.5”) is left uncolored

7a Green Development and Energy Conservation

As detailed in Section 4a, Green Development and Energy Conservation are active and effective programs that help to reduce current and future energy needs on campus and thus provide a strong foundation for CAP goals. While broad-based Green Development and Energy Conservation are good strategies for any sustainability effort, this section looks specifically at the following two proposed future actions related to green development:

- Requiring exceptionally low energy as a standard during renovation projects, focusing on the building stock identified to have high deferred maintenance needs
- Future energy conservation actions with assumed lower payback

Financial Assumptions and Results

In normal practice at Cornell, Energy Conservation and Green Building initiatives are discussed on a case-by-case basis and initiated if the consensus view (typically reviewed at the Trustee Committee level) is that the initiatives will provide a net positive benefit (financial and/or reputational) to Cornell. For this report, it is generally assumed that some form of Energy Conservation Initiative (ECI) will continue, so that energy demands are kept relatively constant over the analysis term even with growth and change to academic programs, as has occurred over the past decade or so. It is also assumed that current or similar Green Building practices, which emphasize low-energy design, remain in place as a component to the overall goal of maintaining steady or slightly-reducing future energy demands.

Three different theoretical scenarios were run, as follows:

- **Green Re-development of Buildings with High Deferred Maintenance.** This evaluation considered the financial costs and benefits of higher-than-current energy standards (such as those being used in the re-design of Upson Hall) during expected improvements or replacements to campus buildings with high levels of deferred maintenance.
- **Aggressive Campus ECI Investment.** This evaluation considered a higher level of future ECI investment in the next ten years than was planned as of early 2016.

- **Increased Campus Commissioning Investment.** This evaluation projects the costs and benefits of adding staff and budget to the current campus re-commissioning team which routinely checks and updates energy control systems across campus to maintain peak performance.

Assumptions used for the green re-development option were based largely on consultant work during the original CAP. Specifically, this analysis assumes that we will spend an additional $20/SF for building improvement to achieve 20% lower energy use in buildings – about 30 kBTU/sf/year less for a typical institutional building. To compare this analysis with options that involve adding renewable energy, this analysis was scaled to compare costs on a "per MWH saved per year" basis. Since 1 MMWh = 3.4 MMBTU, these assumptions equate to improvements over 113 square feet (sf) to accomplish this goal, or an additional cost of about $2260 per MWh.

It should be noted that it is often extremely difficult to predict the additional cost that will result in a specific lower energy use. In some cases, the cost is actually less; for example, many modern high-quality glass-and-metal façade systems are very energy inefficient but cost much more than high-quality masonry facades with more strategic window placements. Additionally, buildings designed for lower energy use typically need less central mechanical equipment and less space to house that equipment. Reduction in required air flows can result in smaller duct sizes which may save on floor-to-floor heights for well-insulated building. However, high-performance institutional buildings also typically have more controls and premium motors and drives. Overall, data analyzed by the United States Green Building Council (USGBC) shows a very poor correlation between low-energy design and per-foot building costs. Nonetheless, for the purpose of this report, we determined that the assumptions used by our CAP consultant ($20/sf to save 30 Btu/sf/year) was reasonable based on the limited comparisons that we have reviewed.

We have much better data to consider relative to ECI investments and commissioning actions. For the ECI investment case, the energy managers within E&S can predict, based on decades of results, that a campus-wide $50M program will reduce campus heating load by about 10% (by adding heat recovery to some buildings and control upgrades, window replacements, and heating system upgrades in others) while simultaneously reducing overall electrical requirements by about 5% (largely through control and lighting improvements).

To analyze the impact of adding capacity to our campus recommissioning effort, we assumed that a crew of 4 persons and a budget for some controls components (for replacement as controls wear out) would cost about $1M per year total and result in a reduction in both heat and cooling of about 5% per year (this expense and that savings would continue for as long as the program was in place). This level of reduction was based on the building-by-building experience of the recommissioning team and their leadership.

Calculating and summarizing led to the results indicated in Table 7.1.

Table 7.1: Financial Results of Demand Reduction Investments

Demand Reduction Action	**Capital Expense**	**Net Present Value**	**Net Annual Cost**
Aggressive ECI Program	$50M	($5M) (Savings)	$(0.4M) (Saving)
Increased Recommissioning	$1M (annually)	($5M) (Savings)	$(0.3M) (Saving)
Aggressive Green Design – Deferred Maint Stock	$2,260/MWh/yr[1]	$1,892/MWh/yr (Cost)	$123/MWh/yr (Added)

Note 1: All figures "per MWh saved per year", for comparison with WWS options

The analysis indicates that ECI and increased commissioning will reduce costs for Cornell compared to the BAU case, based on the assumptions used in the analysis. The Aggressive Green Design alternative is less attractive, since it would cost Cornell additional funds based on the assumptions used, but it may still be less expensive than options for obtaining equivalent renewable energy. Additionally, compared with having to find replacement renewable energy, demand management is much easier to implement since it generally requires no external approvals, no land areas, and has no detrimental environmental impacts.

Quadruple Bottom Line Considerations

QBL ratings determined by the SLCAG committee for these Demand Management alternatives are indicated in Table 7.2.

Table 7.2: QBL Results for Demand Reduction Investments

	Rating (1-5) (1= Lowest; 5=Most Favorable)			
Alternative	*Supports Cornell Mission (Purpose)*	*Supports Cornell Finances (Prosperity)*	*Supports Community Goals (People)*	*Supports Environmental Needs (Planet)*

Supporting Technology				
Green Development	**3.6**	**3.1**	**3.6**	**4.4**
Recommissioning	**3.1**	**4.2**	**3.4**	**4.3**
Energy Conservation	**3.6**	**4.2**	**4.2**	**4.3**

Demand reduction options score relatively well with no significant negative impacts cited.

7b Renewable Electricity from Wind, Water, and Solar (WWS)

Assuming that the external electrical grid will not be entirely carbon neutral (i.e., that "society doesn't solve the problem for us"), the campus will need to generate a substantial amount of carbon-free electricity to achieve carbon neutrality without offsets. Some of the alternatives for providing heat to campus could also provide electricity, while others (such as heat pumps) would require additional electricity to operate. Appendix F provides a summary of the WWS activities now underway or being considered at the University. Table 7.3 summarizes how the options impact the electrical demands of campus.

Table 7.3: Renewable Electricity for Campus (all figures in annual MWHrs)

	Current Status and Plans		
	Current	5-year Plan	Notes
Electrical Load	225,000	225,000	Assumes ongoing energy conservation
PV - ground mount	5,700	35,000	170 acres in Ithaca utility load zone
PV - rooftop	120	120	Existing arrays
Wind Power	0	43,000	Assumes (7) 2.3MW turbines in Ithaca utility load zone
Hydroelectric	6,000	7,200	All Improvements to Existing Hydro
Net Electric Needed *(generated from gas or obtained from the grid)*	213,180	139,680	**34% Reduction Overall**

Table 7.3. includes currently-installed "remote net metered" PV at Snyder Road and Geneva, and planned wind and solar projects. As shown by Table 7.3, obtaining sufficient electricity to power all of campus from near-campus sources is very challenging.

Table 7.4 takes this analysis a step further to provide a "hypothetical" case for supplying 100% of the power (on an annual net basis) for campus. This hypothetical case assumes intense energy conservation, extremely large ground-mount PV arrays, another hydropower plant, and 14 (2.3 MW) power turbines. There are very significant challenges related to each of these hypothetical conditions related to space availability and competition with other uses. Other scenarios are of course possible, but these figures illustrate the great challenge in achieving carbon neutral electricity within our campus "footprint" (and just beyond).

Table 7.4: Hypothetic "Net Carbon Neutral Electric" Solution

	Current Status and Net Zero Potential (all figures in MW-hrs annually)		
	Current Status	Net Zero Future	Notes/Assumptions
Electrical Load	225,000	150,000	Drastic Energy Conservation (33% reduction)
PV – ground mount	5,700	54,000	270 acres
PV - rooftop	120	2,000	PV on essentially all available rooftops
Wind Power	0	80,000	(14) 2.3MW turbines, best avail locations
Hydroelectric	6,000	14,000	Max Existing Hydro + additional run-of-river plant
Net Electric Needed *(generated from gas or purchased from the grid)*	213,180	0	Net Zero (on an annual basis)

This is only a theoretical construct to demonstrate the scale of resources needed for net zero electric. Since space requirements for WWS solutions are so limited and new hydro-electric opportunities specifically are rare, our later financial analysis will utilize only PV and wind to determine financial impacts. That assumption essentially recognizes that PV and Wind resources would likely have to be purchases remotely (not primarily on campus)

The following sections provide some additional background, analysis, and assumptions in support of our WWS review.

PV Density and Space Requirements

Cornell's Snyder Road PV solar farm produces about 2,000,000 kw-hours of energy per year and required about 10 acres. That suggests that we need about 1 acre of available land (or roof top) to generate 200,000 kw-hrs annually – about 0.08% of our current annual electrical production and purchase (per Cornell's published 2105 Energy Fast Facts = 225,000,000 kw-hours). For example, to generate 10% of our current annual electrical demand would require about >100 acres of solar panels based on this density. This area would be unavailable for most other uses, and the production would vary widely – the peak production would be close to 25 MW in total, but this rate drops to a zero (or even a slight negative value) at night or during heavy cloud cover.

Finding acreage for PV panels in locations that could tie directly to the campus grid would be very challenging. A student-led (staff-supported) assessment of all campus rooftop areas resulted in an estimate of maximum annual production of power if every suitable rooftop (about 26 larger roofs in all) were covered with PV panels of about 1.7 GW-hr (about 0.8% of current campus electric supply). Therefore, we would need essentially all of these panels to be located on land (and possibly a small number floating on Beebe Lake). Figure 7.1 shows how the area required would look relative to the campus layout available as shown on the campus map.

By comparison, the Tompkins County Energy Roadmap (TC Planning Department, March 2016) recommends deployment of massive solar PV systems across the county, including a high saturation of rooftop units (accounting for 25% of "urban" rooftops and 50% of "rural and suburban" properties) and ground-mounted arrays covering about 4722 acres (1.5% of the County land area of 292 square miles), to produce about 1,225 GWh total. The production density from that report (around 260,000 kWh/acre) is similar to the figure derived from Cornell's actual experience at Snyder Road (200,000 kWh/acre produced). Cornell's number is somewhat lower due to the fact that the Snyder Road site includes some undeveloped area (due to a small wetland) and access around the site. Similar adjustments may be needed for the average county site depending on local conditions and PV panel selection.

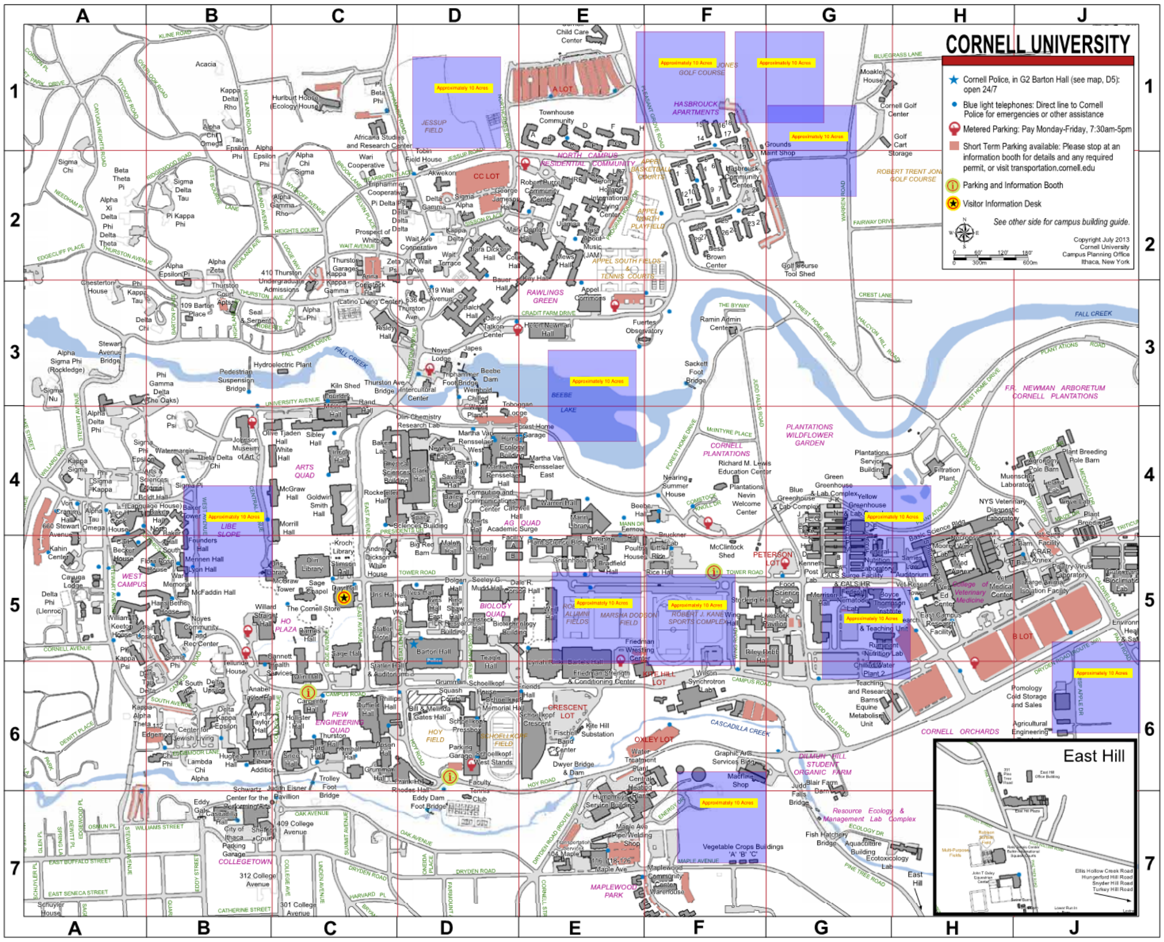
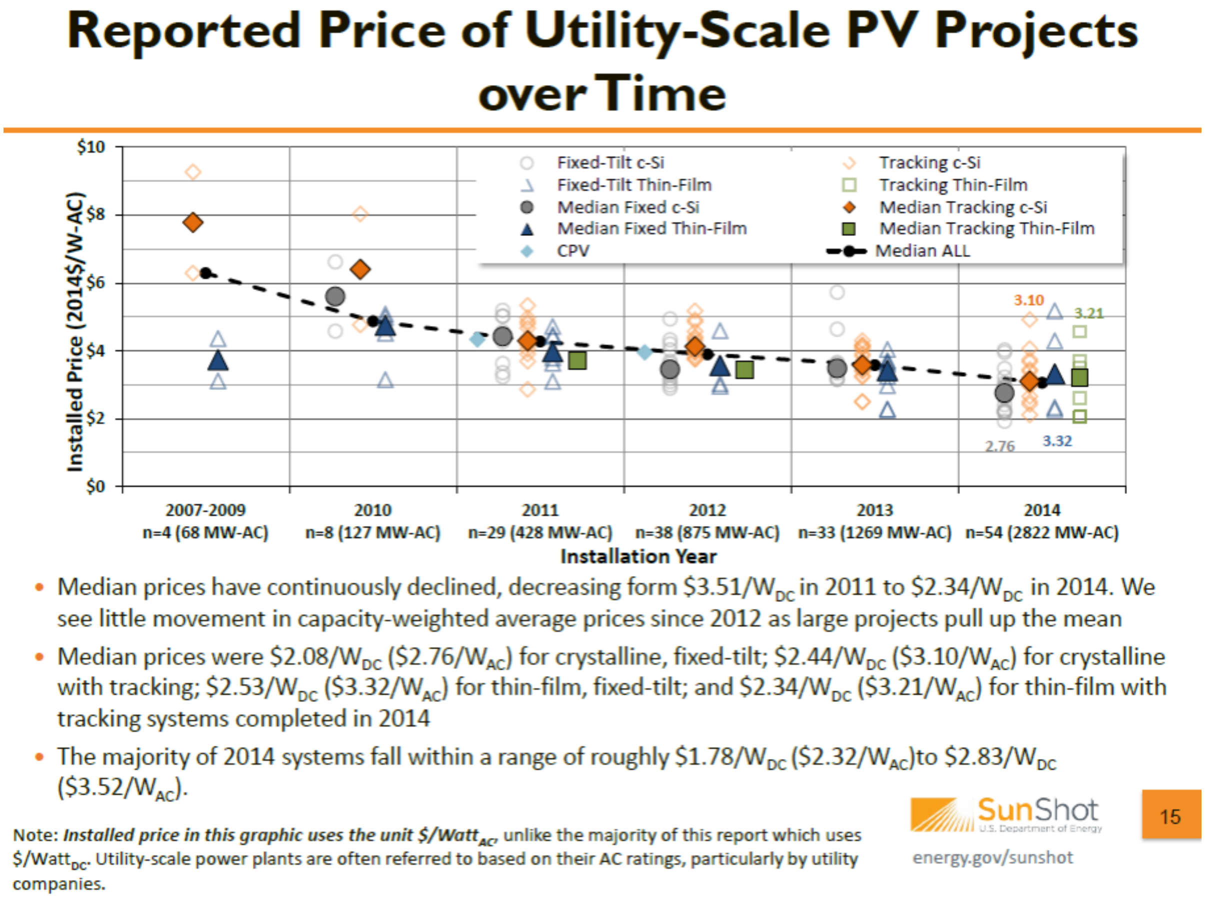


Figure 7.1: Cumulative Area to Achieve 10% Renewable Electric Using PV

Each purple square represents about 10 acres and could potentially accommodate enough PV for <1% of campus needs each. The areas shown for solar are NOT specific sites proposed; all of the areas shown have other designated uses. The purpose is only to show the relative areas required.

Costs for utility-scale PV projects have gone down over time. Figure 7-5 provides some typical cost information, which extended to 2014 only. Note the significant difference between the costs per watt (AC) versus the costs per watt (DC); the conversion to utility-voltage electric significantly impacts the per-unit cost estimates (many cost reports do not seem to recognize this difference, which may have led to some reports of lower-than-expected installation costs).



Reported Price of Utility-Scale PV Projects over Time

- Median prices have continuously declined, decreasing form $\$3.51/W_{DC}$ in 2011 to $\$2.34/W_{DC}$ in 2014. We see little movement in capacity-weighted average prices since 2012 as large projects pull up the mean
- Median prices were $\$2.08/W_{DC}$ ($\$2.76/W_{AC}$) for crystalline, fixed-tilt; $\$2.44/W_{DC}$ ($\$3.10/W_{AC}$) for crystalline with tracking; $\$2.53/W_{DC}$ ($\$3.32/W_{AC}$) for thin-film, fixed-tilt; and $\$2.34/W_{DC}$ ($\$3.21/W_{AC}$) for thin-film with tracking systems completed in 2014
- The majority of 2014 systems fall within a range of roughly $\$1.78/W_{DC}$ ($\$2.32/W_{AC}$)to $\$2.83/W_{DC}$ ($\$3.52/W_{AC}$).

Note: *Installed price in this graphic uses the unit $\$/Watt_{AC}$,* unlike the majority of this report which uses $\$/Watt_{DC}$. Utility-scale power plants are often referred to based on their AC ratings, particularly by utility companies.

Figure 7-5: U.S. DOE Historical Data on PV Installation Costs

Wind Power Space Requirements

Wind power requires substantial overall spacing (to prevent interferences in the wind field between turbines) but much less ground space. The impacts to the site are less than for solar PV since the turbine “footprint” is relatively small and active agriculture or similar uses can co-exist beneath wind turbines. To be economical, turbines must be sited for maximum power generation, which in New York State typically requires siting on locally-high ridges or along expansive water bodies. Tompkins County has generally marginal wind resources. For example, in recent years Cornell academic staff found that we were ineligible for direct participation in a federal wind grant program due to insufficient wind resources in the area.

In 2005, and as reported in the 2009 CAP, Cornell considered a site along the ridges of Mount Pleasant (near the Hoffman Challenge rope course) in the Town of Dryden. As analyzed at that time, the site could support up to eight 1.5 MW wind turbines with a combined rated capacity of 12 MW, which could be connected directly into the Cornell electric system via a ~5-mile route along land controlled by Cornell. Based on a capacity factor of 29 percent, annual output from the turbines would total about 30,500 MWh. (about 13.6 percent of current annual electrical production). This effort was halted in 2005 due to public opposition from several residences who lived near to the proposed site. Other potential concerns for that site were not completely resolved due to the cancellation of that effort, but include the potential for opposition from the FAA or local pilots (the site is near one of the approach paths to the Tompkins County Airport), interference from the WHCU radio tower, and some potential for bird or bat mortality at that location.

Cornell has also worked to support a community initiative in Enfield (Black Oak Wind Farm) which initially was widely supported in the community, but has been delayed recently due to similar local public opposition from a small but vocal minority.

Other sites such as Yellow Barn State Forest, Arnot Forest, and Connecticut Hill would permit some additional electrical production, but there are no known locations proximate to campus that would be able to easily supply electrical energy of similar quantity or efficiency. Smaller turbines would provide mostly symbolic (and, depending on view, aesthetic) value to the campus. Therefore, despite the past opposition from “potential immediate neighbors,” the Mount Pleasant site remains the best candidate for wind deployment which could directly serve Cornell.

By comparison, the Tompkins County Energy Roadmap (Tompkins County Planning Department, March 2016) recommends deployment in the County of 300 “medium scale” 500 kw wind turbines and 20 large scale (2.3MW) wind turbines, with the goal of achieving a total of 530 GWhrs of wind energy (about double Cornell’s current annual usage) County-wide, but is less specific about the locations. The larger turbines referenced in that report were not generally available at the time of the 2009 CAP and might be considered by Cornell for application should Cornell pursue a wind program, as these units are only slightly taller overall (125m versus about 120m, based on standard 80-meter tower) than the 1.5 MW turbine height, so impacts to plane and bird routes should be minimal. Assuming the same capacity factor as the originally-considered 1.5M units, eight (8) 2.3 MW turbines might produce almost 47 GWhr of electricity per year, or about 21% of our annual campus demand. Conversely, larger turbines may create greater bird/bat mortality or pilot flight risks or simply greater community aesthetic concerns.

Hydroelectric Potential

Some limited hydroelectric resources are also available in the area, specifically along the gorges and creeks (Fall Creek and Cascadilla Creek) that pass through campus and potentially along Six Mile Creek, which is just over a mile from campus. Cornell already has a hydroelectric plant in Fall Creek that has been recently upgraded and can deliver about 6,000 MWhr per year, or about 2.7% of campus annual electric needs. However, in recent years the output was lower due to active renewal projects which interrupted operation for extended periods, and in the current (2106) summer production has been curtailed for extended periods as a result of low flow and permit conditions (which require a minimum “bypass flow” be maintained around the system, largely for aesthetic reasons).

As described in the 2009 CAP, improvements to the hydroelectric plant and intake structures could potentially add another ~900 MWhr of production annually, without any significant changes to the gorge or Fall Creek flow, which would increase the renewable energy delivered to about 3.1% of current campus electrical needs.

There are other opportunities along the creeks, but they would likely be much less substantial. The exception may be the potential diversion of some flow from Ithaca Falls where an older plant built for Ezra Cornell, one of Cornell’s founders, once stood. However, Cornell no longer controls that property and a local and State ban against hydropower is currently associated with that site. A reasonable goal for “micro-turbine” electric use throughout the watershed controlled by Cornell is perhaps 1,000 MWhr annually (about 0.5% of current supply) based on technology that exists currently, based on student studies.

There are other local watersheds (Six Mile Creek, Cascadilla Creek, etc.) that have micro-turbine potential using run-of-river technology. Six Mile already contains three small dams which could potentially be used to tap into local hydroelectric potential. Some academic studies have recommended the local community or municipal governments pursue these possibilities, but Cornell as an institution has not actively pursued hydroelectric development in these watersheds.

For our existing plant in Fall Creek, a complicating factor is that the current hydroelectric plant is currently up for (FERC) permit renewal, and the revised permit may require more water bypass due to current standard practices. That change in permit condition could reduce electrical production during low-flow periods (dry weather), impacting the production up to 5% annually.

Energy Storage

A common complaint about many renewable technologies is that the energy produced is not available at all times. Specifically, solar technologies provide energy proportional to the solar intensity at any one time, wind technologies are dependent on variations in wind speed, and even hydroelectric potential is limited by the variable water flow in the creeks.

Similarly, Cornell currently overproduces steam in the summer as a byproduct of our electrical generation and some technologies, notably solar thermal, provide their heat resources only seasonally – in this case in the summer, when Cornell already has excessive steam. Solutions which could allow for long-term or short-term heat storage (for example, using a geothermal well or hot water tanks, respectively) should be studied for any viable solution (ESH, biomass, heat pumps) which might benefit from a reduced peak demand.

To support renewable electricity implementation, there is a strong research imperative to improve energy storage. Researchers at Cornell have been involved in various electrical/Power/energy storage technologies – analyzing battery technologies, considering thermal storage and conversion options, and investigating pumped water storage using a variable height adjustment for the Beebe Lake dam. Each of these areas of research have their own challenges. For example, the Beebe Lake storage solution is greatly complicated by FERC and NYS DEC permitting costs and processes and associated community environmental impact concerns. Despite these practical and regulatory issues, the need to find storage to facilitate the pairing of wind/solar with battery storage and pumped storage to mitigate intermittency and provide for peak demands remains a worthy technical and institutional challenge. However, at the time of this report there were no well-developed solutions suitable for analysis.

Estimates of Cost and Financial Results

Estimates of capital cost for renewable energy options included in the analysis are as follows:

Technology	Capital Cost (per KW-hr/yr)*
Solar Photovoltaic (PV)	$1.80
HydroElectric	$0.71
Wind Power	$0.71

*All costs presented without subsidies, tax incentives, or public/private partnership models

Photovoltaic (PV) capital costs are based on a total installed cost $3.00/watt (AC); capacity factor of 19%: and a yield of one watt is about 1,664 W-hrs annually. Therefore, the cost for 1 MWhr/yr is about $1,800. These costs do not account for investment tax credits (not generally available to not-for-profit institutions) or other PPA financial scenarios, and also do not include current (2016) NYSERDA PV grants available (which today may reduce capital costs ~20%). EIA (2016) says average installed cost was $3.71/W in 2014; DOE reported range of $2.32 to $3.52 in 2014 nationwide. PV output generally declines ~0.5-1% annually as arrays degrade; this loss factor was not included in the analysis since it is smaller than error bars in energy cost estimates and the impact is small until future years when costs/benefits are more heavily discounted.

Hydropower cost assumes a total installed cost of $2.50 per watt (AC); capacity factor of 40%: yield of one watt is about 3504 W-hrs annually & cost for 1 MWh/y is about $713. EIA (2016) says average install cost was $2.29/W in 2013.

Wind Power costs assume a total installed cost of $2.50/watt and a capacity factor of 40% (one watt yields 3504 W-hrs annually). This leads to a calculated cost for 1 MWh/y of about $713 – the same as the hydropower unit cost. EIA (2016) says aver installed cost was $1.90/W in 2013. Assuming slightly higher cost seems reasonable, since local resources are not optimal.

EIA estimates of construction costs (see References) are shown in Figure 7.4.

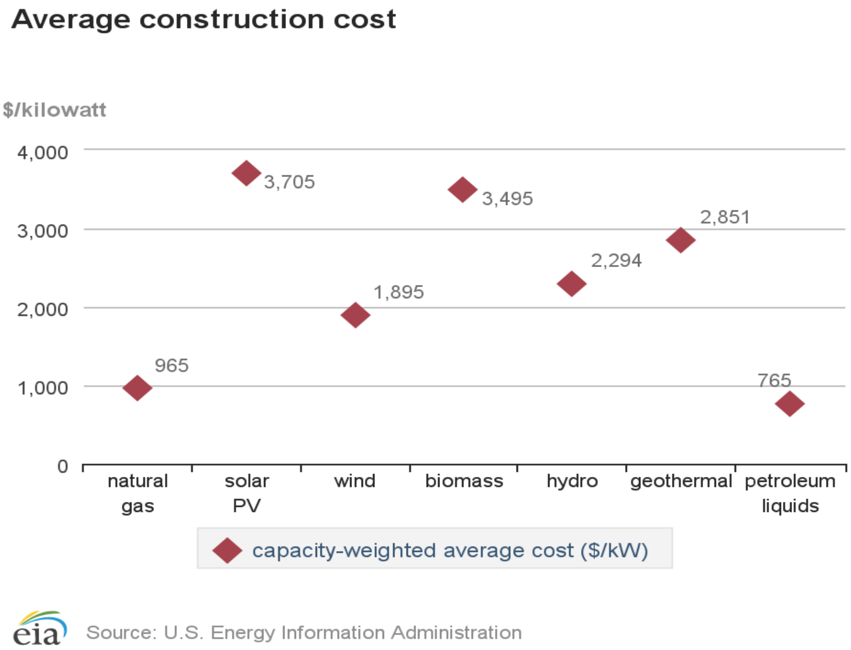


Figure 7.4: U.S. EIA Reporting of Average Renewable Energy Construction Costs (2015)

Using these capital cost estimates, WWS options were financially evaluated in two ways. First, the Net Present Value (NPV) of incremental increases in PV, Wind, and Hydo-electric power were compared on a “per MWh per year” basis (Cornell uses about 225,000 MWh per year of electricity). The results of this “incremental analysis” are noted below:

Table 7.1: Renewable WWS Financial Results (per MWh/y capacity)

Renewable Energy Type	**Capital Expense (CAPEX)***	**Net Present Value (NPV)**
Wind Power	$ 713	$ 1,117 (Cost to Cornell)
Solar PV	$ 1,800	$ 1,830 (Cost to Cornell)
Hydroelectric Power	$ 713	$ 1,556 (Cost to Cornell)

*All costs presented without subsidies, tax incentives, or public/private partnership models

This desktop evaluation shows the wind power, solar, and hydropower require incentives or grants to make then cost-effective (no value for “avoided offsets” was included in this analysis). Additionally, the correct resource is still needed for development.

We also evaluated the theoretical case whereby all of the electric needed to serve campus were developed from WWS resources. For this analysis, it was assumed that 50% of all energy was from PV and 50% from wind (we could not predict any credible additional hydropower resource availability, as is discussed later in this report). Table 7.5 summarizes those financial results.

Table 7.5: Financial Results of WWS Campus-Wide Renewable Electric

Renewable Energy Type	**Capital Expense**	**Net Present Value**	**Net Annual Cost**
50% PV and 50% Wind	$268M	$314M (CU cost)	$20.4M (added)

Note that the added cost is the cost above BAU (excluding offset costs) based on the assumptions discussed in this report rather than the full deployment cost. Total estimated Capital costs for this scenario would be about $268M for options that do not increase electrical needs and $429M for air source heat pump option, which requires significantly more renewable electricity.

As previously noted, all costs represent the full capital cost for deployment, and ignore alternative funding mechanisms that might reduce costs to Cornell or even provide a direct financial benefit. For example, tax incentive programs, grants, and rebates have been used in the past by Cornell to reduce capital costs either directly or through a privatized funding model such as a Power Purchase Agreement (PPA). Therefore, while costs for implementing WWS are higher than BAU in general, the value on a case-by-case basis may vary. For example, Cornell's first large-scale (approximately 2 MW) solar array was constructed with private financing through a PPA and has provided Cornell with positive cash flow.

Overall Quadruple Bottom Line (QBL) Ratings

A summary of our QBL ratings by the SLCAG for WWS solutions are is provided below, based on the process described in Section 3.

Table 7.6: Overall QBL Rankings for WWS Renewable Electricity Options

		Rating (1-5) (1= Lowest; 5=Most Favorable)			
Alternative	Annual Equivalent Cost ($M 2016)	*Supports Cornell Mission (Purpose)*	*Supports Cornell Finances (Prosperity)*	*Supports Community Goals (People)*	*Supports Environmental Needs (Planet)*
Wind Power	*Note 1*	**3.9**	**3.1**	**3.1**	**5.0**
PV Power	*Note 1*	**3.1**	**3.4**	**4.0**	**5.0**
Hydroelectric Power	*Note 1*	**2.8**	**1.9**	**3.0**	**4.6**
WWS – Electric for Entire Campus	*$20M over BAU*[2]	**3.7**	**2.6**	**3.9**	**5.0**

Notes: 1. See analysis in text above; these do not represent a "whole campus" solution

2. This annual equivalent cost represents the annual expense added to other campus solutions that require electricity to make the campus "carbon neutral".

The above ratings were determined based on the following considerations:

- All rated high under “supports environmental needs” as renewable electricity is a vital need in reducing climate impacts and WWS are well-developed technical solutions to that need. No other alternative received a perfect “5” rating in any category.
- PV ranked highest under “Supports Community Goals”. Lower rankings may have been influenced by the demonstrated strong resistance in the community (at Cornell and in Enfield) for industrial-scale Wind Power and the likelihood of community resistance for any larger-scale hydropower project, since new hydropower can be very disruptive to communities.
- Moderate rankings in the “supports Cornell finances” reflected that SLCAG reviewers felt it was unlikely that future WWS opportunities would be cost-neutral based on planned reductions in incentive levels and grant opportunities as the industry matures.
- There was relatively high support for the Cornell Mission.

7c Biomass/biogas Combustion

Summary

The principle behind the use of biomass energy to reduce carbon emissions is that, if harvested sustainably, biomass crops absorb as much carbon each year as is released during combustion. Appendix B includes a Technical Review describing the various related technologies for releasing energy from biomass and utilizing it on campus. The calculations in Appendix C quantify the size and scale of the resources needed for bioenergy to play a major role in campus heating. Appendix C calculations also define how a more modest, but still substantial, quantity of biomass might be deployed as a partial solution (i.e., to provide peak heating needs in mid-winter) in combination with other primary energy options. The BAU+ Offsets Option is shown for comparison.

Description of the Analyzed System

The following is a brief description of the biomass facilities considered for this study:

- A pre-design research program (as envisioned during CURBI planning) which would include smaller-scale materials storage and handling, research spaces with all utilities for testing of application-scale combustion and gasification equipment, and some minor support spaces

- For the biomass combustion facility, a full-scale materials storage and handling facility, boiler building with biomass boilers with emissions controls, a pumping and heat exchanger facility to extract heat from the boiler working fluid, and a hot water pipeline to feed the campus district heating system

- For the biomass gasification facility, a biogas generator, gas pipeline to the CEP, and upgrades to the CEP combustion turbines to allow combustion of lower-grade biogas (which typically has ~40-60% of the heating value per volume of natural gas). Turbines are replaced on a regular frequency, so this would be most cost-effectively implemented in coordination with the normal turbine replacement schedule

- Distribution systems to distribute the heat to campus buildings. The capital costs identified for this option also includes the capital costs for converting the steam distribution system to a hot water distribution system (that would continue to be heated by steam from the CEP until the ESH facilities were proven and ready). Conversion to a hot water system will allow a greater than 20% reduction in the size of biomass facilities and in the need for annual sustainable biomass, since it would reduce distribution losses by ~15% and also allow greater heat extraction at the boiler/distribution interface. The cost of the distribution system in this and other options includes the full cost for converting all buildings from their current steam-to-hot water heating to a water-to-water heat transfer.

Estimates of Cost and Financial Results

Costs were estimated for the two biomass options. The capital expense (CAPEX) budgeting of some primary components of the system was generated from industry average cost figures. EIA reports that the average biomass capital plant cost about $3.50 per watt of electric produced in 2013 (for a plant designed to generate electricity). Since a reasonable conversion efficiency of about 33% is expected, we used as a calculation basis a plant sized for an input energy of about three times that electrical energy value (i.e., the plant cost used is $1.17 per watt of thermal input energy). Converting from watts (electric output) to BTU/hr (energy input) yields a capital cost of about $0.34/ Btu/hr, or about $119M for a plant sized for 350 MMBtu/hour (or project campus peak need after conversion to hot water). For our proposed project, we used $20M for pre-design research program (an estimate from early CURBI planning); $120M for biomass gasifiers and turbine upgrades (matching the EIA estimate), $40M for storage/drying/processing (assumed to be a Cornell facility so that we could accept a variety of biomass); and $236M for distribution conversion.

For the BC case, biomass is combusted for heating only, and all future electricity is purchased from the grid. For the BG gas, additional biomass (and plant size) is needed to generate enough biogas to produce both heat and electricity, so the capital cost is higher, although the cost is offset by future costs since the purchase of electricity is no longer required. Table 7.7 summarizes the results of this analysis.

Table 7.7: Financial Results of Biomass Options

BioMass Option	**Capital Expense**	**Net Present Value**	**Net Annual Cost**
BAU+ Offsets (comparison)	$0	$798M	$52M
Biomass Combustion (BC)	$336M	$967M	$63M
Biomass Gasification (BG)	$416M	$860M	$56M

QBL Ratings Results

Table 7.8 provides a summary SLCAG TBL rating results for the biomass options.

Table 7.8: TBL Ratings results for Biomass options

		Rating (1-5) (1= Lowest; 5=Most Favorable)			
Alternative	Annual Equivalent Cost ($M 2016)	*Supports Cornell Mission (Purpose)*	*Supports Cornell Finances (Prosperity)*	*Supports Community Goals (People)*	*Supports Environmental Needs (Planet)*
Biomass Combustion (BC)	$63	**3.4**	**3.1**	**2.1**	**2.4**
Biomass Gasification (BG)	$56	**4.1**	**3.3**	**2.2**	**2.0**

Some considerations in these QBL ratings were as follows:

- The medium rankings (3.4 to 4.1) in the "Purpose" category is reflective of the broad-based research and academic involvement which would in involved in these biomass technologies, which couple well to Cornell's strength in engineering and agriculture and our interest in advancement of understanding of agricultural sustainability. However, there are fewer researchers involved directly in the energy conversion aspects. The issue of biomass sustainability is of broad interest well beyond the local region.
- The mid-level rankings (3.1 to 3.2) in the Prosperity categories reflect the moderate costs (compared to other options) and reasonable cost certainty (since these technologies are reasonably well understood and in practice in many locations). Cornell would still likely need significant outside financial support (donor or grant monies) to advance this idea and would follow a phased approach (testing technologies and field practices first), but the work seems well-suited for grant funding.
- The relatively low ranking (2.1 to 2.2) in the People category reflects a mix of two sentiments. Although a biomass energy plant would provide substantial short-term (construction) and long-term (biomass growing, harvesting, transporting, and processing biomass for use), the scale of these technologies as a campus-wide solution would greatly increase local traffic and local impacts (dramatic changes in land use, high local emissions, etc.).

- The high (3) ranking in the Planet category also reflects this two-edged condition: the development of climate-neutral biomass could greatly reduce emissions, but the large scale needed will have other potentially-damaging environmental impacts.

See Appendix A for a more in-depth review of the rationale for these ratings. Many of these ratings may be subjective and may vary based on the benefit audience. The primary "low" ratings also may be a matter of scale; smaller-scale biomass options used in tandem with other primary energy options are also explored, with varying results.

7d Earth Source Heat (ESH) and Biomass/ ESH Hybrid (B/ESH)

Summary

Earth Source Heat (ESH), which the geothermal industry terms an Enhanced Geothermal System (EGS), is an emerging technology that proposes to utilize the heat energy available deep beneath the earth's surface to generate district heating (and potentially some electricity). At least two wells are needed to extract heat, one for injection of cool water and one for production of hot water. Barring the discovery of natural permeable layers in this area, hydraulic stimulation of the bedrock is required to enhance the permeability of the natural bedrock fracture network. Injected water is heated by the earth as it flows through the fractures in the bedrock from the injection well to the production well. As discussed in Section 5, Cornell has interest in ESH as a research focus at the University.

Appendix B includes a Technical Review of ESH. The calculations in Appendix C quantify the size and scale of the resources needed for ESH to play a major role in campus heating.

The concept of B/ESH is that, although biomass resources sufficient to provide the entire campus heat load may be too high to be sustainable in the area, a relatively manageable biomass storage and delivery component (representing ~3-9% of the overall campus load) may be much more appropriate and could significantly reduce the peak demand of the ESH facility, allowing for less wells and a more economical development. Figure 7.5 illustrates this concept.

Estimates of Cost and Financial Results

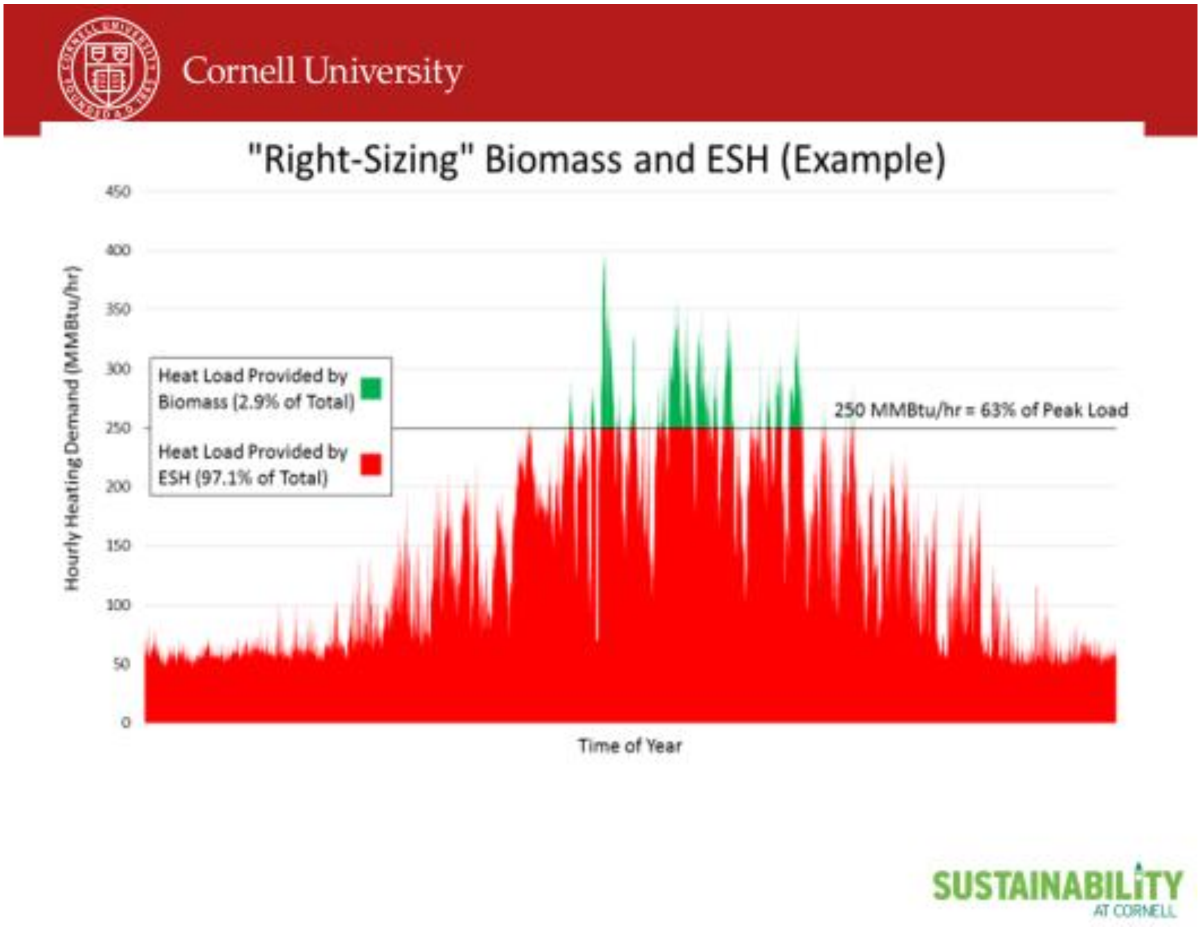
Costs were estimated for two alternative applications of ESH. The first alternative would require ESH systems sized to match the peak campus load. The second alternative would be use biomass, harvested and stored throughout the year, to provide energy for peak heating periods, as discussed in Chapter 5. That second alternative is abbreviated B/ESH, for "biomass/Earth Source Heat".

An ESH solution would include the following systems and components:

- A number of deep well-pairs (seven pairs are estimated here) extending to a depth of between 8,000 and 15,000 feet below the surface (depth determined through a test well)

- A pumping and heat exchanger facility, not unlike the Lake Source Cooling pump and heat exchanger facility next to Cayuga Lake. Heat exchangers would provide a separation between the hot recirculating fluid from the geothermal wells and the closed campus loop, similar to the separation with the Lake Source Chilled Water loop.

- Distribution systems to distribute the heat to campus buildings. The capital costs identified for this option also includes the capital costs for converting the steam distribution system to a hot water distribution system (that would continue to be heated by steam from the CEP until the ESH facilities were proven and ready). Conversion to a hot water system is necessary to ensure that the ESH fluids can efficiently transfer heat to the campus heating loop (accessible ESH fluid temperatures are predicted to be in the range of 248-300°F) without the use of steam, and to reduce heating system losses (15-20%).


Cornell University

"Right-Sizing" Biomass and ESH (Example)

Figure 7.5: Right-Sizing Biomass and ESH to create a B/ESH solution

The capital costs for the ESH option include $210M for the development of ESH well sets (7 sets), based on analysis of industry costs documents 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 costed 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 B/ESH option would be similar, except that less wells are used but 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).

Similar costs were used for the B/ESH option except that only 5 wells pairs are provided (sufficient to capture about 97% of the annual heat load), valued at $150M. Additional costs for this option $20M for a peaking biomass plant and $6M for a biomass storage and processing center. These 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.

Table 7.9 summarizes the results of the financial analysis of the two ESH options.

Table 7.9: Financial Results of ESH Options

ESH Option	**Capital Expense**	**Net Present Value**	**Net Annual Cost**
BAU+ Offsets (comparison)	$0	$798M	$52M
Earth Source Heat (ESH)	$466M	$1,100M	$72M
Biomass/ESH (B/ESH)	$427M	$1,060M	$69M

This analysis assumes that the full capital cost of the systems is borne by Cornell. However, ESH is considered a research initiative which could be of interest to a broad audience (locally, regionally, nationally, and even globally). Therefore, Cornell will pursue outside funding if we are to advance this effort. An analysis of the costs indicate that Cornell can "break even" with the BAU+ Offsets case if we are responsible for about 48% of the total capital funding and would be cost-neutral with the BAU case (no offset costs) if we can reduce our internal financing to about 28% of the total capital cost of construction (i.e., about $130M Cornell "match" for ESH). Thus, grant-funding could be vital to the future of ESH at Cornell.

It would be fully expected that other components might be added to a real system to optimize capital and operating costs. Potential additional systems might include hot water storage tanks or strategically-used heat pump facilities. However, under the assumption that these additions would only be used and a cost-optimizing strategy to reduce the overall costs, we have not added costs in this analysis to cover those potential additions.

Developing an ESH or B/ESH technology to completely replace fossil fuels for campus heating remains, as characterized by Lance Collins, Dean of the College of Engineering, a "moon-shot" idea with significant financial, environmental, and social hurdles. However, it aligned particularly well with Cornell's academic mission, since Cornell has among their faculty some of the foremost experts in this field, led by Dr. Jefferson Tester. Significant research and/or philanthropic financial support remains a prerequisite.

QBL Ratings Results

Table 7.10 provides a summary of the QBL ratings for ESH options as determined by SLCAG.

Table 7.10: QBL Ratings for ESH Options

		Rating (1-5) (1= Lowest; 5=Most Favorable)			
Alternative	Annual Equivalent Cost ($M 2016)	*Supports Cornell Mission (Purpose)*	*Supports Cornell Finances (Prosperity)*	*Supports Community Goals (People)*	*Supports Environmental Needs (Planet)*
ESH	$72	**4.4**	**3.0**	**3.5**	**4.3**
B/ESH	$70	**4.8**	**2.3**	**3.3**	**4.3**

Some considerations in these QBL ratings were as follows:

- The high rankings (4-5) in the "Purpose" category is reflective of the broad-based research and academic involvement which would in involved in the ESH technology development and, for the B/ESH option, the even greater involvement if sustainable biomass harvesting and combustion systems are included. These areas represent areas of key research interest with additional opportunities and interest from university economists and social scientists.
- The lower ranking (~2) the Prosperity category is reflective of the high degree of uncertainty in the cost and the high capital costs involved. Cornell would like need significant outside financial support (donor or grant monies) to advance this idea and would follow a phased approach.
- The middle ranking (3+) in the People category reflects a balance between the high level of both short-term and longer-term employment opportunities represented by these technologies (ESH primarily involving short-term construction opportunities while biomass representing long-term jobs in growing, harvesting, transporting, and processing biomass for use) and the potential risks or risk perception in the community regarding both each of the technologies involved in this alternative.
- The high (4+) ranking in the Planet category reflects the elimination of GHGs required for heating with almost no impacts to electrical usage. The successful implementation of this project could also prove a model for other Northeast (or beyond) communities looking to reduce GHG emissions.

See Appendix A for a more in-depth review of the rationale for these ratings. Many of these ratings may be subjective and may vary based on the benefit audience.

7e Heat Pumps

Summary

Heat pumps use electricity to move heat from one medium to another (i.e., from air to air, from water to water, or any combination) as an alternative to burning fuel for heat. There are different heat pump designs, but they all operate on the same basic principle – the transfer of heat from a colder reservoir to a hotter reservoir.

Heat pumps convert electrical energy to transported thermal energy (heating or cooling) according to the coefficient of performance (COP), which is the ratio of thermal energy output to the input electrical energy. In appropriate applications, this technology can reduce energy usage, but a source of energy generation is still required, either on site or off site.

Cornell already has Lake Source Cooling to provide all campus cooling, at efficiencies not possible with heat pumps in a cooling mode, and therefore the heat pumps systems are modeled as providing only heating. Two different types of heat pumps solutions were investigated. The first option includes Air Source Heat Pumps (ASHPs), which require heat exchange with the ambient air, such that heat must be extracted from generally colder air in the winter. This impacts the heat pump’s COP and its choice of refrigerant, since COP depends primarily on the required exchange temperatures.

The second option, Ground Source Heat Pumps (GSHPs), exchange heat with the earth, which allows for more moderate seasonal exchange and overall higher efficiency. A location for this well field has not been selected, although in NYC Tech (and Ithaca College) well fields were placed under areas determined appropriate to remain open spaces, as no infrastructure remains on the surface after development. Well fields are also commonly placed under parking areas. Since local ground temperatures below top ground surfaces are only about 52-56^{o}F and would drop with seasonal heat extraction (largely recovered between seasons), systems must generally be oversized to prevent down-hole freezing and to ensure peak performance (the lower the temperature, the lower the COP during the winter).

Heat pumps are assumed to be tied into the central heating distribution loop, rather than integrated building-by-building. This assumption is based on the following:

- Due to the natural diversity of campus loads, the total heat pump capacity (and hence price) can be about 40% lower with central facilities. That is both due to the fact that peak loads occur at different times in different facilities and also because a system designed for a single building must have significant redundancy or extra capacity to ensure performance over time, especially if activities change in the building over time, and also to account for imperfect energy estimates, whereas the entire campus peak loads are well known and a smaller total additional capacity can be provided at one location, since changes in uses across many buildings tend to balance out over time.

- Building are all designed for central heat transfer now and most do not have space, and some do not have electrical capacity, to accommodate new heating plants building-by-building.

- Larger and more efficient heat pumps can be purchased for central facilities at lower per-energy-unit cost.

- Typical heat pump output temperatures are much lower than needed for our current buildings, which were designed with the assumption of abundant steam. Like Stanford, if we were to use heat pumps for our buildings, we would select special “industrial” machines with special refrigerants that require close management.

- Centralizing heat pumps (as per Stanford) allows for centralized maintenance and refrigerant management, which reduces O&M costs.

Using this assumption, the overall systems analyzed (and for which costs are estimated) include the following:

- Heat pumps would be centrally-located at up to four facilities (to allow larger equipment and facilitate noise control, maintenance, and refrigerant management) and connected to the central heating loop.

- For the ASHP, a significant dry thermal exchange facility and significant refrigeration equipment would be needed to circulate super-cold refrigerant in the winter and extract heat from the environment for heating.

- For the GSHP system, a large geothermal well-field (see details in Appendix B) would also be constructed on adjacent campus land.

- Distribution systems to distribute the heat to campus buildings. The capital costs identified for this option also includes the capital costs for converting the steam distribution system to a hot water distribution system (that would continue to be heated by steam from the CEP until the Heat Pump facilities were proven and ready). This is necessary because heat pumps are not available which can provide the high temperatures we need for current building design. Conversion to a hot water system will allow a 15% reduction in the size of heat pump facilities and in the need for annual sustainable biomass, since it would reduce distribution losses by ~15%. The cost of the distribution system in this and other options includes the full cost for converting all buildings from their current steam-to-hot water heating to a water-to-water heat transfer.

- Additional upgrades to buildings are also included in the cost estimate for both heat pump solutions, because even specially-designed industrial heat pumps will not provide the very high temperatures needed to heat campus buildings currently during the coldest weather. Rather, extensive building system heat transfer upgrades (to terminal units and central coils) is likely needed, as was the case for more temperate Stanford, to make this solution viable.

Estimates of Cost and Financial Results

Costs were estimated for the two alternative heat pump applications.

For the ASHP option, estimates included $80M for the central heat pumps facilities and equipment, based on conversations with Stanford University and comparison of their facility costs and capacity; $236M for distribution conversion (higher than ESH since lower temps require larger pipe); $150M additional for low-temp building conversions; and $20M for electrical upgrades to handle the additional campus electrical requirements for heat-pump heating (estimate from E&S). As a comparison, Stanford spent $463M for a system of very similar peak loads but much more temperate weather conditions. This system did not utilize outdoor heat exchangers or ground loop.

Similar costs were developed for the GSHP options except that, due to the better COPs modeled, the amount of equipment is smaller, so that the central facilities estimate is reduced to $50M, and the electrical upgrade cost is reduced to $10M. An additional $150M was estimated as the total budget for the well field (about half the unit cost of the NYC Tech well field but in line with costs at other institutions).

In terms of operating costs, in both cases, it is assumed that the system is sized for the entire heat load but that all electricity is purchased to operate the heat pumps and circulating pumps. For the ASHP, this increases annual electrical purchases more significantly, by about 50%, while the higher COP for the GSHP solution increased electric load by only about half that value. Electrical grid peak load demand impacts are significant for both options especially during peak winter conditions.

Table 7.11 provides the financial results of the analysis for the heat pump options.

Table 7.11: Financial Results of ASHP and GSHP Analysis

Heat Pump Options	**Capital Expense**	**Net Present Value**	**Net Annual Cost**
BAU+ Offsets (comparison)	$0	$798M	$52M
ASHP	$486M	$1,214M	$79M
GSHP	$596M	$1,191M	$77M

Appendix B includes a Technical Review describing various Heat Pump options. The calculations in Appendices B and C quantify the size and scale of the resources needed for Heat Pumps to play a major role in campus heating. Table 7.12 provides a summary of rating results for two primary Heat Pump options.

Table 7.12: QBL Ratings for Heat Pump Options

		Rating (1-5) (1= Lowest; 5=Most Favorable)			
Alternative	Annual Equivalent Cost ($M 2016)	*Supports Cornell Mission (Purpose)*	*Supports Cornell Finances (Prosperity)*	*Supports Community Goals (People)*	*Supports Environmental Needs (Planet)*
ASHP	$79	**2.6**	**2.3**	**3.1**	**2.8**
GSHP	$77	**2.9**	**2.3**	**3.2**	**3.7**

Some considerations in these QBL ratings were as follows:

- The mid-level (~3) rankings in the "Purpose" category is reflective of the relatively focused research and academic involvement which would in involved in this alternative compared to other actions.
- The lower ranking (~2) the Prosperity category is reflective of the high costs expected to be required for this action. Cornell would like need significant outside financial support (donor or grant monies) to advance this idea, but the technologies are well-developed and may be less likely to attract research or demonstration grant funding.
- The middle ranking (3) in the People category reflects the relatively low impacts on the community (good or bad). While the ASHP and GSHP systems would likely be of low concern to the public, they would also not provide substantive long-term jobs for the area.
- The middle-to-high (3-4) ranking in the Planet category reflects positively the GHG improvements of these technologies with little land use or other environmental implications and the virtual certainty of such positive environmental performance; however, both options will require more electricity (which has embedded carbon and for which insufficient WWS is foreseen in the future to meet significant GHG-reduction goals even based on current demands).

These ratings are based on using heat pumps as a "primary" energy source for campus. The use of heat pumps in conjunction with other utilization and storage options may provide a more uniform benefit, as will be discussed in some of the hybrid option analyses.

7f Small Modular Nuclear Reactor

Summary

Nuclear power facilities create energy from controlled fission reactions, which produce heat absorbed by a fluid (typically water). The heating pressurizes the fluid (steam), which can then drive a turbine to produce electricity. Small modular reactors (SMRs) are currently under development by several large corporations. Compared to traditional large reactors, SMRs offer the potential advantages of lower initial capital investment, scalability, and siting flexibility.

Appendix B includes a Technical Review of SMRs. The calculations in Appendix C quantify the capital cost and operations impacts of SMRs. Appendix A includes a rating summary of a theoretical SMR solution.

Financial Analysis

There is no similar community or institutional Small Modular Reactor system yet constructed, so costs are speculative. At this time, there is no complete SMR system suitable for our campus in manufacture or production so only industry projections and some data from larger plants is available for comparison. That limited data was used for the financial analysis.

Industry prospectus documents suggest a price range of $100-250M construction cost for an SMR with an electrical capacity of ~30MW. By comparison, a recent (larger) nuclear plant being supplied by Russia for Saudi Arabia was reported to have a construction cost of about U.S. $7/W, which for a 30MW plant would equate to about $350M. For the analysis it was assumed that the "high" end of the prospectus industry pricing would apply, since we lack a large water body for heat transfer, our desire to modify the basic design for combined heat and power service, and our expectation of non-plant site safety infrastructure needs. A 1.33 factor was applied to ensure some redundancy for re-fueling and maintenance needs (i.e., assumes the construction of 4 units, each with a 1/3 peak service capacity, so that Cornell could meet peak needs with one unit out of service). Finally, similar to other options, a 40% factor was added to reflect typical Cornell "soft costs" to derive the final project cost ($465M) for the nuclear portion.

We also added $236M for conversion of the distribution system to hot water, the same value as used in other options. Although a nuclear plant can create hot enough temperatures for steam production, a financial analysis found that hot water distribution, while costly, was more cost-effective on a "leveled annual cost" basis than maintaining a steam distribution system, as well as being more a more practical implementation of this technology. The following factors were considered:

- Nuclear power plants generators, like any steam/pressurized fluid turbine system, will be more efficient if they can exchange heat with a lower temperature sink.

- The total energy that can be extracted to a hot water system is at least 20% higher with hot water than steam, due to inherent ground and steam losses in distribution and the ability to extract heat down to lower temperatures. Thus the use of a distributed hot water system would allow a reduction in the overall SMR system of about 20%. This also would reduce future operating costs since radioactive fuel is needed throughout the operating lifetime (the fuel is not "free" as it is in some other renewable options).

- Generating steam that would be distributed across campus from a radiative source is unprecedented. It is also more dangerous in terms of shielding and ensuring safety and we would expect those safety concerns to be an important design consideration. It may be expected that environmental reviewers concerned with safety would require a double-exchange system so that the intermediate system could be monitored closely and any issues corrected before any real risk of contamination – i.e., the reactor heat to moderate pressure hot water (perhaps 350F or so) and then to distribution water through a second isolation. Steam-to-steam conversions are much more difficult and expensive to design safely, especially if radioactivity of the primary fluid is a concern.

We also needed to estimate the fuel costs over the nuclear plant's lifetime. The Nuclear Energy Institute (2014) reported that commercial plants spend 1.51 cents/KWhr for fuel and related O&M costs. However, we thought it would be inaccurate to directly scale this cost; most plants are much larger and round-the-clock NRC-licensed operators will be needed. Instead, after comparison with our current steam plant operating cost and conversations with two on-staff employees who have been involved in small nuclear plant operations while in the military, we assumed and annual budget of $12M for plant O&M (in-house or operating contract). The operating estimate also retained $10M for electrical system annual O&M (same as the current BAU without grid purchases) and we added a thermal distribution budget of $4M net. Finally, on the advice of staff involved in nuclear programs, we added to that budget $4M annually for the overall campus costs for safety and security to meet the anticipated requirement of Homeland Security and the Nuclear Regulatory Commission.

The plant was assumed to have a design life of over 30 years with refueling (estimated at $20M per event) every 10 years, per industry expectations. A residual value was applied both for the distribution system ($100M) and for portions of the plant ($50M) at the end-of-life (2056).

These financial assumptions led to the financial results presented in Table 7.13.

Table 7.13: Financial Results of SMR calculation

Alternative	**Capital Expense**	**Net Present Value**	**Net Annual Cost**
BAU+ Offsets (comparison)	$0	$798M	$52M
SMR	$701M	$1,176M	$76M

The results suggest that the net annual cost for an SMR plant would be much higher than BAU. Costs differences would be reduced it substantial capital costs were borne by others (i.e., the USDOE as part of a test-of-concept grant).

Quadruple Bottom Line Impacts

Table 7.14 shows the QBL rankings for the SMR option as determined by SLCAG reviewers:

Table 7.14: QBL Results for SMR

		Rating (1-5) (1= Lowest; 5=Most Favorable)			
Alternative	Annual Equivalent Cost ($M 2016)	*Supports Cornell Mission (Purpose)*	*Supports Cornell Finances (Prosperity)*	*Supports Community Goals (People)*	*Supports Environmental Needs (Planet)*
SMR	$76	**1.7**	**2.2**	**1.8**	**2.9**

Some considerations in these QBL ratings were as follows:

- The relatively low ranking in the “Purpose” category is reflective of the lack of a strong mission link due to the lack of a nuclear engineering program at Cornell. Mission Alignment is also poor since the technology is being exclusively developed by large corporate entities interested in capitalizing on decades of technology work (and patents), likely allowing only limited involvement in the technology development by Cornell faculty or staff.
- The lower ranking in the Prosperity category is reflective of the high costs expected to be required for this action and the uncertainty and lack of control over costs (since costs are primarily under the control of the technology developer). Cornell would like need significant outside financial support (donor or grant monies) to advance this idea and it would be difficult to use a “stage-gate” approach to control cost risk, due to the likely need to enter into a long-term agreement early in the process to secure delivery. However, as a first-of-its-kind system, there may be opportunities for outside funding support.

- The relatively low ranking in the People category reflects the lack of local jobs (both the capital construction and operations are likely to be substantially outsourced due to the specialized nature of reactors) and the likely high real or perceived risks by the local community involving both radiation and security concerns.
- The middle (~3) ranking in the Planet category reflects the complete GHG elimination that the successful implementation of this project would represent balanced against the environmental concerns related to radiation waste, which represents a significant unresolved issue for nuclear power in the United States. The plant would also need a large amount of water (or very large area of dry coolers) in order to maintain production in summer months, when heat cannot be effectively exchanged for campus use. It is uncertain whether local water resources are sufficient for this purpose.

A major concern for SMRs related to approvals. Approvals would be needed at the local (Site Plan), state (Water Use, and perhaps others), and federal (Nuclear Regulatory Commission) would all be necessary. Ithaca is also a community with strong Site Plan Approval Laws and a community known for anti-nuclear leanings; for example, current local legislation includes a provision that "*No high-level radioactive materials shall be transported into or through or stored within the City of Ithaca*". Approvals at the Federal Level (NRC) will also likely required; a former small research reactor was decommissioned in the past decade primarily due to the very high costs and regulatory burdens placed on such plants by the NRC.

Despite some negative assessments, SMRs have great potential as non-GHG energy production facilities. Should SMRs be developed further in the next decade, Cornell might reconsider the costs and benefits of this technology. SMRs located in our local grid might also help the grid move toward carbon-free electricity. However, the rankings and rational consideration of the local community suggest that Cornell is not well-positioned as a "test site" for the nation's first SMR.

7g Integrated Solutions

Several of the alternatives studies would result in the projection of heat only and would therefore require the purchase or production of electricity. As such, these "heat-only" options would not be carbon neutral unless the electricity were generated entirely from non-carbon sources. Therefore, a select group of integrated solutions, combining heat generation with the WWS alternative, are analyzed and discussed.

Other combinations of solutions are possible and strategic combinations of solutions are in fact most likely to produce overall the most cost-effective, reliable, and practical carbon neutral solution. The B/ESH solution was already presented and may represents an opportunity to provide broader academic involvement in the GHG solution. As another example, Stanford University primarily uses heat pump transfer to distribution hot and chilled water across campus, but they also employ hot water storage, a geothermal field, and large off-campus investments in renewable electricity (mainly PV) in pursuit of reliability, cost-effectiveness, and significantly-reduced GHGs. Cornell would likely consider a similar strategy if a determination is made to transform the campus to a GHG-free (or low-carbon) future.

7.g.1 ESH or B/ESH with WWS

Summary

ESH (to generate campus heat) combined with WWS (for renewable electricity) was explored as a "total GHG elimination" (for central plant emissions) alternative. The combination of ESH with Biomass Peaking (B/ESH) and WWS was also analyzed. These analyses did not consider the practical difficulties with getting enough WWS to completely power campus, as previously discussed in the WWS analysis, but simply combines the capital and operating costs of the two analyses alternatives (using the same assumptions in each case). Tables 7.15 provide the financial results of these analyses.

Table 7.15: Financial Results of B/ESH with WWS Analysis

Alternative	**Capital Expense**	**Net Present Value**	**Net Annual Cost**
BAU+ Offsets (comparison)	$0	$798M	$56M
ESH with WWS	$734M	$1,105M	$72M
B/ESH with WWS	$695M	$1,099M	$71M

QBL Rating for B/ESH and WWS

SLCAG members participated in the QBL rating for this alternative. During the initial exercise, B/ESH with WWS was considered, but ESH with WWS was not, so only the former was rated by the members at that time. The ratings shown for the ESH/WWW, estimated by staff, are similar to the B/ESH with WWS ratings, with slight adjustments made in response to SLAG feedback at the QBL rating session. Table 7.16 shows the results of that rating exercise.

Table 7.16: QBL Ratings for B/ESH with WWS

		Rating (1-5) (1= Lowest; 5=Most Favorable)			
Alternative	Annual Equivalent Cost ($M 2016)	*Supports Cornell Mission (Purpose)*	*Supports Cornell Finances (Prosperity)*	*Supports Community Goals (People)*	*Supports Environmental Needs (Planet)*
ESH w/WWS	$72	**4.5**	**2.8**	**3.0**	**4.8**
B/ESH w/WWS	$71	**4.7**	**2.8**	**3.2**	**4.6**

Some considerations in these QBL ratings were as follows:

- The high ranking in the “Purpose” category is reflective of the broad-based research and academic involvement which would in involved primarily in the ESH technology development and, for the B/ESH option, the sustainable biomass harvesting and combustion systems. Both of these areas represent areas of key research interest with additional opportunities and interest from university economists and social scientists. The coupling with WWS further expands research and academic interest opportunities.
- The lower ranking in the Prosperity category is reflective of the high degree of uncertainty in the cost and the high capital costs involved. Cornell would likely need significant outside financial support (donor or grant monies) to advance this idea and would follow a phased approach. A Test Well is recommended to help confirm the geothermal resources and provide a better estimate of cost.
- The middle ranking (~3) in the People category reflects a balance between the high level of both short-term and longer-term employment opportunities represented by these technologies (ESH and WWS primarily involving short-term construction opportunities while biomass representing long-term jobs in growing, harvesting, transporting, and processing biomass for use) and the potential risks or risk perception in the community regarding both each of the technologies involved in this alternative.
- The high ranking in the Planet category reflects the complete GHG elimination that the successful implementation of this project would represent and also the substantial value of that success to other communities.

7.g.2 Heat Pump Solutions with WWS

As noted in the analysis of the two heat pump solutions (air source and ground source), If heat pumps were used for heating campus, Cornell would no longer operate their Combined Heat and Power (CEP) facilities and would instead buy all of the electricity we need currently, plus the additional electricity we would need to operate the heat pumps.

Financial Results

The financial analysis of the ASHP and GSHP options with WWS simply combined the prior analysis. However, unlike the B/ESH case, in these options the size of the WWS investment is higher, since WWS is needed both for the existing electrical loads and for additional electricity needed to operate the heat pumps for heating. The results are summarized in table 7.17.

Table 7.17: Financial Results of Heat Pumps solutions combined with WWS

Alternative	Capital Expense	Net Present Value	Net Annual Cost
BAU+ Offsets (comparison)	$0	$798M	$52M
GSHP with WWS	$929M	$1,243M	$81M
ASHP with WWS	$915M	$1,286M	$90M

Table 7.18 provides the SLCAG QBL ratings for these combined option.

Table 7.18: QBL Ratings for Heat Pump Options with WWS

		Rating (1-5) (1= Lowest; 5=Most Favorable)			
Alternative	Annual Equivalent Cost ($M 2016)	*Supports Cornell Mission (Purpose)*	*Supports Cornell Finances (Prosperity)*	*Supports Community Goals (People)*	*Supports Environmental Needs (Planet)*
ASHP w/WWS	$90	**3.1**	**1.4**	**3.3**	**3.9**
GSHP w/WWS	$81	**3.7**	**2.3**	**3.6**	**4.2**

Some considerations in these QBL ratings were as follows:

- The mid-level (3 to 4) rankings in the "Purpose" category is reflective of the relatively focused research and academic involvement which would in involved in this alternative compared to other action.
- The lower ranking (~2) the Prosperity category is reflective of the high costs expected to be required for this action (higher than other options studied). Cornell would like need significant outside financial support (donor or grant monies) to advance this idea, but the technologies are well-developed and may be less likely to attract research or demonstration grant funding.
- The middle ranking in the People category reflects the relatively low impacts on the community (good or bad). While the ASHP and GSHP systems would likely be of low concern to the public, they would also not provide substantive long-term jobs for the area. These options also require the highest amount of WWS which will more likely result in some community opposition for some PV or wind opportunities (based on past experience).
- The relatively high (~4) ranking in the Planet category reflects the complete GHG elimination that the successful implementation of this project would represent; however, the positive impact is tempered somewhat by the very large space needs for the WWS component of this solution.

7h Transportation Initiatives – Electric Vehicles and Charging Stations

The options discussed to date primarily involve the GHGs associated with campus building energy use – heat, cooling, and electricity. However, the Climate Commitment included two transportation-related sources of GHGs too, namely, emissions associated with commuting and emissions associated with "business travel". Each of these sources represents about 29,000 tons of carbon equivalent; together they represent over a quarter of the current total campus emissions.

The original CAP included a number of Actions to reduce these emissions, including:

- Continuing a robust Transportation Demand Management Program (supporting bus services, ride-share and car-pool services, walking and biking, and similar options to individual commuting)
- Supporting community plans for more housing stock closer to campus, where it would be easier to take advantage of commuting options (and also to reduce commuting distances for those unwilling to use such options).
- Creating and supporting systems and facilities to allow web-based meetings and conferencing and similar options to travel.
- Supporting work-from-home options for those employees with appropriate jobs and duties
- Improving the average mileage rating of fleet vehicles and supporting alternative fuel vehicles (with lower emissions) as the market made such vehicles available.

Many of these actions have advanced, although Cornell continues to encourage a relatively high level of travel (generally supporting our outreach and academic mission) and TDM involvement appears to have leveled off. Since most of these actions were already in some stage of development prior to the CAP, much of the effort is focused on preventing “back-sliding”.

However, there have been changes in technology and the marketplace outside of Cornell since the first CAP was prepared. These include:

- New airliners are more energy-efficient
- There are many more options for hybrid and even all-electric vehicles available today
- Charging stations and other infrastructure has become more commonplace and the prices for this supporting infrastructure has come down substantially

One additional option considered for this report is the installation of more electric charging stations to encourage greater use of all-electric and electric/hybrid vehicles. In general, this is acknowledged to be a net cost to Cornell, so must be justified on environmental or social grounds.

There was also the understanding that Cornell would not likely be able to negate these types of emissions, since we didn’t expect to ban academic and staff travel and wouldn’t have full control over the emissions produced by airlines and/or other transportation options.

7.i Capital Investment for Financial Parity with BAU

Cornell is not-for-profit educational institution which is a frequent recipient of donor funding and grant awards. Thus, Cornell frequently subsidizes capital investments with monies that would not be otherwise available and the net cost (which might be considered the “cost to the endowment” for the purpose of this report) of the facilities is less. For example, grants and/or donor funds were used to help build the Cornell Synchrotron, the former Cornell-operated Arecibo Observatory, and several named Cornell facilities. A substantial portion of the under-construction NY Tech campus on Roosevelt Island is similarly funded in part with donor and local (City of New York) monies.

Table 7.19: Financial Commitments for BAU Parity

Alternative	*Total CAPEX ($2016 $M)*	*CU CAPEX for BAU Parity (% of total)*	*CU CAPEX for "BAU+ Offsets" Parity (%)*
Baseline Comparison(s)		-	-
BAU	0	-	-
BAU+ Offsets	0	-	-
Alternatives		-	
BG	$416	45%	85%
BC	$336	10%	47%
ESH	$466	28%	47%
B/ESH	$427	25%	48%
ASHP	$486	NA	10%
GSHP	$596	12%	30%
SMR	$701	20%	44%
ESH + WWS	$734	39%	59%
B/ESH + WWS	$695	40%	60%
ASHP + WWS	$915	26%	42%
GSHP + WWS	$929	35%	52%

NA = Not Achievable – Operating Costs higher even with full CAPEX by others.

Since climate neutrality is a broad-based societal goal, there is a potential to attract similar funding for any option Cornell pursues, but some options may be better suited for funding opportunities. This section provides a high-level evaluation of how funding options may impact the decisions. Specifically, it evaluates what levels of outside funding might be necessary such that the "net" annual cost to Cornell is at parity with BAU. This financial exercise was performed using the same spreadsheets as used in the overall financial analysis and utilizes the same assumptions.

The results of that exercise is indicated in Table 7.19. These results reveal that fiscal parity is as much a matter of WHO is paying for the system as it is WHAT the total capital cost for the system is. In this example, a comprehensive B/ESH solution may be cost-effective for the University based on a Cornell cost of up to 25-28% of the overall capital investment, while an SMR becomes cost-neutral with a cost-share of about 20% (compared to BAU without offsets) to 44% (if the value of offsets is incorporated).

This type of analysis may be useful for grant targeting. Ideas and systems with high research or demonstration value may be more likely to be suitable for funding, whereas “standard” solutions may cost less, but may be less likely to be successful targets of grant funding.

Section 8: Offsets

Carbon offsets (or credits) refer to investments in off-campus projects (local, regional, international) that remove carbon from the atmosphere, either directly or by reducing the flow of greenhouse gases to the atmosphere. International standards stipulate that any carbon offset activity must be real, permanent, additional, verified, and audited through third-party organizations.

Developing a portfolio of local offset projects is perhaps the single most impactful action that links solutions to climate disruptions with economic disparities. Mission-linked offsets can provide Cornell with the opportunity to reach beyond our hill and invest in tangible actions with multiplicative benefits to our immediate and global community. A portfolio of local offset initiatives is recommended to mitigate currently unavoidable emissions, namely commuting and business travel.

8a Offset purchases

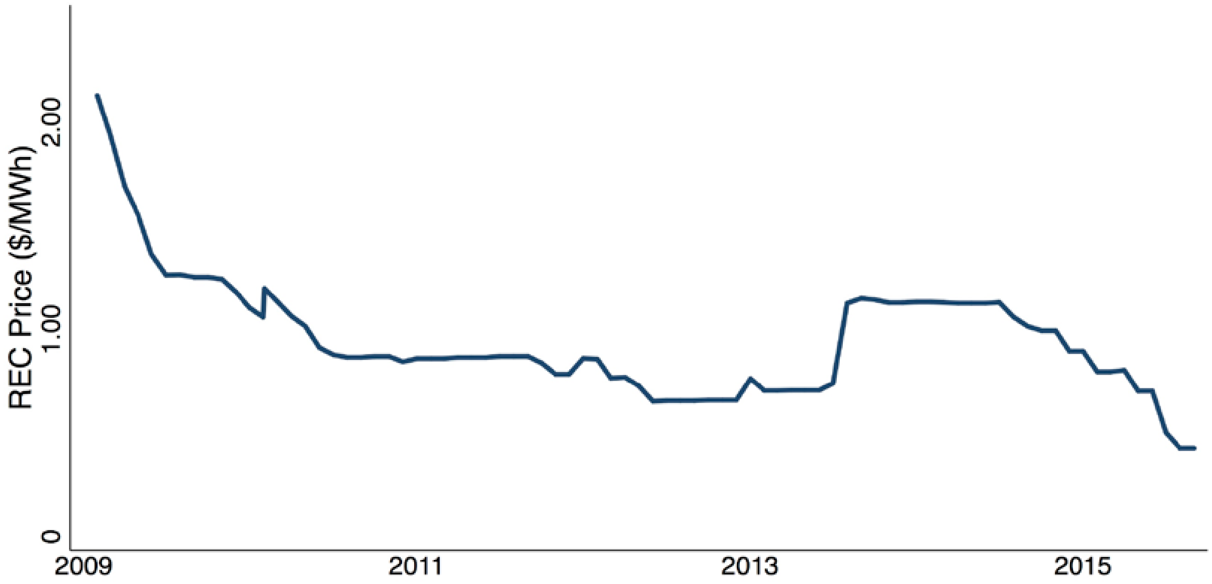
The voluntary carbon offset market allows consumers and institutions to purchase carbon offsets to compensate for the greenhouse gas emissions resulting from their normal operations. The most common type of offset involves purchasing Renewable Energy Credits (RECs) created during the generation of renewable energy. RECs unbundle the sale of the electrical energy from the renewable attributes and to allow flexibility in investment in renewable energy generation. Other options include supporting energy efficiency projects, destruction of landfill methane, and forestry projects. We should note that a 2011 survey conducted by CU Professor Katherine McComas which polled 677 Tompkins County residents found that the purchase of offsets have a negative relationship with community support when compared with more active approaches to changing the energy infrastructure.

Renewable Energy Credits (RECs)

RECs are tradable non-tangible energy commodities which grant the environmental attributes for the generation of renewable energy. Typically traded RECs include energy generation by solar, wind, low-impact hydro, geothermal, biomass, landfill gas, and hydrogen powered fuel cells. RECs incentivize the production of carbon-neutral electricity into the power grid by providing additional value to the producer for each unit of power produced.

In the United States, ten regional electronic REC tracking systems facilitate the creation, management, and retirement or RECs. These systems ensure that each REC is counted only once, and interactions between these systems allow RECs to be imported and exported across REC tracking system boundaries.

While RECs purchased for regulatory compliance must be purchased from the same geographic region, those that are voluntarily purchased may be sourced either regionally, nationally, or possibly even internationally. REC prices are extremely volatile and vary dependent upon several factors including the generating technology, generation vintage, region that the power is produced, and current natural gas prices. Greater flexibility in what region the RECs are generated results in lower priced options becoming available to the purchaser.



National Voluntary REC prices, Source: Marex Spectron (2015)

8b Offset Investment in Renewable Energy Generation

Direct, partnered investment in renewable energy generation creates the opportunity for the university to claim and collect project environmental benefits, while also creating the potential for income streams.

<u>Campus Example – Snyder Road solar farm Power Purchase Agreement (PPA)</u>

This investment opportunity has included the long-term lease of underutilized university property to a third party solar developer who owns, operates, and maintains the facility. Under electrical net metering rules, the project generates electricity which is then applied to a separate campus owned utility meter. The university retains all generated renewable energy credits, hedges electrical costs for the term of the lease, and realizes an arbitrage between the value of the electricity sold (higher metered value) versus the electrical energy purchased (lower metered value). At the completion of the term, the University may renew, purchase, or require the removal of the system from our land asset. The Cornell Snyder Road Solar Farm is a 2MWdc array on eleven acres of Cornell property in the Town of Lansing. It was completed in September 2014 and is expected to reduce the university's annual GHG emissions by 650 metric tons per year. The array will produce roughly 2.5 million kilowatt-hours annually – about 1 percent of Cornell's total electricity use.

Additional Renewable Energy Opportunities on University Owned Land Assets

The University is pursuing several additional net-metering PPA opportunities at the Geneva Experimental Station, Musgrave Research Farm in Ledyard, NY, and the Cornell Ruminant Center in Harford, NY. These agreements have been pursued as they are economically advantageous. However, due to utility net metering regulation, the Campus has maximized our regulatory generation capacity under this route of investment.

Additional proposals are under consideration using a different solar incentive program (community solar). Given the current market interest in solar development in New York State, additional opportunities in solar renewables continue to appear. Cornell maintains a sizable portfolio of land assets that are attractive to solar development firms. These investment opportunities present an intriguing mixture of income streams in the form of lease payments, opportunity for low-cost electrical power purchase, and the opportunity to obtain the RECs generated onsite (or equivalent replacement RECs depending upon NYS regulatory decision making currently underway). Annual lease payment rates currently being observed in the local market vary anywhere from $500-$1,500/acre, though these may not include the associated RECs.

It should be noted that the public utility infrastructure can support only a limited amount of solar input on each electrical circuit. As such, this capacity may be viewed as first-come first-served. Projects proposed after the available capacity is absorbed will face the economic hurdle of utility service upgrades that will likely make them unattractive to all parties.

A potential downside of construction of third-party owned and operated solar PV arrays on University owned land assets is the tie-up of university land assets for an extended lease period. These leases typically extend 25-35 years and remove the land from university control for the lease period. The question of the final disposition of the arrays is a concern, however, this concern can be dealt with via contract (removal, renegotiation, or surrender of the installation at the end of the term). Simplified solar racking using anchors, ballast, and shallow foundations coupled with salvage value have significantly reduced the difficulty in removing the systems at the end of the term and restoring the site to its pre-developed condition.

8c Offset Projects – Active Forest Management

Afforestation and active forest management can enhance the carbon-storage capacity of Cornell lands, as well as enhance the educational and research mission of the university. The annual carbon sequestration rate on 9,500 acres of Cornell forest land (including both Plantations and non-Plantations forests) is approximately 11,260 tons of CO2, or 1.2 tons CO2 per acre per year. If the university does not actively plant new trees and manage its mature forest stands, the carbon abatement capacity of these lands will diminish over time. An estimated 3,000 acres of Cornell lands that currently are abandoned fields or marginal farmland could be used to plant native tree species. Sequestration via advanced forest management is a generally acceptable carbon offset practice; however, Cornell would need to develop a methodology that can be third-party verified and audited.

Active forest management has the potential to enhance not only the carbon-storage capacity of University lands, but also provides a potential feedstock for other bio-based energy systems.

8d Offset Projects – Community Investments

Cornell could meet its climate neutrality goal very quickly by purchasing carbon offsets through international markets. Although this might be the quickest and possibly the least expensive pathway, it could delay the long-term changes that could and should be made in Cornell operations and personal behavior. By applying internal offset fees to external local initiatives, Cornell can create a wealth of local mission-linked offsetting opportunities to mitigate its unavoidable emissions and accelerate progress towards climate neutrality. Opportunities exist for community scale data collection via these actions. In addition to carbon offsetting opportunities, direct investment in the community would generate valuable goodwill, and give back to the community that supports us in a tangible way. Working with established local partners, Cornell can directly engage in and help scale up real and verifiable offsets initiatives.

Below are a few viable options for further development:

Energy Efficiency Renovations in Low-Income and Rental Properties

There are a over 38,500 households in Tompkins County, with about 46% of the population renting and about 20% living below the poverty line. Rental housing for lower-income workers is often substandard and wasteful of energy, further exacerbating these workers’ financial vulnerability. Because of the split incentive in rental units, landlords are reluctant to invest in energy-efficiency measures because they can pass along increased utility costs to their tenants. Tenants have little reason to conserve energy unless they pay for utilities directly. There is an opportunity to address the community’s need for energy-efficient housing with weatherization projects that comply with the international additionality standards for offsets.

Heating Fuel Switch for Farms and Rural Homes

Home energy retrofits could also include fuel replacement programs like CCETC's Southern Tier Bulk Wood Pellet Infrastructure program. These projects could take advantage of relationships with Cornell faculty and or staff for bulk purchasing and installation of pellet boilers or furnaces.

The New York State Energy Research and Development Agency currently offers income qualified residential wood pellet and cordwood system installation or upgrade subsidies for homeowners. The potential exists for providing additional subsidy to area residents for the installation of these types of high-efficiency, low-emission wood heating systems.

Resident Solar PV Installation

Community members interested in installing solar photovoltaic panels at their private homes are presented with an installer quote that itemizes NYSERDA, State, and Federal incentives and credits based on their installation size and cost that substantially reduces the cost of installation. A potential opportunity would be partnering with the local solarize organizations to work with local installers.

If subsidized, these installers could present an additional line item reduction attributed to Cornell University. Instead of purchasing RECs from the international market, this system would allow the University to encourage local conversion to a renewable energy source, support local industries, and gain renewable offsets for the life of the systems.

Improve Soil Carbon Storage in Agricultural Soils

Agricultural practices have depleted soil carbon stocks however rebuilding these stocks is possible based on research by Cornell faculty. The agriculture sector in New York provides a significant offset opportunity. The AWG proposes wider implementation of the soil health practices promoted by the Soil Health Program at Cornell (http://soilhealth.cals.cornell.edu) . This would require some additional investment in extension education, but Cornell and Cornell Cooperative Extension already have the research and extension infrastructure to engage the agricultural sector in this effort in a cost-effective manner.

Reduce Methane Sources in Agricultural Industries

A major source of methane in Cornell operations come from leakage in natural gas use, animal agriculture, and composting/landfill. Capturing methane and using it as a fuel to produce heat and power reduces the climate forcing from methane. In addition to reducing methane emission from its own operations, Cornell has the potential to reduce significant methane sources throughout Upstate New York by encouraging the use of methane capture and conversion technologies, particularly within the agricultural industry.

An excellent example of these types of agricultural offsets in action can be found at Duke University. The Duke Carbon Offsets Initiative is working with local farms to install innovative swine waste management systems that significantly reduce methane emissions. With one ton of methane equivalent to 21 tons of CO2 emitted this targeted offset focuses on greenhouse gas multipliers.

8e Impact of Upstream Methane Loss on Greenhouse Gas (GHG) Emissions

As documented by Cornell Researchers and others, the impact on the global climate of methane loss during the extraction and pipeline transmission of shale-derived natural gas may be much greater than currently reflected by established GHG accounting protocols, including those used by Cornell in its prior Climate Action Plan updates and prior annual emissions reporting. Currently, Cornell generates nearly all of its heat and electric from shale-derived natural gas.

The impact of methane (CH_4) on climate warming is calculated to be much higher than that of carbon dioxide (CO_2), although CH_4 degrades to CO_2 with a half-life of only a few years. Thus CH_4 reductions are generally considered more important in terms of shorter-term effects (i.e., over the next 1-5 years) while CO_2 reductions are considered critical over the long term. While there are alternative views on the factors to be used in measuring CH4 versus CO2 (i.e., the "CO_2 equivalent of CH_4") this study adopted the values proposed by Cornell researchers (Howarth et al). When applying these figures, Cornell's central energy plant emissions (including both direct combustion of natural gas and purchased electricity, the "embedded" emissions of which are also primarily shale gas)

Cornell appropriately calculates all of the emissions that occur on campus (Scope 1 Emissions) and includes as "Scope 2" emissions the estimated GHG impact of the electricity it purchases. However, neither of those figures includes this "upstream" impact of methane loss, since these impacts are not directly within the control of Cornell (or, typically, the owners of power plants that generate electricity within our electrical grid area). However, Cornell could choose to incorporate such emissions as "Scope 3" emissions, which reflect recognized emissions impacts which are indirectly attributable to our actions on campus. Scope 3 emissions could also include emissions such as those associated with waste, water usage, building materials, the purchase of goods and services, etc. However, these "upstream methane" losses represent much larger GHG impacts than any other typical Scope 3 source, such that if added they would approximately quintuple Cornell's GHG emissions.

Table 8.1 shows the financial evaluation results of an evaluation whereby Cornell "accepts" these "Scope 3" emissions as the responsibility of Cornell and embeds then with the "Social Cost of Carbon" in its analyses for future actions.

Table 8.1: Impact of Scope 3 Methane Emissions on Financial Analysis

	Annual Equiv Costs, Current Scope 1 & 2 ($M 2016)	**Annual Equiv Costs, Scope 1, 2, & 3 (Upstream CH_4) ($M 2016)**
BAU + Offsets (Comparison)	52	85
Alternative		
BC (Biomass Combustion)	63	71
BG (Biomass Gasification)	56	56
ESH (Earth Source Heat)	72	80
B/ESH (Biomass/ESH)	70	78
ASHP (Air Source Heat Pump)	79	92
GSHP (Ground Source HP)	77	87
SMR (Small Modular Reactor)	76	76
ESH + Wind, Water, Solar	72	72
B/ESH + WWS	71	71
GSHP + WWS	81	81
ASHP + WWS	90	90

Table 8.1 shows that when upstream emissions are included and valued at the “social cost of carbon”, all of the alternatives except for some of the heat pump options (which are not well-matched to campus needs) become financially preferable.

8e Carbon Pricing for Alternative Solutions to Reach Parity with BAU

For each of our solutions, an additional evaluation was performed to determine the effective “carbon price” which would result in price parity between the Alternative Solution and the BUA case. This additional analysis utilized the “conventional” GHG emissions (i.e., does not incorporate “upstream” methane emissions). At this carbon price, the annual cost calculated for the option is the same as the BAU+ Offsets base case. Table 8.2 summarizes the results of that evaluation

Table 8.2: Carbon Pricing for Price Parity

	Annual Equiv Costs, Including SCOC[1] ($M 2016)	**Carbon Cost Resulting in Price Parity with BAU+ ($/MT CO_2)[2]**
BAU + Offsets (Comparison)	52	
Alternative		
BC (Biomass Combustion)	63	150
BG (Biomass Gasification)	56	80
ESH (Earth Source Heat)	72	215
B/ESH (Biomass/ESH)	70	200

ASHP (Air Source Heat Pump)	79	330
GSHP (Ground Source HP)	77	280
SMR (Small Modular Reactor)	76	200
ESH + Wind, Water, Solar	71	175
B/ESH + WWS	72	180
GSHP + WWS	81	230
ASHP + WWS	90	286

Note 1: SCOC = Social Cost of Carbon at 3% Discount Rate per Section 3, Assumptions.

Note 2: Carbon Costs in dollars per Metric Ton (MT) CO_2*-equivalent*

From this analysis, a market-driven “carbon tax” or self-imposed voluntary offset cost of $80/metric ton (MT) would be needed to make bioenergy gasification (BG) cost-competitive with BAU (with purchased offsets or imbedded carbon taxes), assuming this technology was technically and socially feasible. A cost of about $200/MT would make B/ESH, Biomass Combustion (BC), ESH + WWS, B/ESH + WWS, and SMR all cost-competitive. A higher cost (up to $330/MT) would be necessary for price parity with the various heat pump options.

For comparison, $80/ton would add $0.015/kWh to the price of wholesale electric (based on grid emission factor of 186 kg/MWh) and $4.24 to the price of 1 decatherm (MMBtu) of natural gas (based on USEPA emissions value of 53.06 kg/MMBtu) and $200/ton would add $0.0375/kWh and $10.60/dekatherm. As discussed in the last section, this analysis does not incorporate the impact of Scope 3 emissions, which creates price parity at lower offset values (due to higher offset quantities).

Section 9: Conclusions and Recommendations

Summary Findings

The analysis of various options was completed. The results from this work provide information and insight that can help guide Cornell decision-makers in their search for future carbon neutrality.

A primary conclusion of our analysis is that, to achieve carbon neutrality “within our campus limits”, Cornell will need to incorporate a major unconventional energy sources such as ESH with substantial WWS, an SMR, a very large bioenergy system, heat pumps with substantial WWS, or a combination of these actions. This assumption is based on the expectation that the external electrical grid continues to be powered in part by carbon-emitting sources; if only heat were required, more options become viable.

Each of the alternatives we reviewed present serious technical, social, and fiscal challenges, which can be seen as alternately both as a problem and an opportunity. The particular benefits and challenges of each action are detailed in the Analysis section (Chapter 4).

The detailed analysis also suggests that a combination of actions is likely to optimize overall economy and effectiveness in reducing GHG impacts. This is due to many factors, including:

- The need to replace a variety of fossil fuels involved in our GHG footprint (i.e., gas, purchased electricity, and liquid fuels)
- The technical and fiscal changes inherent in meeting specific campus needs (i.e., baseline energy versus peak loads, season loads, etc.)
- Technical limitations related to many of the options (limited biomass availability; limited land area for PV; limited wind and water resources; uncertain ESH capacity)

To confront this challenge, SLCAG may wish to develop GHG-reduction goals expressed as academic and research targets rather than implied commitments. Alternatively, SLCAG may wish to consider a more limited GHG-reduction goal which is more readily achievable, but would not result in a carbon-neutral campus, at least until and unless practical whole-campus solutions become more evident.

As an alternative to large-scale changes to energy infrastructure, Cornell could also achieve neutrality in an “accounting” sense by the purchase of **offsets** or **renewable energy credits** in amounts representing all of the energy used on campus. Chapter 6 explored these “offsetting” options and presents some information related to offset costs and practical impacts to the University. In general, offsetting options which can be documented to have real and lasting impact, especially if applied locally or to economically-distressed areas, may provide additional social value and improve the potential for community and donor support.

Quadruple-Bottom Line (QBL) Rankings of Options Considered

Table E-1summarizes the QBL Rankings for each of the Options considered, as detailed in the Analysis Section. Color is used to provide a more visual “snapshot” of these analyses.

Table 9.1: Summary: Annual Equivalent Costs and Quadruple-Bottom-Line Rankings for Campus GHG-Reduction Options

(see text for financial and other assumptions and for rating details)

		Rating (1-5) (1= Lowest; 5=Most Favorable)			
Alternative	Annual Equivalent Cost[1] ($M 2016)	*Supports Cornell Mission (Purpose)*	*Supports Cornell Finances (Prosperity)*	*Supports Community Goals (People)*	*Supports Environmental Needs (Planet)*
Baseline Comparison					
BAU (no offsets)	45	2.0	3.5	1.7	1.5
Complete GHG Solutions					
BAU+ Offsets	52/85	3.0	1.5	2.0	2.0
BG	56/56	4.1	3.3	2.2	2.6
SMR	76/76	1.7	2.2	1.8	2.9
ESH + BC + WWS	72/72	4.5	2.8	3.0	4.8
B/ESH + BC + WWS	71/71	4.7	2.8	3.2	4.6
ASHP + WWS	90/90	3.1	1.4	3.3	3.9
GSHP + WWS	81/81	3.7	2.3	3.6	4.2
Partial GHG Solutions					
Wind Power	*Note 2*	3.9	3.1	3.1	5.0
PV Power	*Note 2*	3.1	3.4	4.0	5.0
Hydroelectric Power	*Note 2*	2.8	1.9	3.0	4.6
WWS – Electric for Campus	*+ $20M* [2]	3.7	2.6	3.9	5.0
ASHP	79/92	2.6	2.3	3.1	2.8
GSHP	77/87	2.9	2.3	3.2	3.7
BC	63/71	3.4	3.1	2.1	2.4
ESH	72/80	4.4	3.0	3.5	4.3
B/ESH	70/78	4.8	2.3	3.3	4.3

Table 9.2: Quadruple-Bottom-Line Rankings for GHG-Reduction Supporting Actions

	Rating (1-5) (1= Lowest; 5=Most Favorable)			
Alternative	*Supports Cornell Mission (Purpose)*	*Supports Cornell Finances (Prosperity)*	*Supports Community Goals (People)*	*Supports Environmental Needs (Planet)*
Supporting Technology				
Electric Charging Stations	**1.6**	**2.3**	**3.9**	**4.1**
Green Development	**3.6**	**3.1**	**3.6**	**4.4**
Recommissioning	**3.1**	**4.2**	**3.4**	**4.3**
Energy Conservation	**3.6**	**4.2**	**4.2**	**4.3**

Overall Findings

Findings based on the assumptions described in the Analysis Section include the following:

- The **Business-As-Usual (BAU)** case is the most cost-effective and has the lowest physical impact on the campus. However, it does not advance Cornell towards climate neutrality nor provide additional support for its academic or research mission.

- The **Business-As-Usual (BAU) case with the additional purchase of Carbon Offsets** at the assumed "Social Cost of Carbon" rate is the most cost-effective solution to a claim of carbon neutrality. However, this action does little in support of Cornell's academic mission and costs substantially more (about $7 per year more) than BAU. If this "neutrality option" is selected, the investment of "offset costs" in the local or regional community might help improve the perception of this alternative, at least locally.

- When the **Social Cost of Carbon** is embedded in all costs and Cornell models our impacts to include **methane losses associated with shale gas development** as proposed by Cornell researchers (Howarth et al), then most of the options reviewed are financially comparable to the BAU+ Offsets case. However, this would represent a doubling of the BAU (without offsets) base case annual cost (from about $42M per year to about $85M per year).

- Without incorporating "upstream" methane losses, **Biomass Gasification (BG)** is the next lowest cost option, but technically does not appear feasible as a campus-wide solution, due to the huge amount of biomass needed, which could not be sustainably harvested from available Cornell lands. Cornell academic experts calculate that the maximum sustainable yield on "local" Cornell lands (those potentially available for biomass within 25 miles of central campus) would at best provide about **15%** of the energy needed for heating campus. However, as a partial solution, BG rates relatively high in its potential support of the academic and research mission of Cornell and particularly in its role as a land-grant institution, as greater academic work into the concept of "renewable biomass" is needed. Further academic research might be necessary to determine the level of biomass production and use that can be considered "net zero".

- A **Small Modular Reactor (SMR)** is the only "stand-alone" option studied that would be predicted to provide all the heat and electricity needed for campus. This solution is also technically-advanced to a point that there is little concern about meeting the campus capacity, albeit with fuel that would be imported. Significant concerns regarding this choice include unclear capital costs and operating costs, timing of technology (suitable for institution application) availability, likely permitting challenges, and predicted local approvals and environmental assessment challenges.

  While technically feasible, no non-military institution or community of our size has ever been operated with an SMR. Cornell also does not currently have a nuclear engineering academic discipline, reducing the value of this choice to the academic mission. Also, the Ithaca community has not shown an openness to nuclear power in the past and has passed local ordinances against the transportation of nuclear fuel on local roads. Therefore, Cornell may be an unsuitable site for the first national "test case" of a campus SMR. Rather, an SMR may be more suitable to be located elsewhere in the local grid, where a more economically-sized (larger) unit may be considered with carbon-free benefits extended throughout the grid. Should this occur, the analysis of this report would be altered, since offset costs calculated are currently based on the current emissions of power generators in the grid. A carbon-free or very low-carbon grid would foster a heat-only solution for campus and make moot the concern for finding adequate WWS.

  If developed at Cornell, SMRs would likely be "turnkey" project with lesser formal alignment with the University's mission of education, research, and outreach, since considerable technical development (and associated "intellectual property") is in the hands of private firms and changes to the manufacturer's specifications might create unique safety concerns. Nonetheless, since development of this technology is not mission-linked and is independent of campus research, this technology could still be considered in future evaluations if it becomes commercially available.

- Other alternatives will likely require **combinations of actions**. For example, the current **Earth Source Heat (ESH)** conceptual plan does not anticipate the production of fluid at temperatures suitable for substantial electric production, so other renewable electricity would be needed. Therefore, **a combined ESH with Wind, Water, and Solar (WWS)**

solution was evaluated, with ESH providing all of the campus heat and WWS all of the campus renewable electricity.

- It may be more cost-effective to use biomass (and/or hot water storage and/or strategically-placed heat pumps) to provide peaking on extreme cold days than to oversize ESH for peak loads. Therefore, another “total energy” concept analyzed for **ESH includes both “peaking” biomass boilers (B/ESH) and use of (WWS)** for electrical production. While conceivable, the acquisition of sufficient WWS for the region is a huge challenge. An alternative future might be one where the grid itself becomes essentially carbon-neutral (a large portion of the electricity in our local grid currently is attributed to hydroelectric and nuclear power, both carbon-free sources), although it would require substantial changes to current production.

  ESH is of great interest as an academic and research. For this academic value to become an economical system for campus, the subsurface resource much first be confirmed and tests performed to verify the temperature and flow rates that could be accomplished with engineering of the resource in our area. As a starting point, a test well would be necessary to better confirm ESH potential and update probable costs. ESH would only be advanced if the test well results demonstrate feasibility.

- **Air-Source or Ground-Source Heat Pumps (ASHPs and GSHPs)** are technically proven and immediately available, but estimated total costs for heat pumps as a campus-wide solution are high. Heat pumps are not well-matched to our current campus needs, as Cornell has super-efficient Lake Source Cooling (5-10 times more efficient than heat pumps) and requires only heating. Additionally, our buildings are currently designed for, and need, substantially higher temperature heat than is available from standard heat pumps, thus requiring significant capital renewal for integration of this heat.

  Heat pumps work are most cost-effective when annual heating and cooling needs are nearly balanced (as in the NYC environment, or at Stanford, for example). In Ithaca, annual heating needs far outstrip annual cooling needs, a fact exacerbated by Lake Source, which entirely removes the need for heat pump cooling. Therefore, we would need to make a high capital investment for equipment sized only for the heart of winter. Heat pumps, despite their mechanical advantage over electric resistance heating at warmer temperatures, still require substantial electricity, putting further pressure on already-challenging efforts to develop renewable electric resources to meet climate neutrality.

  Thus, heat pumps options (either ground-source or air-source) thus aren’t recommended for providing a high proportion of Cornell’s heat load, but should continue to be analyzed as “accessory” technology for appropriate applications (heat recovery or temperature attenuation). Opportunities for strategic integration are nearly boundless; right-sized specialty heat pumps could provide peaking capacity and effectively multiple the heat recovery form an ESH well or similar technology or boost building temperatures by transferring temperature between building heating system supply and return circuits only on peak heating days, thus reducing distribution infrastructure costs.

In analyzing heat pump alternatives, it is recognized that typical heat pump output design temperatures (which may be as low at 122°F, although custom units can provide up to about 176°F) are too low for direct integration into campus systems. Substantial changes to building systems would be necessary in addition to a distribution system conversion from steam to hot water, although limited (targeted) direct use in buildings might be have less impacts.

Completely converting campus to heat pumps for heating would also require significant additional electricity which would greatly impact the local electrical grid. If this electricity was generated on-site with gas turbines, this might increase our carbon footprint; if sourced from the current grid, the positive effect is small; but if sourced from a future carbon-free grid (or campus power sources), it could reduce carbon impacts by up to 40-50%. Thus, the net GHG impact of this solution is heavily dependent on the source of electricity needed to power the heat pumps. If coupled with WWS, this becomes a full-campus solution, but, as noted in the next bullet, obtaining sufficient WWS renewable electricity is a substantial challenge. Nonetheless, strategic use of heat pumps for limited “peaking” use may be very economical when combined with other solutions for heat provision and could reduce both capital and operating costs while assisting in GHG reductions if strategically applied.

We are not currently aware of broad academic interest in heat pump technology (for instance, unlike Stanford, Cornell does not have a Heat Pump Institute) but the technology does represent a flexible “tool” that could be incorporated into energy production or enhancement in many ways, and as such presents a broad palette of applied research opportunities that could be compatible with a number of our Engineering College disciplines, especially if combined with other technologies.

- **Wind, Water, and Solar (WWS)** are all proven technologies for the generation of renewable electricity, but strongly dependent on the availability of local resources. Significant increases in renewable WWS are necessary for most carbon-neutral solution or low-carbon solutions, barring complete external transformation of the electric grid.

Due to the relatively dense and energy-dependent nature of the campus, obtaining all of the electricity we need from renewable resources would require a significant commitment of land and resources, including off-campus resources. Options which *increase* electrical loads (e.g., extensive heat pumps) create additional WWS needs and thus further challenges to identifying sufficient renewable resources to reach climate neutrality. In addition, the use of off-campus resources complicates the "accounting" applicable to carbon neutrality since the actual energy we would import from the grid is indistinguishable; the claim of carbon neutrality would be one of "netting" our use versus our various distributed production and, while supportive of renewable energy goals, does not represent an institutional advancement of the field.

- Transportation Options (**electric vehicles and charging stations**) are promising technologies that "score" well with no significant weaknesses other than incurring additional financial costs to the University. If implemented fully, these technologies could reduce campus carbon emissions about 13% if the additional electricity required could be sourced from renewable sources. Carbon emissions reduction is still about 11% if the electricity is grid-sourced, assuming current grid emission factors.

- **Continued energy conservation, commissioning, and green building standards reduce energy demands and are essential** to minimizing capital costs for non-BUA options and also are necessary to improve the potential for GHG reductions for all options except SMR. Reducing energy needs is least critical for SMRs because many current reactors under development are already oversized for the needs of the Ithaca Campus. However, if this extra "conserved" power could be locally supplied to the community or to the grid, continued conservation measures would extend the carbon-reducing impact of the SMR further beyond campus boundaries.

Based on the above summary findings listed above and as resulting from the Quadruple-Bottom-Line analysis of options available, the following summary recommendations are offered for consideration by SLCAG:

- **Expand support for electric and hybrid vehicles on campus.** Encouraging and supporting electric vehicle use can reduce that portion of our GHG impact related to commuting (about 13%) while improving both global GHG emissions and local air quality. Electric vehicle use is a practical and effective way for Cornell to deal with these types of emissions, although this option also relies on outside market forces (availability of economic electric vehicles) and social forces (high level participation by our commuters, who represent a substantial share of the emissions included in this analysis).

- **Adopt aggressive building energy standards and continue and expand energy conservation programs.** Better energy standards and energy conservation at both the building and system level saves energy, avoids unnecessary capital expenses for supply and distribution systems, reduces costs for future system replacements, and reduces potential GHG emissions. Cornell's energy conservation programs have been documented to significantly reduced both energy peaks and average loads, and past programs have been either cost-neutral or cost-positive when all costs are considered.

- **Establish and enforce formal heating system design standards that prescribe building system temperatures immediately.** Future buildings and current building heating system upgrades should be designed to allow for both a lower supply temperature and a significantly reduced return temperature limit. This would significantly reduce costs of future system infrastructure and enable integration of cost-effective renewable and waste heat recovery as these technologies are developed and implemented. This general approach has been widely adopted across Europe and is gaining significant inroads in the United States, including at many of the institutions who are working towards or already claiming significant GHG reductions (Ball State, Stanford, and Dartmouth, to name a few).

- **Convert the current "primarily steam" system to a "steam-driven cascading heat system".** Currently, nearly 20% of imported energy (natural gas) is "wasted" due to thermal losses and cumulative steam leaks. In this improved system, the majority (or all) of the campus heat is distributed as hot water, reducing losses (and associated GHGs) to about 2%. The cost of a phased system conversion is incorporated into each of the options (except BAU), which all assumed hot water distribution. Once the system is converted, heat supply systems (i.e., Earth Source Heat, Heat Pumps, Nuclear Energy waste heat, Biomass Boilers, etc.) can be integrated. Many campuses across the nation which began with steam systems have completed or begun working towards the same goal. Once completed, a hot water system is substantially less expensive to operate and maintain, less expensive to extend or replace, and safer to operate.

- **Seek funding for an ESH Test Well.** An ESH test well program is needed to verify if ESH is a viable alternative to be part of a future climate-neutral campus. ESH holds great promise as a multi-disciplinary research focus and could have regional and national energy implications. Such research is appropriate for a premier research institution like Cornell. While the overall financial benefits of ESH are currently uncertain, a number of potential funding partners have been identified which may be interested in supporting this academic effort, which is of great interest to a broad group of Cornell researchers, thus creating the potential to reduce the capital costs and thus create a much more viable financial return. Once constructed, a geothermal exchange system could be relatively easy to operate, much like Lake Source Cooling.

  As the costs and potential of ESH remain uncertain, future support for ESH *beyond* a test well should be contingent on test well results, research value, and funding availability.

- **Initiate a research program to explore the integration of appropriate levels of biomass into the campus energy system.** The development of a sustainable bioenergy system at Cornell is a long-standing goal for many researchers since the concept of the Cornell University Renewable Bioenergy Initiative ("CURBI") was launched almost a decade ago. A functional research platform (i.e., location for the storage, management, and processing of biomass) for bioenergy research will allow multi-disciplinary teams to explore the costs, benefits, and environmental trade-offs implicit in bioenergy production and create a national model for sustainable harvesting practices. Actual field tests on various Cornell lands will provide robust multi-disciplinary research opportunities.

  Bioenergy research could be a tremendously valuable academic mission focus for a Land Grant institution like Cornell with strong agriculture and engineering programs. However, the scale or our campus heating need is too high to be solely (or primarily) accommodated through the sustainable harvesting of biomass on Cornell lands and nearby lands. As suggested by the analysis, this makes bioenergy an ideal candidate for a right-sized application: supporting peak heating needs via a "hybrid" scenario with another technology.

  In addition to pure research value, the selection of an appropriate conversion technology (biogas generator, boiler, or similar system) will be enhanced by site-specific testing and practical experimentation with wood/crop storage and handling methods to develop best practices for mitigating unintended negative consequences. A key goal will be to establish an appropriate scale and practices for future bioenergy integration and to identify campus leaders willing to champion CURBI.

- **Continue to explore conventional renewable electric (WWS) opportunities**. Integration of PV and wind energy into the local campus grid and continued recent efforts to optimize the existing hydroelectric plant in Fall Creek are key components for a carbon-neutral campus. Additional WWS resources on Cornell lands located beyond CU's distributed electric grid and support for WWS within the broader community will be also be needed to further reduce carbon impacts. While most projects will have a relatively small impact on the overall campus GHG profile, the overall portfolio of projects can make a measureable difference and helps Cornell demonstrate support for these conventional resources.

- **Continue to follow progress in other innovative technologies,** such as small modular nuclear reactors. Because Cornell does not have special expertise in this field and progress is likely to originate with private corporations, Cornell may not be able to impact development substantially but should be poised to revisit this option as external development occurs.

- **Continue to explore Community "Offsetting Actions"**. Initial research shows that financial-only offsetting acts have limited (or even potentially-negative) social value.

However, providing more direct support to the local community is likely to be more favorably viewed and could provide practical community economic benefits as well as environmental gains.

- If considering the purchase of Offsets from outside the community, **investigate unique or mission-linked opportunities** that highlight Cornell's commitment to sustainability. This approach may offset concerns that Cornell is merely "buying their way" out of the issue of climate change impacts.

- **Communicate the challenge.** There is no simple or obvious cost-effective path to climate neutrality. However, Cornell is more likely to obtain grant support for innovative or significant research or application improvements which fulfil core University mission goals if the University targets dramatic reductions in carbon emissions and demonstrates an institutional commitment to those goals. While achieving zero emissions may appear unrealistic at this time, the University is better positioned for leadership in this area than most institutions. While aiming for a high standard, the challenge of that goal and recognition of the important role of research and innovation should be readily acknowledged.

Summary of Additional Impacts

This report focused on financial and GHG impacts of various scenarios, but other areas of impact also exist. Table 9.2, adopted from an early internal study, compares various impact areas of the alternatives studied.

Table 9.3: Comparison of GHG Reduction Options

Technology	**CAPEX ($2016)**	**OPEX (Year One:2028) ($2016)**	**Electric Load Impact (MWh/yr)**	**GHG reduced (MT/yr)**	**Land Area Required (acres)**	**Fuel trucks per year**
BAU+ (Business as Usual+ Offsets)(for comparison)	$0M	$50M	No Change	None	N/A	N/A
ESH (Earth Source Heat)	$466M	$36M	No Change	97,000	5 [1]	N/A
B/ESH (Biomass + ESH)	$427M	$38M	No Change	97,000	5 [1] + 430[2}	~675
BC (Biomass Combustion)	$336M	$43M	No Change	103,000	14,000 [2]	~7,500
BG (Biomass Gasification)	$416M	$32M	None (all self-generated)	All CEP GHGs	26,000 [2]	~14,000
GSHP (Ground Source Ht Pmps)	$596M	$43M	Adds ~70,000	73,000	150 [3]	N/A
ASHP (Air Source HPs)	$486M	$50M	Adds ~110,000	65,000	5 [4]	N/A
SMR (Modular Nuclear Reactor	$701M	$34M	None (all self-generated)	All CEP GHGs	10 [5]	N/A
GSHP + WWS (GSHP plus Wind, Water, and Solar Elect)	$929M	$26M	None (all self-generated	All CEP GHGs	150 [3] 940 [6]	~1,250
ASHP + WWS	$915M	$28M	None (all self-generated	All CEP GHGs	5 [4] 1090 [6]	~5,500
ESH + WWS	$734M	$22M	None (all self-generated	All CEP GHGs	5 [1] + 725 [6]	N/A
B/ESH + WWS	$695M	$24M	None (all self-generated	All CEP GHGs	5 [1] + 430[2] +725 [6]	~1,500

[1] Wellhead infrastructure and heat exchange facility
[2] Biomass crop production (assumed to be all shrub willow for comparison purposes)
[3] Geothermal wells
[4] Heat exchange facilities
[5] Reactor/cooling facility
[6] WWS PV and Wind land areas; some assumed off-campus

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